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Air Emissions Inventory Guidance Document for Stationary Sources at Air Force Installations

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13. ABSTRACT *(Maximum 200 words)*

This report serves as a guidance document for the preparation of stationary source air emissions inventories at U.S. Air Force installations. Air emissions inventories are prepared at Air Force installations to comply with Federal, State, and local air quality regulatory requirements. Inventories are also used in the implementation of various environmental programs, including pollution prevention opportunities, emissions trading, risk assessments, and environmental auditing. In the past, inventories have been prepared at Air Force installations using a wide variety of different procedures and formats. The purpose of this document is to provide a uniform and logical approach for preparing these inventories. This approach will enhance the Air Force's ability to utilize inventory data, as well as eliminate many of the common errors typically found in air emissions inventories. The report provides recommended methodologies for calculating both actual and potential emissions from the most common types of stationary sources (emission units/processes) found at Air Force installations. The report also contains the latest Environmental Protection Agency emission factors associated with these source types. The pollutants addressed in this report include the criteria pollutants, hazardous air pollutants, and ozone-depleting substances.

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SECTION 1

INTRODUCTION

1.1 Background and Purpose: The Clean Air Act Amendments of 1990 (CAAA-90) as well as other Federal, State, and local programs have expanded the requirements for industry to quantify and report the amount of air pollutant emissions released into the atmosphere. In addition, these regulatory programs have increased the number of pollutants which must be addressed.

The quantification of air pollutant emissions from an industrial facility, such as a military installation, is accomplished by conducting an air emissions inventory (AEI). In general, an AEI is defined as a compilation of pollutant emissions over a given period of time, typically one year.

This document was prepared by the Air Quality and Hazardous Waste Branch of the Institute for Environment, Safety & Occupational Health Risk Analysis (IERA/RSEQ) as a means of providing a uniform approach to estimating pollutant emissions from the most common types of stationary sources (emission units/processes) found at Air Force installations. The document details IERA/RSEQ's recommended methodologies for calculating actual emissions from these processes. In addition, the document provides the following:

- Summary of regulatory requirements/policies applicable to air emissions inventories
- Current Environmental Protection Agency (EPA) emission factors for the sources addressed
- Example problems for calculating actual emissions for the sources addressed
- Guidance for calculating potential emissions for the sources addressed
- Detailed list of data elements for the sources addressed
- Listing of hazardous air pollutants (HAPs)
- Recommended inventory format

As mentioned above, this document addresses emissions from common Air Force *stationary* sources. Emissions from common Air Force *mobile* sources (e.g., motor vehicles, aerospace ground support equipment, aircraft flying operations, etc.) are not addressed. Please contact IERA/RSEQ for information (methodologies, emission factors, etc.) on mobile sources.

Any questions concerning this document, and/or request for additional information pertaining to Air Force air emission inventories, should be directed to the Air Quality personnel at IERA/RSEQ (Commercial Phone 210-536-3305 or DSN 240-3305).

1.2 Methodologies: When conducting an AEI, the amount of regulated pollutants emitted from all emission sources located at the industrial facility (except those sources which are specifically exempt) must be determined. Several methods can be used to quantify air pollutants from emission sources, including:

- Emissions monitoring/sampling (e.g., continuous emissions monitoring and/or stack sampling)
- Emission factors
- Material balances
- Process-specific empirical relationships
- Engineering estimates

Of these methods, monitoring/sampling is the most accurate and should be used whenever possible. However, for many emission sources no monitoring or sampling data is available. For this reason, the use

of published emission factors and/or material balance calculations are the most common methods used to estimate emissions and are the methods specified in this document.

In general, emission factors are "typical" values applicable to a specific source type. These values are usually expressed as the weight of pollutant emitted per a certain unit weight, volume, distance, or duration associated with the activity emitting the pollutant (e.g., pounds of particulate emitted per ton of coal burned by a boiler).

1.3 Pollutants: Although there are several types (groups/classes) of Federal and State regulated pollutants which may be addressed in an air emissions inventory, this document focuses strictly on the three main pollutant groups regulated under the Clean Air Act: criteria pollutants, hazardous air pollutants, and ozone depleting substances. The following is a summary of each of these three pollutant groups:

a. Criteria Pollutants

Criteria pollutants are usually referred to as the pollutants for which the EPA has established National Ambient Air Quality Standards (NAAQS). These include carbon monoxide, lead, nitrogen dioxide, ozone, particulate matter with an aerodynamic diameter ≤ 10 microns, and sulfur oxides. However, for the following reasons, the list of "criteria pollutants" for emissions (and emissions inventory) purposes is slightly different than the pollutants regulated by NAAQS:

(1) Ozone is created in the atmosphere (ambient air) through a photochemical reaction involving the following two precursors: volatile organic compounds (VOC) and nitrogen oxides (NO_X).

(2) Nitrogen dioxide (NO_2) in the ambient air is a result of emissions of various nitrogen oxide (NO_X) compounds, not just NO_2.

Based on these items, criteria pollutants for air emissions inventory purposes include the following:

- Carbon Monoxide (CO)
- Lead (Pb)*
- Nitrogen Oxides (NO_X) [Note - NO_X is also referred to as "Oxides of Nitrogen"]
- Particulate Matter with an aerodynamic diameter ≤ 10 microns (PM_{10}) [Note - if PM_{10} data is not available, Total Particulate Matter (Total PM) data can be used as a worst-case substitute]
- Sulfur Oxides (SO_X) [Note - SO_X is also referred to as "Oxides of Sulfur"]
- Volatile Organic Compounds (VOCs)

***Note** - Although lead is a criteria pollutant, it is also a hazardous air pollutant. Therefore, to avoid duplication, this document will address lead as a hazardous air pollutant but not as a criteria pollutant.

b. Hazardous Air Pollutants (HAPs)

HAPs include the 188 toxic compounds listed under Section 112(b) of the Clean Air Act. Two listings of these HAPs (one in alphabetical order and the other in CAS number order) are provided in Appendix A of this document.

c. Ozone Depleting Substances (ODSs)

ODSs include the Class I and Class II compounds listed in 40 CFR 82. Class I substances include chlorofluorocarbons (CFCs), Halons, carbon tetrachloride, methyl chloroform, methyl bromide, and hydrobromofluorocarbons (HBFCs). Class II ODSs include hydrochlorofluorocarbons (HCFCs).

1.4 Inventory Data Elements and Format:

a. Inventory Data Elements

In order to calculate the emissions needed to compile an air emissions inventory, certain input information is required. For example, in order to calculate the emissions from asphalt paving operations the following information is needed: 1) types of cutback asphalt used during the year (e.g., rapid cure, medium cure, slow cure); 2) quantity (pounds) of each type of cutback asphalt applied during the year; and 3) volume percent solvent in each type of cutback asphalt used.

Based on the calculation methodologies presented in this document, Appendix B contains a listing of data elements for each source type. It is recommended that the Air Quality Manager (AQM) review the listing and contact the applicable shops on base to ensure this data is being recorded.

b. Inventory Format

Although inventory calculations are usually performed electronically (e.g., using spreadsheets or an air quality management program/database), in most cases the completed inventory is submitted as a written report. Currently, the Air Force and the EPA do not specify any particular format for preparing air emissions inventory reports. Therefore, unless State and local regulatory agencies specify a certain format, inventory reports are usually in the format chosen by the person(s) or organization(s) who prepared the inventory. As the repository for Air Force air emissions inventories, IERA/RSEQ believes there are several advantages to having Air Force inventory reports prepared in a similar manner. For example, having inventory reports in a similar format makes it easier to compare data, aggregate data, perform trend analyses, etc. Therefore, a recommended format for air emissions inventory reports is provided in Appendix C of this document. The format is designed to assist air managers and State/local regulators in reviewing and/or completing the AEIs. The format starts with summary tables which provide convenient snapshots of the air emissions. Other items contained in the format include Source Classification Codes (SCCs), Standard Industrial Classification (SIC) codes, qualifying assumptions, example calculations, references, etc.

1.5 Inventory Requirements and Uses:

a. Regulatory Requirements

Air emissions inventories are usually accomplished to meet one or more regulatory requirement(s). The most common regulatory requirements for conducting an AEI are summarized below:

(1) *Title I of the CAAA-90*

The Clean Air Act (CAA) requires States to develop State Implementation Plans (SIPs) for attaining and maintaining NAAQS. Per Title I of the CAAA-90, SIPs must include provisions for States to submit emissions inventories to the EPA and for sources to submit emissions inventories to the State. The following is a summary of inventory requirements implemented by Title I of the CAAA-90:

(a) According to Section 172 of the CAA, a State must include a current inventory of each criteria pollutant whenever a State Implementation Plan (SIP) revision is submitted to the EPA. The inventory of each pollutant will only include actual emissions from sources located in areas which are in nonattainment for that particular pollutant (note - for ozone nonattainment areas, this would include an inventory of VOCs and NO_X).

(b) Section 182(a)(1) of the CAA required each State to submit a current inventory of actual VOCs and NO_X emissions (from sources in areas which are in nonattainment for ozone) and of actual CO emissions (from sources in areas which are in nonattainment for CO) to the EPA by November 1992. This inventory included emissions for calendar year 1990 and is referred to as the baseline year emissions inventory. Subsequent to the baseline inventory, States must submit periodic inventories every three years until the area reaches attainment.

(c) Section 182 of the CAA also required States to submit SIP revisions (by 15 November 1992) requiring stationary sources in ozone nonattainment areas to report their actual VOC and NO_X emissions to the State by 15 November 1993 and annually thereafter (note - States may waive this requirement for sources which emit less than 25 tons per year of VOC or NO_X).

(2) *Title III of the CAAA-90*

Under Title III of the CAAA-90 (Section 112 of the CAA), the EPA is required to promulgate National Emissions Standards for Hazardous Air Pollutants (NESHAPs) to regulate certain source categories which emit HAPs. Some of these NESHAPs, such as the Aerospace Manufacturing and Rework NESHAP, only apply to sources which are considered to be a "major source" for HAPs. A major source for HAPs is defined as any stationary source or group of stationary sources located within a contiguous area and under common control that emits or has potential to emit $\geq$ 10 tpy of any single HAP or $\geq$ 25 tpy of any combination of HAPs. In order for a source (e.g., military installation) to determine if it is a major source for HAPs, an inventory of HAP emissions must be accomplished.

It's important to note that fugitive emissions must be included when determining if a source is a major source for HAPs. Fugitive emissions are those emissions which could not reasonably pass through a stack, chimney, vent, or other functionally-equivalent opening. It's also important to mention a 16 May 1995 EPA policy memorandum titled "Potential to Emit for MACT Standards – Guidance on Timing Issues." In this memorandum, the EPA states that if a facility must comply with a NESHAP because it is a major source for HAPs (i.e., it is a major source for HAPs on the "first compliance date" of the NESHAP) then the facility must always comply with that NESHAP even if it later becomes a non-major source (area source) for HAPs. This is know as the "once in, always in" policy.

(3) *Title V of the CAAA-90*

Under Title V of the CAAA-90 (and Title V of the CAA), all stationary sources which are classified as a "major source" are required to obtain a Title V operating permit. A major source under Title V includes the following:

(a) A major source under Section 112 of the Clean Air Act (i.e., a major source for HAPs)

(b) A stationary source (or group of stationary sources that are located on one or more contiguous properties, are under common control, and belong to the same two-digit Standard Industrial Classification code) which emits more than 100 tons per year (tpy) of any air pollutant (as defined under

section 302(g) of the CAA). For some of the criteria pollutants, lower limits exist for certain nonattainment areas. These lower limits include the following:

- 50 tpy of VOC and NO_X emissions in "serious" ozone nonattainment areas and in ozone transport regions
- 25 tpy of VOC and NO_X emissions in "severe" ozone nonattainment areas
- 10 tpy of VOC and NO_X emissions in "extreme" ozone nonattainment areas
- 50 tpy of CO emissions in "serious" CO nonattainment areas
- 70 tpy of PM_{10} emissions in "serious" PM_{10} nonattainment areas

In order for a source (e.g., military installation) to determine if it is a major source under Title V, an emissions inventory (of actual and potential emissions) must be accomplished. It's important to note that with the exemption of the HAPs regulated under Title III, when making a major source determination under Title V you do <u>not</u> need to include fugitive emissions unless the emissions come from one of the 27 source categories listed in 40 CFR 70.2. However, if a Title V permit is required, then fugitive emissions need to be included in the permit application.

(4) *Section 313 of the Emergency Planning and Community Right-to-Know Act (EPCRA)*

EPCRA Section 313 (40 CFR 372) contains a list of over 680 toxic chemicals and requires facilities to submit annual Toxic Release Inventory (TRI) reports for all chemicals which are either manufactured/processed or otherwise used at the facility above threshold levels. These threshold levels include the following:

- 25,000 pounds for any chemical manufactured or processed at the facility during the year
- 10,000 pounds for any chemical otherwise used at the facility during the year

For those chemicals above threshold levels, the facility must submit an EPA Form R which specifies the amount of the chemical which was released to the environment (i.e., via air, water, and land). The amount released to the air is usually obtained from emissions inventory data. Although this document does not specifically address the EPCRA Section 313 chemicals, most of the chemicals which are applicable to the Air Force are also on the list of HAPs (e.g., methyl ethyl ketone, toluene, methyl chloroform, methylene chloride, phenol, etc).

(5) *General Conformity*

The general conformity program (found under 40 CFR 93) requires all Federal actions in nonattainment and maintenance areas to comply with the appropriate SIP. The Federal agency responsible for the action is required to perform a determination to verify that the action(s) conform. An emissions inventory is usually required as part of the conformity determination to identify/quantifying air emissions from the Federal actions.

(6) *National Environmental Policy Act (NEPA)*

NEPA requires Federal agencies to evaluate the environmental impacts associated with major actions that they either fund, support, permit, or implement. As part of the NEPA process, an Environmental Assessment (EA) is required if it's determined that the Federal action may have a significant environmental impact. The EA is a study submitted to the EPA that provides background information and preliminary analyses of the potential impact of the proposed Federal action. If the results of the EA indicate that further study of the proposed action is necessary, then a more comprehensive

Environmental Impact Statement (EIS) must be prepared. The EIS addresses all possible impacts (both beneficial and adverse) which may result from the proposed action as well as possible alternatives to the action. Data from air emissions inventories can be used in EAs and EISs to help identify possible environmental consequences associated with air emissions from proposed Federal actions.

(7) *State/Local Programs*

Some State and local regulatory agencies have unique programs which require some sort of air emissions inventory. One example is California's Air Toxics "Hot Spots" Information and Assessment Act of 1987 (Assembly Bill 2588). The Air Toxics "Hot Spots" Act regulates over 600 substances which may pose chronic or acute health threats when present in the air. The "Hot Spots" Act requires applicable facilities to prepare/submit an Emissions Inventory Plan (EIP) which indicates how air toxic emissions will be measured or calculated. After the EIP is approved, the facility is required to prepare/submit an Emissions Inventory Report (EIR) which quantifies the air toxic emissions.

(8) *Air Force Instruction (AFI) 32-7040*

AFI 32-7040, "Air Quality Compliance," states the following: "Prepare and periodically update a comprehensive base air emissions inventory. Inventory data will be provided to Federal, State, and local regulatory agencies as required or upon request. Coordinate with Armstrong Laboratory on inventory development and ensure that base emissions inventory data are transferred to the Air Force emissions inventory repository custodian at Armstrong Laboratory."

It's important to note that Armstrong Laboratory no longer exists and that the Air Force emissions inventory repository is maintained by IERA/RSEQ. A copy of all final emissions inventory reports should be mailed to the following address:

IERA/RSEQ
(Attn: Air Emission Inventory Custodian)
2513 Kennedy Circle
Brooks AFB TX 78235-5123

(9) *24 July 1995 Air Force Policy Memorandum*

This policy memo, titled "Air Force Pollution Prevention Strategy," includes a requirement that Air Force installations reduce their volatile air emissions (i.e., VOC emissions) by 50 percent from 1993 baseline levels. The suspense for accomplishing this reduction is 31 December 1999. In order to demonstrate compliance with this requirement, VOC emissions inventories will be required.

b. <u>Other Inventory Uses</u>

Although meeting regulatory requirements is the main reason AEIs are performed, it is not the only reason. An air emission inventory can be a useful tool in helping industrial facilities implement various environmental programs. The most common of these programs include the following:

(1) *Pollution Prevention (P2) Opportunities* - An air emissions inventory can be a useful tool in identifying air-related P2 opportunities on military installations. The inventory identifies the types of air pollution sources on base as well as the emissions.

(2) *Emissions Trading* - The EPA developed the emissions trading policy to provide sufficient flexibility to industry and States in meeting CAA requirements. In general, emissions trading includes several methods which may be used to create surplus emissions which may be traded within a source (e.g., within a facility, plant, installation, etc.) or between different sources in order to meet applicable air pollution control requirements. These trading methods include emission bubbles, emission netting, emission offsets, and emission reduction banking. The following is a brief description of each:

(a) Emission bubbles allow for an increase in emissions at one or more processes at a source (e.g., a facility) in exchange for a decrease in emissions at another process located at the facility.

(b) Emission netting may exempt a modification to an existing process from the preconstruction permit review requirements under the New Source Review (NSR) program as long as no net emissions increases occur at other emission points at the facility.

(c) Emission offsets require new sources or modifications to existing sources located in nonattainment areas to secure sufficient emission reductions from other sources located in the same area in order to "offset" the emissions which will result from the start-up of the new source or source modification.

(d) Emission reduction banking allows sources to store emission reduction credits (ERCs) in EPA-approved banks in order to use such credits in bubble, netting, or offset transactions. These banked ERCs may be sold or traded to other sources (depending on individual bank rules) in order to meet emissions limitations.

In order for a source (facility) to trade emissions, the emissions from its processes must be known (quantified). This information may be obtained from air emissions inventories.

(3) *Risk Assessments* - In certain cases it may be necessary to assess the risk(s) which air emissions from a military installation can have on specific public receptors. Data from air emissions inventories can be used in conjunction with approved dispersion models to perform these risk assessments.

(4) *Environmental Auditing* - An environmental audit is an objective review of a facility's operations and practices done in order to determine if the facility is meeting its environmental requirements. Audits can be designed to verify compliance with environmental requirements, evaluate the effectiveness of environmental management systems already in place, or assess risks from regulated and unregulated materials and practices. In addition, the audit can be used by management to plan environmental activities for the future. Data from air emissions inventories can be used in the audit process to help identify current and/or potential future air pollution problems associated with a facility's operations and practices.

1.6 Potential to Emit (PTE): A source's potential to emit (PTE) is an essential part of an air emissions inventory. Potential emissions are used to categorize a source as either "major" or "minor" for criteria air pollutants and either "major" or "area" for hazardous air pollutants. Compliance costs vary greatly depending on the source's regulatory status. Under Titles III and V of the 1990 Clean Air Act Amendments, complex and lengthy requirements were established for any facility classified as a "major source," as defined under 40 CFR 63 and 70, respectively. Both Title III and V could conceivably have tremendous economic and operational impacts at U.S. Air Force (USAF) installations. Avoiding major source status can save a facility millions of dollars in manpower costs, equipment modifications, and fees. However, all too often inventories contain overly conservative (and sometimes unrealistic) calculation

methods, which result in greatly inflated PTEs and an incorrect classification of the facility as a major source of emissions. Section 37 of this report provides recommended methods for calculating PTE from typical Air Force processes, in a manner which is both realistic and reasonably conservative.

1.7 Major Source Determination: As mentioned above, many of the requirements under Titles III and V of the 1990 Clean Air Act Amendments apply only to Major Sources. Over the past few years, the EPA has published policy memorandums which provide guidance on how some sources (such as military installations) may be able to avoid Major Source status. The following is a summary of these policy memorandums:

a. PTE Transition Policy

On 25 January 1995 the EPA published a memo titled "Options for Limiting the Potential to Emit (PTE) of a Stationary Source Under Section 112 and Title V of the Clean Air Act (Act)." In this memo the EPA recognized that there were few programs/strategies available for sources to obtain federally-enforceable PTE limitations due to delays in State adoption or EPA approval of programs or in their implementation. For this reason, the EPA initiated a transition policy for a period up to two years from the date of the memo (i.e., 25 Jan 95 to 25 Jan 97). During this two year period, the EPA gave State and local air regulators the option of treating the following types of sources as non-major:

(1) Sources which maintain adequate records to demonstrate that actual emissions are less than 50 percent of the major source threshold.

(2) Sources which have actual emissions between 50 - 100 percent of the major source threshold, but holding State-enforceable limits that are enforceable as a practical matter. These sources must also submit a written notification to the EPA that they will comply with the limits as a restriction on their PTE.

On 27 August 1996 the EPA published another memorandum titled "Extension of January 25, 1995 Potential to Emit Transition Policy." In this memo, the EPA issued an 18 month extension to the transition policy (i.e., from 25 January 1997 to 31 July 1998). Then, on 10 July 1998 the EPA published a third memorandum titled "Second Extension of January 25, 1995 Potential to Emit Transition Policy and Clarification of Interim Policy." In this memo the EPA states they are currently engaged in a rulemaking process which will address/clarify federal enforceability issues associated with PTE. The EPA also stated in this memo that they are once again extending the transition policy. The new extension is to 31 December 1999, or until the effective date of the final rule in the PTE rulemaking, whichever is sooner.

b. Major Source Determinations for Military Installations

As mentioned in the discussions above on Title III and Title V of CAAA-90, a "Major Source" can be a group of stationary sources that are located on one or more contiguous properties, are under common control, and (for Title V only) belong to the same two-digit Standard Industrial Classification (SIC) code. If the combined potential emissions from such a group of stationary sources exceeds threshold levels, then the entire group is treated as a single Major Source. On 2 August 1996, the EPA published a memorandum titled "Major Source Determinations for Military Installations under the Air Toxics, New Source Review, and Title V Operating Permit Programs of the Clean Air Act." This memo established several policies regarding major source determination at military installations. The following is a summary of these policies:

(1) *Common Control Determinations*

According to the 2 August 1996 memo, the EPA considers pollutant-emitting activities that are under the control of different military services not to be under common control. More specifically, pollutant-emitting activities under the control of the following entities may be considered under separate control when making major source determinations at military installations:

- Air Force
- Army
- Marine Corps
- National Guard
- Navy
- Defense Agencies*

***Note** - The 2 August 1996 memo contains a listing of 17 defense agencies. Three examples include the Defense Logistics Agency (DLA), the Defense Commissary Agency (DCA), and Defense Nuclear Agency (DNA). All defense agencies at a military installation would fall under common ownership.

As an example of common control, if a National Guard unit was located at an Air Force base, then the emissions associated with the National Guard activities would not be counted towards the Air Force base's emissions when making a Major Source determination for the Air Force base. The National Guard unit would perform its own Major Source determination which would be based solely on emissions from National Guard activities.

In addition to addressing common control issues associated with different military services, the 2 August 1996 memo also addresses common control issues associated with leased activities and contract-for-service activities. In general, leased activities located at a military installation may be considered under separate control if they are not under the direct or indirect control of the lessor (e.g., through a contract-for service arrangement) and they do not support any activities that are owned or operated by the lessor (note - the lessor refers to the military entity who owns the installation). These leased activities generally would be considered "tenants" on military bases. Examples of leased activities that may be considered under separate control include "civilian reuse" activities; academic (e.g., university) activities; and activities under the control of other Federal, State, interstate, or local entities; provided that these activities are not contracted to provide services to a military controlling entity located at that military installation. The term "civilian reuse" is used to describe the use by nonmilitary entities of property that is part of a military installation but has been scheduled for closure or realignment pursuant to the Base Closure and Realignment Act of 1988 or the Defense Base Closure and Realignment Act of 1990. For example, an Air Force base is in the process of closing and no longer needs the use of one of its hangars. The base then leases the hangar to an aircraft manufacturer who uses it only for their own aircraft (no Air Force aircraft). This hangar can therefore be considered to be under separate control from the military entity who owns the installation.

In contrast to leased activities, contract-for-service (or contractor-operated) activities at military installations are usually considered to be under the control of the military entity that controls the contract. Therefore, emissions from contract-for-service activities would be included in the military installation's Major Source determination.

(2) *Industrial Grouping and Support Facility Determinations*

[**Note** - this subsection is applicable to major source determination under Title V of the CAAA-90 and under the New Source Review (NSR) program but is not applicable to major source determination under Title III of the CAAA-90]

As mentioned above, part of the criteria for making a major source determination under Title V of the CAAA-90 is that the stationary sources (emission units/activities) which are grouped together have the same two-digit SIC code. Historically, all activities at a military installation have been grouped under Standard Industrial Classification (SIC) code 97, "National Security and International Affairs." However, according to the 2 August 1996 memo, the EPA has determined that this procedure is inappropriate for major source determinations at some military installations. The EPA believes a more appropriate approach is to think of military installations as combinations of functionally distinct groupings of pollutant-emitting activities that may be identified and distinguished the same way that industrial and commercial sources are distinguished. First, the activities at a military installation are classified as either “primary” or “secondary” (note - at most Air Force installations, primary activities include activities like operation and maintenance of aircraft, training of military personnel, etc.). Second, each activity is assigned the 2-digit SIC code that best describes it (note - SIC code 97 should be used if no other appropriate SIC code exists). Next, those activities with the same 2-digit SIC code (and under common control) are aggregated to form an industrial grouping. Each industrial grouping can then be addressed separately for major source determination. It’s important to note that when making a major source determination, each support activity is considered to be part of the same source as the primary activity it supports.

A listing of two-digit SIC codes is provided in Appendix D of this document. It’s important to note that in order to assign the proper two-digit SIC code to an activity, it may be necessary to first determine the more specific four-digit code (note - the two-digit code is the first two numbers of the four-digit code). It’s also important to note that in 1997 the SIC Code system was replaced with the North American Industry Classification System (NAICS). However, it’s unknown at this time what impact, if any, this system change will have on EPA’s policies/definitions which involve SIC codes. The following are a couple of good internet sites which provide listings of four-digit SIC codes and corresponding NAICS codes:

- http://www.census.gov/epcd/www/naicstab.htm
- http://www.webplaces.com/naics/

As mentioned in the 2 August 1996 memo, military installations include numerous activities that are not normally found at other types of sources. These types of activities include residential housing, schools, day care centers, churches, recreational parks, theaters, shopping centers, grocery stores, BX gas stations, and dry cleaners. These activities are located on military installations for the convenience of military personnel (both active duty and retired), their dependents, and DoD civilian employees working on the base, and they often do not represent essential activities related to the primary military activity(ies) of the base. Therefore, the EPA believes these types of activities may appropriately be considered not to be support facilities to the primary military activities of a base. As such, these activities may be treated as separate sources for all purposes for which an industrial grouping distinction is allowed. Such activities should be separately evaluated for common control, SIC code, and support facility linkages to determine if a major source is present.

1.8 References

1. U.S. Environmental Protection Agency, *Introduction to Air Pollutant Emission Estimation Techniques for Industry*, Draft Version, 30 November 1992.

2. U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources* (AP-42), Introduction, January 1995.

3. Title 40 Code of Federal Regulations Part 50 (40 CFR 50), *National Primary and Secondary Ambient Air Quality Standards*.

4. Title 40 Code of Federal Regulations Part 63 (40 CFR 63*), National Emission Standards for Hazardous Air Pollutants for Source Categories*.

5. Title 40 Code of Federal Regulations Part 70 (40 CFR 70), *State Operating Permit Programs*.

6. Title 40 Code of Federal Regulations Part 93 (40 CFR 93), *Determining Conformity of Federal Actions to State or Federal Implementation Plans*.

7. Title 40 Code of Federal Regulations Part 372 (40 CFR 372), *Toxic Chemical Release Reporting: Community Right-to-Know*.

8. Engineering-Science, *NEPA Technical Presentation*, AFOEHL Project Management Workshop at Brooks AFB TX, 18 October 1990.

9. California Air Resources Board (CARB), *Overview of the Air Toxics "Hot Spots" Information and Assessment Act*.

10. Air Force Instruction (AFI) 32-7040, *Air Quality Compliance*, 9 May 1994.

11. Air Force Policy Memorandum, *Air Force Pollution Prevention Strategy*, 24 July 1995.

12. U.S. EPA Policy Memorandum, *Options for Limiting the Potential to Emit (PTE) of a Stationary Source Under Section 112 and Title V of the Clean Air Act (Act*), 25 January 1995.

13. U.S. EPA Policy Memorandum, *Potential to Emit for MACT Standards – Guidance on Timing Issues*, 16 May 1995.

14. U.S. EPA Policy Memorandum, *Calculating Potential to Emit (PTE) for Emergency Generators*, 6 September 1995.

15. U.S. EPA Policy Memorandum, *Major Source Determinations for Military Installations under the Air Toxics, New Source Review, and Title V Operating Permit Programs of the Clean Air Act*, 2 Aug 96.

16. U.S. EPA Policy Memorandum, *Extension of January 25, 1995 Potential to Emit Transition Policy*, 27 August 1996.

17. U.S. EPA Policy Memorandum, *Potential to Emit (PTE) Guidance for Specific Source Categories*, 14 April 1998.

SECTION 2

ABRASIVE BLASTING

2.1 Background: Abrasive blasting operations involve the use of a hard material such as sand, plastic beads, or glass beads to remove old paint and/or corrosion from equipment. A high pressure gun is used to blast the sand or beads at the equipment being stripped/cleaned. Depending on the size of the equipment, blasting is usually performed in either a small enclosed cabinet (i.e., glove box), in a booth, or in a hangar. For example, an aircraft wheel is usually stripped in a cabinet, Aerospace Ground Support Equipment (AGSE) is usually stripped in a booth, and complete aircraft are usually stripped in a hangar.

The exhaust from blasting operations, which contains a mixture of blasting material and stripped paint dust, is usually ventilated to a control system consisting of a fabric filter (i.e., baghouse) or a fabric filter preceded by a cyclone. The purpose of the cyclone (if used) is to separate large beads from the smaller particulate matter in the exhaust stream. The large beads are then sent back to the blasting system to be reused while the smaller particulate matter, which consists primarily of small non-reusable beads and paint dust, is vented to the baghouse where it is captured and collected in a bin for disposal.

Depending on the coatings (paint and primer) being stripped, the material exhausted from blasting operations may contain inorganic HAPs such as chromium, lead, or cadmium. Typical Air Force shops which perform controlled abrasive blasting include Corrosion Control, Wheel & Tire, and AGSE. In addition, some bases may also perform uncontrolled abrasive blasting (e.g., emissions are exhausted directly into the atmosphere). Possible uncontrolled abrasive blasting operations include small scale (touch-up) blasting of equipment, blasting of large outdoor structures such as buildings or water towers, and blasting of road surfaces.

2.2 Emission Calculations:

a. Controlled Operations

Calculating the particulate matter (PM) emissions from controlled blasting operations is based on the efficiency of the fabric filter control device and the amount of waste material captured/collected. The following procedures are used to perform the calculations.

(1) The first step is to calculate the total amount (mass) of waste material exhausted to the fabric filter. This is done by dividing the amount (mass) of waste material collected by the efficiency of the fabric filter.

$$WM_{total} = (WM_{col}) / (eff/100)$$

Where,

WM_{total} = Total amount of waste material exhausted to the fabric filter (lb/yr)
WM_{col} = Amount of waste material captured by the fabric filter (lb/yr)
eff = Efficiency of fabric filter (%)

(2) The second and final step is to calculate the PM emission rate (E_{PM}) by subtracting the amount of waste material collected from the total amount of airborne waste material entering the fabric filter.

$E_{PM} = WM_{total} - WM_{col}$

HAP pollutants may be generated from abrasive blasting operations if the paint/coating being stripped is known to contain an inorganic HAP such as chromium, lead, or cadmium. Although HAP emissions from abrasive blasting are usually relatively low, they can be estimated, if desired, by performing a chemical analysis of the waste material collected by the fabric filter. The analysis must be for total metal content and not for Toxic Characteristic Leachate Procedure (TCLP). A total metal analysis will usually provide results mg/kg (e.g., mg chromium/kg waste). The units can then be converted from mg/kg to lb/lb. Finally, the emissions of an inorganic HAP are calculated by multiplying the lb/lb analytical result by the pounds of PM emitted to the atmosphere.

b. Uncontrolled Operations

The PM emissions from uncontrolled blasting operations can be estimated using a simple mass balance. Basically, the amount of raw blasting material used is assumed to equal Total PM emissions. Unfortunately, this method does not account for the emissions contributed by the coating/corrosion being removed from the equipment surface. However, most of the PM emissions from abrasive blasting come from the spent abrasive material and not the removed coating/corrosion.

c. Emission Calculations using Emission Factors

As an alternative to the above procedures, emissions from both controlled and uncontrolled abrasive blasting operations may be calculated by using emission factors. Unfortunately, only a few emission factors currently exists for abrasive blasting. These factors are listed in Table 2-1 below. If an appropriate emission factor is available, the emissions from an abrasive blasting operation can be estimated by simply multiplying emission factor by the amount (mass) of abrasive material used.

$E_{PM} = AM * EF$

Where,

E_{PM} = PM Emission Rate (lb/yr)
AM = Amount of Abrasive Material Used (10^3 lb)
EF = Emission Factor (lb/10^3 lb)

Table 2-1. Emission Factors for Blasting Operations

Source	Particle size	Emission Factor ($lb/10^3$ lb abrasive material used)
Uncontrolled sand blasting of mild steel panels (SCC 3-09-002-02)[a]	Total PM[b] 5 mph wind speed 10 mph wind speed 15 mph wind speed PM_{10}[c] $PM_{2.5}$[c]	 27 55 91 13 1.3
Abrasive blasting of unspecified metal parts, controlled with a fabric filter[d] (SCC 3-09-002-04)[a]	Total PM	0.69

[a] SCC = Source Classification Code
[b] Uncontrolled PM emissions are dependent on wind speed. Higher wind speeds increase emissions by enhanced ventilation of the process and by retardation of coarse particle deposition.
[c] Emissions of PM_{10} and $PM_{2.5}$ are not significantly wind-speed dependent.
[d] Based on abrasive blasting with garnet blast media.

2.3 Information Resources: Information associated with abrasive blasting can be obtained from the specific shops/organizations performing the blasting operations (e.g., Corrosion Control, Wheel & Tire, AGSE, Civil Engineering, etc.)

2.4 Example Problems

a. Problem # 1

The corrosion control shop on base performs abrasive bead blasting of entire aircraft. The blasting is performed in a large hangar. Exhaust from the hangar is ventilated to a cyclone which separates the large and small material. The large beads are returned back to the blasting equipment to be reused while the small particulate matter (small beads, paint dust, etc.) is sent to a baghouse. Shop records show that 3,275 pounds of waste material was captured/collected by the baghouse and disposed of. Based on information supplied by the baghouse manufacturer, the estimated control efficiency of the baghouse for this material is 96%. A review of the Material Safety Data Sheets for the primer and paint used on the aircraft reveals that the primer contains zinc chromate. Since chromium is a HAP, a sample of the waste material was collected by the base Bioenvironmental Engineer and sent to an analytical laboratory for total chromium analysis. Results from the laboratory indicate the total chromium content is 940 mg/kg. Calculate both the PM and chromium emissions.

(1) First calculate the total amount of waste material exhausted to the baghouse based on the amount of waste material collected by the baghouse and on the efficiency of the baghouse.

$WM_{total} = (WM_{col}) / (eff/100)$
$WM_{total} = 3{,}275 \text{ lb} / (96\%/100) = \underline{3{,}411 \text{ lb}}$

(2) Next calculate the particulate matter emissions as follows:

E_{PM} = WM_{total} - WM_{col}
E_{PM} = 3,411 lb - 3,275 lb = **<u>136 lb</u>**

(3) Before calculating the chromium emissions, first convert the total chromium analytical result from mg/kg to lb/lb.

(940 mg Cr/kg waste)* (1 lb/453,590 mg) * (1 kg/2.205 lb) = <u>9.40×10^{-4} lb Cr/lb waste</u>

(4) Finally calculate the chromium emissions as follows:

E_{Cr} = E_{PM} * (lb Cr/lb waste)
E_{Cr} = (136 lb) * (9.40×10^{-4} lb Cr/lb waste) = **<u>0.13 lb</u>**

b. <u>Problem # 2</u>

Base Civil Engineering used approximately 6,500 pounds of sand during the year to perform abrasive blasting on various outdoor metal structures on base. Calculate the annual PM_{10} emissions.

E_{PM10} = AM * EF
E_{PM10} = (6.5×10^3 lb) * (13 lb/10^3 lb) = **<u>84.5 lb</u>**

2.5 References

1. U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources* (AP-42), Section 13.2.6, September 97.

SECTION 3

AIRCRAFT ENGINE TESTING

3.1 Background: Testing of aircraft engines is performed at most Air Force installations (i.e., those with flying missions) on a routine and as needed basis. Testing is necessary to ensure proper engine operation prior to fight, especially after any maintenance has been performed.

Testing of an aircraft engine may be performed with the engine either on or off the aircraft. Engines removed from the aircraft are typically tested in a test cell or hush house. A few installations also test removed engines in outdoor test stands. Testing of engines while on the aircraft is performed either in hush houses or outdoor trim pads.

In general, testing of engines removed from the aircraft is usually considered a stationary source, while testing of engines on the aircraft is usually considered a mobile source. However, it's important to note that some State/local regulatory agencies may have a different interpretation. For this reason, the appropriate State and/or local regulatory agencies should be contacted (e.g., prior to performing an air emission inventory) to ensure proper designation.

Emissions of concern from aircraft engine testing operations include the criteria pollutants and a variety of HAPs (both organic and inorganic). Unfortunately, most previous available emission factors for engines used on Air Force aircraft were based on the use of JP-4 fuel. With the recent Air Force conversion to JP-8 fuel, these emission factors are no longer considered valid. It's important to note that some previous emission factors were based on JP-5 fuel (instead of JP-4) and that these emission factors are still considered valid since JP-5 is very similar to JP-8. During the last few years, the Air Force has performed emissions sampling on a variety of aircraft engines, as well as a few Auxiliary Power Units (APUs), while burning JP-8 or JP-5 fuel. This sampling was still in progress at the time this report was written, and emission factors were not able to be published in this document. However, these emission factors will be published in a separate report. Once this separate report is published, emission factor data will also be made available on IERA/RSEQ's Air Quality Internet site (http://sg-www.satx.disa.mil/iera/rse/air.htm).

Until the report containing the aircraft emission factors is published, the following individual should be contacted to obtain available aircraft emissions information:

Mr. Mark Wade
IERA/RSEQ
Tel: DSN 240-4858 or Comm (210) 536-4858
E-mail: Mark.D.Wade@esoh.brooks.af.mil

Aircraft engines are typically tested at different power settings. These power settings are usually identified using terms such as Idle, Approach, Intermediate, Military, Afterburner, etc. The emission factors in this report are provided for the common power settings applicable to each engine. The corresponding fuel flow rate listed for each engine power setting is the fuel rate used during the emissions sampling to derive the emission factors. The actual fuel rates used during the testing of aircraft engines at individual Air Force installations may be slightly different. If known, the actual fuel rates used by the base during engine testing should be the ones used to calculate emissions.

3.2 Emission Calculations: Emissions associated with the testing of a particular aircraft engine are determined by first calculating the emissions associated with testing at each different power setting and

then summing up these emissions. Calculating the emissions associated with testing at a particular power setting is accomplished by multiplying the appropriate emission factor times the actual fuel flow rate (used during testing) and then times the actual time spent testing the engine at that power setting.

$$E_{pol} = EF * FR * t$$

Where,

E_{pol} = Emissions of a particular pollutant resulting from testing an aircraft engine at a specific power setting (lb/yr)
EF = Emission factor in pounds pollutant per thousand pounds of fuel burned (lb/1000 lb)
FR = Fuel flow rate at the applicable power setting (1000 lb/hr) [Note - gallons of fuel can be converted to pounds of fuel by multiplying the gallons times the fuel density (e.g., density of JP-8 is 6.8 lb/gal)]
t = Total annual time in which the engine was tested while operating at the applicable power setting (hr/yr) [Note - if the amount of time spent to test an engine at a particular power setting is about the same for each test, then the total annual testing time can be estimated by multiplying the number of tests performed during the year times the average time per test]

Note – Some installations keep records of the total quantity of fuel consumed during the year at each power setting the engine is tested at. In this case, the "FR * t" portion of the equation should be replaced with the quantity of fuel consumed (1000 lb/yr) at the applicable power setting.

As mentioned in subsection 3.1 above, pollutant emission factors derived from actual aircraft engine testing will be published in a separate document. However, one pollutant which is not being measured via sampling is SO_X. Instead, SO_X emission factors are derived by assuming all the sulfur in the fuel is converted to SO_X (as SO_2) during combustion. Based on this, SO_X emission factors are calculated using the following equation:

$$EF_{SOx} = 20 * S$$

Where,

EF_{SOx} = SO_X emission factor [pounds SO_X emitted per thousand pounds of fuel combusted (lb/1000 lb)]
20 = Factor which is derived by converting "weight percent" into units of "lb/1000 lb" and then multiplying times the ratio of the molecular weight of SO_2 to the molecular weight of sulfur
S = Weight percent sulfur content of the fuel

The weight percent sulfur content of the fuel (S) usually varies depending on the supplier and the geographical location where the fuel is produced. Therefore, a typical sulfur content value should be obtained from the fuel supplier whenever possible. If this information is not available, then one of the average sulfur content values listed in Table 3-1 below can be used.

Table 3-1. Average Sulfur Content Values for JP-8 Fuel[a]

Geographic Region[b]	States or Countries[b]	Average Sulfur Content (weight %)
East Coast U.S.	ME, VT, NH, MA, RI, CT, NY, PA, NJ, DE, MD, VA, WV, NC, SC, GA, FL	0.023
East Central U.S.	ND, SD, MN, IA, NE, WI, MI OH, KY, TN, IN, IL, MO, KS, OK	0.085
Gulf Coast U.S.	AL, MS, AR, LA, TX, NM	0.042
West Central U.S.	MT, ID, WY, UT, CO	0.026
West Coast U.S.	WA, OR, CA, NV, AZ	0.048
Middle East	Kuwait, Bahrain	0.010
European	Europe, Israel, Turkey	0.079
Pacific	Korea, HI, AK, Australia	0.067

[a] Based on average 1996 values obtained from the report titled "Survey of Jet Fuels Procured by the Defense Energy Support Center, 1990 - 1996."
[b] Applies to the location of the refinery which produces the fuel.

3.3 Information Resources: The Aircraft Maintenance organization should be contacted to obtain the information needed to calculate emissions from aircraft testing operations; including the types of engines tested, the total time spent testing an engine at each power setting, and the typical fuel flow rate used during testing at each power setting.

3.4 Example Problem: An Air Force installation uses a test cell to perform evaluations on the TF33-P-7 engine which is used on their C-141B aircraft. The base is located in Southeastern part of the U.S. and uses JP-8 fuel which is produced (refined) in Louisiana. According to records kept by the Aircraft Maintenance organization, 102 engine tests were performed during the year. Each test involved the following power settings: Idle, Approach, Intermediate, and Military. The operating times and fuel flow rates for each power setting were approximately the same for each test, and are as follows:

Power Setting	Average Fuel Flow Rate During Testing (lb/hr)	Average Operating Time per Test (minutes)
Idle	1,100	20
Approach	4,900	45
Intermediate	6,375	15
Military	8,280	15

Calculate the CO and SO_X emissions associated with the testing of the TF33-P-7 engine.

a. The first step is to calculate the total time (hours) during the year in which testing was performed at each power setting.

Total Time in Idle: 102 test/yr * 20 min/test * (1 hr/60 min) = 34 hr/yr
Total Time in Approach: 102 test/yr * 45 min/test * (1 hr/60 min) = 76.5 hr/yr
Total Time in Intermediate: 102 test/yr * 15 min/test * (1 hr/60 min) = 25.5 hr/yr
Total Time in Military: 102 test/yr * 15 min/test * (1 hr/60 min) = 25.5 hr/yr

b. The second step is to calculate the carbon monoxide emissions from testing at each power setting and then summing these values to get the Total CO emissions.

Power Setting	Fuel Flow Rate (1000 lb/hr)		Total Time Tested (hr/yr)		CO Emission Factor* (lb/1000 lb)		CO Emissions (lb/yr)
Idle	1.100	x	34	x	134.91	=	5,046
Approach	4.900	x	76.5	x	9.69	=	3,632
Intermediate	6.375	x	25.5	x	4.16	=	676
Military	8.280	x	25.5	x	1.49	=	315
					Total CO Emissions	**=**	**9,669**

*Note – emission factors obtained from IERA/RSEQ as specified in subsection 3.1 above.

c. The next step is to calculate the SO_X emission factor based on the sulfur content of the jet fuel (obtained from Table 3-1 above).

$EF_{SOx} = 20 * S$
$EF_{SOx} = 20 * 0.042 = 0.84$ lb/1000 lb

d. The final step is to calculate the SO_X emissions.

Power Setting	Fuel Flow Rate (1000 lb/hr)		Total Time Tested (hr/yr)		SO_X Emission Factor (lb/1000 lb)		SO_X Emissions (lb/yr)
Idle	1.100	x	34	x	0.84	=	31
Approach	4.900	x	76.5	x	0.84	=	315
Intermediate	6.375	x	25.5	x	0.84	=	137
Military	8.280	x	25.5	x	0.84	=	177
					Total SO_X Emissions	**=**	**660**

3.5 References

1. Defense Energy Support Center, *Survey of Jet Fuels Procured by the Defense Energy Support Center, 1990 – 1996*.

SECTION 4

ASPHALT PAVING OPERATIONS

4.1 Background: Virtually all Air Force installations experience some sort of asphalt road repair/construction each year. Asphalt surfaces and pavements are composed of compacted aggregate (stones, gravel, etc.) and an asphalt binder. The purpose of the asphalt binder is to hold the aggregate together, thereby preventing displacement and loss of aggregate and providing a waterproof cover for the base. Asphalt binders may be in the form of asphalt cement (the residue of the distillation of crude oils) or liquified asphalts. Asphalt cement is a semisolid which must be heated prior to mixing with aggregate. The resulting hot mix asphalt concrete is generally applied in thicknesses of two to six inches. Liquified asphalts come in two types, cutback asphalt and emulsified asphalt. Cutback asphalt is essentially asphalt cement which has been thinned or "cutback" with volatile petroleum distillates such as naptha, kerosene, etc. Emulsified asphalt is a nonflammable liquid produced by combining asphalt and water with an emulsifying agent, such as soap. Liquified asphalts are used in tack and seal operations, in priming roadbeds for hot mix application, and for paving operations up to several inches thick.

The primary pollutants of concern from asphalts and asphalt paving operations are VOCs. Of the three types of asphalts, the major source of VOC emissions comes from cutback asphalts. Since only minor amounts of VOCs are emitted from the other two types of asphalts (emulsified asphalts and asphalt cement), these two types are typically not addressed in an air emissions inventory. In addition, since there is usually little or no HAP content in cutback asphalt, HAP emissions from asphalt paving operations are also typically not addressed in an air emissions inventory.

VOC emissions from cutback asphalts result from the evaporation of the petroleum distillate solvent (diluent) used to liquify the asphalt cement. Emissions occur at both the application site and the mixing plant. At the application site, VOCs are emitted from the equipment used to apply the asphaltic product and from the road surface. The largest source of emissions, however, is the road surface itself.

Cutback asphalts fall into three broad categories: rapid cure (RC), medium cure (MC), and slow cure (SC) road oils. RC, MC, and SC cutbacks are prepared by blending asphalt cement with naptha and gasoline solvents, kerosene-type solvents, or heavy residual oils, respectively. Depending on the viscosity desired, the proportions of solvent added generally range from 25 to 45 percent by volume.

The two major variables affecting both the quantity of VOCs emitted and the time over which emissions occur are the type and the quantity of petroleum distillate used as a solvent. As an approximation, long-term emissions from cutback asphalts can be estimated by assuming that 95 percent of the solvent evaporates from RC cutback asphalts, 70 percent from MC cutbacks, and about 25 percent from SC asphalts, by weight percent.

4.2 Emission Calculations: VOC emissions from cutback asphalt paving operations can be calculated by multiplying the total amount of cutback asphalt applied during the year times the weight percent of cutback asphalt which is expected to evaporate.

$$E_{VOC} = QA * (WP_{evap}/100)$$

Where,

E_{VOC} = Emissions of VOC (lb/yr)
QA = Quantity (mass) of cutback asphalt used during the year for road pavement (lb/yr)

WP_{evap} = Weight percent of cutback asphalt which evaporates (%)

The weight percent of cutback asphalt which evaporates (WP_{evap}) can be obtained from Table 4-1 below. The values are dependent on the volume percent of solvent in the cutback asphalt and on the type of cutback asphalt (i.e., rapid cure, medium cure, or slow cure).

Table 4-1. Evaporative VOC Emissions from Cutback Asphalts

	Volume Percent of Solvent in Cutback Asphalt[b]		
Type of Cutback[a]	**25%**	**35%**	**45%**
Rapid Cure	17[c]	24[c]	32[c]
Medium Cure	14[c]	20[c]	26[c]
Slow Cure	5[c]	8[c]	10[c]

[a] Typical densities assumed for the solvents used in RC, MC, and SC cutbacks are 5.8, 6.7, and 7.5 lb/gal, respectively. The amount of solvent (by weight percent) assumed to evaporate from the RC, MC, and SC cutbacks is 95%, 70%, and 25%, respectively.
[b] Solvent contents typically range between 25 - 45%, by volume. Emissions may be linearly interpolated for any given volume of solvent between these values.
[c] These numbers represent the percent, by weight, of cutback asphalt evaporated (WP_{evap}).

4.3 Information Resources: Asphalt paving operations on base are performed either by civil engineering or by a commercial contractor. However, base civil engineering should have, or be able to obtain, the information necessary to calculate emissions from road paving operations. This includes the quantity (mass) of each type of cutback asphalt used (e.g., rapid cure, medium cure, slow cure) and the volume percent of solvent found in each type.

4.4 Example Problem: According to base civil engineering, approximately 3,500 pounds of cutback asphalt were used for road paving on base during the year. All cutback asphalt applied was of the rapid cure type. Civil engineering estimates the average solvent content in the cutback asphalt to be around 35%, by volume. Calculate the VOC emissions.

a. The first step is to determine the weight percent of cutback asphalt which evaporates (WP_{evap}). A review of Table 4-1 above reveals this value to be 24%.

b. The VOC emissions can now be calculated as follows:

E_{VOC} = QA * (WP_{evap}/100)
E_{VOC} = 3,500 lb/yr * (24%/100) = **<u>840 lb/yr</u>**

4.5 References

1. U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources* (AP-42), Section 4.5, July 1979 (Reformatted January 1995).

2. Emissions Inventory Improvement Program (EIIP), *Volume III: Chapter 17, "Asphalt Paving,"* Draft Version, May 1998.

SECTION 5

CHROMIUM ELECTROPLATING AND CHROMIC ACID ANODIZING

5.1 Background: Some Air Force installations (especially Logistics bases) perform chromium electroplating and/or anodizing on various parts and materials. The following are brief descriptions of the chromium electroplating and the chromic acid anodizing operations.

a. Chromium Electroplating

Chromium electroplating is the process of applying a chromium coating to an article (e.g., metal part) by passing an electric current through an electrolyte in contact with the article, thereby forming a surface having properties or dimensions different from those of the article. Electroplating is usually performed for purposes of providing corrosion resistance and/or to provide a decorative appearance. Essentially any electrically conductive surface can be electroplated.

The essential components of an electroplating process are an electrode to be plated (the cathode or substrate), a second electrode to complete the circuit (the anode), an electrolyte containing the metal ions to be deposited, and a direct current power source. The electrodes are immersed in the electrolyte with the anode connected to the positive leg of the power supply and the cathode to the negative leg. As the current is increased from zero, a point is reached where metal plating begins to occur on the cathode. The plating tank is either made of or lined with totally inert materials to protect the tank. The majority of power supplies are solid-state silicon rectifiers, which may have a variety of modifications, such as stepless controls, constant current, and constant voltage. Plate thickness is dependent on the cathode efficiency of a particular plating solution, the current density, and the amount of plating time. Plating tanks are typically equipped with some type of heat exchanger. Mechanical agitators or compressed air supplied through pipes on the tank bottom provide uniformity of bath temperature and composition. Chromium electroplating requires constant control of the plating bath temperature, current density, plating time, and bath composition.

Hexavalent chromium plating baths are the most widely used baths to deposit chromium on metal. Hexavalent chromium baths are composed of chromic acid, sulfuric acid, and water. The chromic acid is the source of the hexavalent chromium that reacts and deposits on the metal and is emitted to the atmosphere. The sulfuric acid in the bath catalyzes the chromium deposition reactions. The evolution of hydrogen gas from chemical reactions at the cathode consumes 80 to 90 percent of the power supplied to the plating bath, leaving the remaining 10 to 20 percent for the deposition reaction. When the hydrogen gas evolves, it causes misting at the surface of the plating bath, which results in the loss of chromic acid to the atmosphere. The main types of controls used to reduce emissions to the atmosphere include add-on control devices (e.g., packed-bed scrubber, chevron-blade mist eliminator, mesh-pad mist eliminator, composite mesh-pad mist eliminator) and chemical fume suppressants. Emissions can also be reduced slightly by adding hollow plastic balls (polypropylene balls) to the surface of the plating bath.

There are two main types of chromium electroplating; hard and decorative. In hard plating, a relatively thick layer of chromium (typically 1.3 to 760 μm) is deposited directly on the base metal (usually steel) to provide a surface with wear resistance, a low coefficient of friction, hardness, and corrosion resistance, or to build up surfaces that have been eroded by use. Hard chromium electroplating is typically performed at current densities ranging from 149 to 604 Amperes per square feet (A/ft^2) and for total plating times ranging from 20 minutes to 36 hours depending upon the desired plate thickness. In decorative plating, a thin layer of chromium (typically 0.003 to 2.5 μm) is deposited on a base metal, plastic, or undercoating to provide a bright surface with wear and tarnish resistance. Decorative

chromium electroplating is typically performed at current densities ranging from 50 to 223 A/ft^2 and for total plating times ranging from 0.5 to 5 minutes. Some decorative electroplating is performed using a trivalent chromium bath instead of hexavalent chromium bath. The advantages of the trivalent chromium processes over the hexavalent chromium processes are higher productivity, lower operating costs, and fewer environmental concerns due to the lower toxicity of trivalent chromium. The disadvantages of the trivalent chromium process are that the process is more sensitive to contamination than the hexavalent chromium process, and the trivalent chromium process cannot plate the full range of plate thicknesses that the hexavalent chromium process can.

b. Chromic Acid Anodizing

Chromic acid anodizing is used primarily on parts that are subject to high stress and corrosion. Chromic acid anodizing is used to provide an oxide layer on aluminum for corrosion protection, electrical insulation, ease of coloring, and improved dielectric strength. There are four primary differences between the equipment used for chromium electroplating and that used for chromic acid anodizing. These differences include the following: chromic acid anodizing requires the rectifier to be fitted with a rheostat or other control mechanism to permit starting at about 5 volts; the tank is the cathode in the electrical circuit; the aluminum substrate (part being anodized) acts as the anode; and sidewall shields typically are used instead of a liner in the tank to minimize short circuits and to decrease the effective cathode area. The chromic acid solution, which serves as the electrolyte in the anodizing process, typically has a concentration ranging from 50 to 100 grams per liter (g/L). During anodizing, the voltage is applied step-wise (5 volts per minute) from 5 to 40 volts and maintained at 40 volts for the remainder of the anodizing time. The current density applied during chromic acid anodizing varies depending on the size of the aluminum parts, but typically ranges from 144 to 720 A/ft^2.

5.2 Emission Calculations

a. Chromium Electroplating

The pollutants of concern from chromium electroplating operations include chromium compounds and particulate matter. Emissions can be estimated by multiplying the total energy input times the appropriate emission factor.

$$E_{pol} = EI * 0.001 * EF$$

Where,

E_{pol} = Emissions of a pollutant (lb/yr)
EI = Total Energy Input (A-hr)
0.001 = Factor for converting “A-hr” to “1000 A-hr”
EF = Emission Factor (lb/1000 A-hr)

Note: A-hr equals Ampere-hours

Emission factors for chromium electroplating operations are listed in Tables 5-1 and 5-2 below.

Table 5-1. Emission Factors for Hard Chromium Electroplating Operations[a]
(SCC 3-09-010-18)

Control Type	Chromium Compounds (lb/1000 A-hr)[b]	Total PM (lb/1000 A-hr)[b]	PM_{10}[c] (1b/1000 A-hr)[b]
Uncontrolled	0.12	0.25	0.25
With moisture extractor[d]	0.0020	0.0040	0.0040
With polypropylene balls[d]	0.0060	0.0126	0.0126
With fume suppressant[d]	0.0023	0.0049	0.0049
With fume suppressant and polypropylene balls[d]	4.3×10^{-4}	9.0×10^{-4}	9.0×10^{-4}
With packed-bed scrubber[d]	3.0×10^{-4}	6.3×10^{-4}	6.3×10^{-4}
With packed-bed scrubber, fume suppressant, and polypropylene balls[d]	3.7×10^{-5}	7.9×10^{-5}	7.9×10^{-5}
With chevron-blade mist eliminator[d]	1.3×10^{-3}	0.0026	0.0026
With mesh-pad mist eliminator[d]	1.7×10^{-4}	3.7×10^{-4}	3.7×10^{-4}
With packed-bed scrubber and mesh-pad eliminator[d]	4.6×10^{-7}	9.6×10^{-7}	9.6×10^{-7}
With composite mesh-pad mist eliminator[d]	5.4×10^{-5}	1.1×10^{-4}	1.1×10^{-4}

[a] Emission factors taken from EPA's FIRE program (Version 6.01)
[b] Emission factors are in units of pounds pollutant emitted per 1000 Ampere-Hour of current applied.
[c] According to both FIRE and AP-42, all PM from chromium electroplating is likely to be emitted as PM_{10}.
[d] The emission factors listed in FIRE for controlled emissions are in units of grains/dscf. These emission factors were first converted to grains/A-hr by multiplying times 100 (as specified in FIRE and in AP-42). The grains/A-hr values were then divided by 7 to convert to lb/1000 A-hr.

Table 5-2. Emission Factors for Decorative Chromium Electroplating Operations[a]
(SCC 3-09-010-28)

Control Type	Chromium Compounds (lb/1000 A-hr)[b]	Total PM (lb/1000 A-hr)[b]	PM_{10}[c] (1b/1000 A-hr)[b]
Uncontrolled	0.033	0.069	0.069
With fume suppressant[d]	1.7×10^{-5}	3.6×10^{-5}	3.6×10^{-5}

[a] Emission factors taken from EPA's FIRE program (Version 6.01)
[b] Emission factors are in units of pounds pollutant emitted per 1000 Ampere-Hour of current applied.
[c] According to both FIRE and AP-42, all PM from chromium electroplating is likely to be emitted as PM_{10}.
[d] The emission factors listed in FIRE for controlled emissions are in units of grains/dscf. These emission factors were first converted to grains/A-hr by multiplying times 100 (as specified in FIRE and in AP-42). The grains/A-hr values were then divided by 7 to convert to lb/1000 A-hr.

b. Chromic Acid Anodizing

As with chromium electroplating, the pollutants of concern from chromic acid anodizing operations are chromium compounds and particulate matter. Emissions from a chromic acid anodizing tank can be estimated by multiplying the tank operating time by the tank surface area and then by the appropriate emission factor.

E_{pol} = OT * 0.001 * SA * EF

Where,

E_{pol} = Emissions of a pollutant (lb/yr)
OT = Tank operating time (hr/yr)
0.001 = Factor for converting "hours" to "1000 hours"
SA = Tank surface area (ft^2)
EF = Emission Factor (lb/hr-ft^2)

Emission factors for chromic acid anodizing operations are listed in Table 5-3 below.

Table 5-3. Emission Factors for Chromic Acid Anodizing Operations[a] (SCC 3-09-010-38)

Control Type	Chromium Compounds (lb/1000 hr-ft^2)[b]	Total PM (lb/1000 hr-ft^2)[b]	PM_{10}[c] (1b/1000 hr-ft^2)[b]
Uncontrolled	2.0	4.2	4.2
With polypropylene balls	1.7	3.6	3.6
With fume suppressant	0.064	0.13	0.13
With fume suppressant and polypropylene balls	0.025	0.053	0.053
With packed-bed scrubber	0.0096	0.020	0.020
With packed-bed scrubber and fume suppressant	0.00075	0.0016	0.0016
With mesh-pad mist eliminator	0.0051	0.011	0.011
With packed-bed scrubber and mesh pad mist eliminator	0.00054	0.0011	0.0011
With wet scrubber, moisture extractor, and high efficiency particulate air filter	0.00048	0.0010	0.0010

[a] Emission factors taken from EPA's FIRE program (Version 6.01)
[b] Emission factors are in units of pounds pollutant emitted per 1000 hours of operation per square foot of tank surface area.
[c] According to both FIRE and AP-42, all PM from chromium electroplating is likely to be emitted as PM_{10}.

5.3 Information Resources: All information needed to calculate emissions from chromium electroplating and/or chromic acid anodizing operations can be obtained from the base plating shop(s).

5.4 Example Problems

a. Problem # 1

A base plating shop operates two hard chromium electroplating tanks (Tank A and Tank B). The exhaust from each tank is vented to a packed-bed scrubber. No other controls are used. According to shop records, the approximate energy inputs for the year were 667,000 A-hr for Tank A and 532,000 A-hr for Tank B. Calculate the annual chromium and PM emissions.

E_{pol} = EI * 0.001 * EF
E_{Cr} = (667,000 A-hr/yr + 532,000 A-hr/yr) * 0.001 * (3.0×10^{-4} lb/1000 A-hr) = **0.36 lb/yr**
E_{PM} = (667,000 A-hr/yr + 532,000 A-hr/yr) * 0.001 * (6.3×10^{-4} lb/1000 A-hr) = **0.76 lb/yr**

b. Problem # 2

A base plating shop operates a single chromic acid anodizing tank. The tank is rectangular and has cross-sectional dimensions of 6 ft by 3 ft at the surface of the chromic acid solution. The exhaust from the tank is vented to a packed-bed scrubber. No other controls are used. According to shop records, the tank was operated for approximately 1,275 hours during the year. Calculate the annual chromium and PM emissions.

E_{pol} = OT * 1/1000 * SA * EF
E_{Cr} = 1,275 hr * 0.001 * 18 ft^2 * (0.0096 lb/1000 hr-ft^2) = **0.22 lb/yr**
E_{PM} = 1,275 hr * 0.001 * 18 ft^2 * (0.02 lb/1000 hr-ft^2) = **0.46 lb/yr**

5.5 References

1. U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources* (AP-42), Section 12.20, July 1996.

2. U.S. Environmental Protection Agency, *Factor Information Retrieval System* (FIRE), Version 6.01, May 1998.

SECTION 6

DRY CLEANING OPERATIONS

6.1 Background: Although most Air Force installations offer some sort of dry cleaning service, in many cases the actual dry cleaning is performed at off-site locations. However, there are some Air Force installations which have dry cleaning machines located on-site (on base property). Therefore, the emissions from these on-site dry cleaning machines must be included in an air emissions inventory.

Dry cleaning involves the cleaning of fabrics (e.g., garments, draperies, leather goods, etc.) with nonaqueous organic solvents. Two general types of cleaning fluids are used in the industry, petroleum solvents and synthetic halogenated solvents. Petroleum solvents, such as Stoddard solvent (mineral spirits), are inexpensive combustible hydrocarbon mixtures similar to kerosene. The most common type of synthetic halogenated solvent used for dry cleaning is perchloroethylene. However, small amounts of other halogenated solvents, such as trichlorotrifluoroethane (CFC-113) and 1,1,1-trichloroethane, are used for specialty cleaning operations. Depending on the type of solvent used, the emissions of concern from dry cleaning operations are VOC (i.e., from petroleum solvents), organic HAPs (e.g., perchloroethylene, 1,1,1-trichloroethane), or ozone depleting substances (e.g., trichlorotrifluoroethane).

There are two basic types of dry cleaning machines, transfer and dry-to-dry. With transfer machines, the material is washed in one machine and manually transferred to another machine to dry. Emissions occur during the transfer as well as from the washer and dryer vents. In the dry-to-dry process, both washing and drying take place in one machine. Dry-to-dry machines are either vented during the drying cycle or are ventless, where emissions occur only during loading and unloading operations. Transfer units are an older technology which produce more emissions than dry-to-dry machines. The use of transfer units has significantly declined due to new air quality standards, such as those regulated under the EPA's National Emission Standards for Hazardous Air Pollutants (NESHAP) program and those regulated under State/local programs.

Most facilities using perchloroethylene use dry-to-dry machines. CFC-113 is used exclusively in dry-to-dry systems. Because petroleum solvents are flammable and may form explosive mixtures, their use has been limited to transfer machines where the solvent concentration in vapors do not build up to high levels. However, commercial petroleum solvent dry-to-dry machines are now being manufactured. It's important to note that National Fire Protection Association codes may limit the locations in which petroleum solvents can be used.

The dry cleaning industry can be divided into three sectors: coin-operated facilities, commercial operations, and industrial cleaners. Coin-operated dry cleaning units are self-service machines that are usually found in laundromats. Coin-op units usually have a capacity of 8 to 25 pounds of clothes per load, with one or two machines per facility. Commercial dry cleaners are usually independent small businesses that offer dry cleaning services to the public. The average capacity of commercial dry cleaning units is 35 pounds, with a range of 15 to 97 pounds per load. Most of these units are dry-to-dry. Industrial launderers who use dry cleaning solvents are usually part of a business operation that generates soiled fabrics, where it is convenient or cost-effective to perform dry cleaning on-site. Industrial launderers can also be large businesses that provide uniform and other rental services to business, industrial, and institutional customers. The average capacity of industrial dry cleaners is 140 pounds per load for dry-to-dry units and 250 pounds per load for transfer units.

Due to the increase in air quality regulations and the high cost of synthetic halogenated solvents, many dry cleaning machines are equipped with control devices which capture/reduce emissions from air

vents. The two primary types of control devices used on dry cleaning machines are refrigerated condensers and carbon adsorbers. After separating out the water, the solvent captured by a refrigerated condenser is placed back into the pure solvent supply tank. In order to recover/reclaim the solvent collected by a carbon adsorber, it must be desorbed off the carbon adsorption material (usually accomplished using steam). Desorbed solvent and water are then condensed and separated. Reclaiming solvent captured via carbon adsorption can be accomplished either on- or off-site. If done on-site, the solvent is placed back into the pure solvent supply tank.

To help understand the dry cleaning process, the following is an excerpt from AP-42 which provides an operational description of a typical perchloroethylene transfer machine:

"After the clothes have been washed, the used solvent is filtered, and part of the filtered solvent is returned to the charged solvent tank for washing the next load. The remaining solvent is then distilled to remove oils, fats, greases, etc., and is returned to the pure solvent tank. The collected solids (muck) are usually removed from the filter once a day. Before disposal, the muck may be "cooked" to recover additional solvent. Still and muck cooker vapors are vented to a condenser and separator, where more solvent is reclaimed. In many perc plants, the condenser offgases are vented to a carbon adsorption unit for additional solvent recovery.

After washing, the clothes are transferred to the dryer to be tumbled in a heated air stream. Exhaust gases from the dryer, along with a small amount of exhaust gases from the washer/extractor, are vented to a water-cooled condenser and water separator. Recovered solvent is returned to the pure solvent storage tank. In some plants, the condenser offgases are vented to a carbon adsorption unit for additional solvent recovery. To reclaim this solvent, the unit must be periodically desorbed with steam, usually at the end of each day. Desorbed solvent and water are condensed and separated, and recovered solvent is returned to the pure solvent tank."

6.2 Emission Calculations: The primary method of calculating emissions from dry cleaning operations is to use a mass balance approach, similar to the method found in the "Solvent Cleaning Machines" section of this document. For certain types of dry cleaning operations, an alternative approach involving emission factors may be used. Both methods are described below.

a. Mass Balance Method

In general, the amount of solvent emitted is approximately equal to the total amount of fresh solvent added to the dry cleaning process minus the amount of waste solvent which is removed from the process for purposes of disposal, recycling, or reclamation. If a carbon adsorber is used to control emissions and the solvent captured is not recovered (desorbed) on-site and reintroduced into the process, then the quantity captured by the carbon adsorber must also be subtracted from the total amount of fresh solvent added to the process.

$$E_{solvent} = [(VFS - VWS) * D] - VCS$$

Where,

$E_{solvent}$ = Emissions of solvent (lb/yr)
VFS = Volume of fresh solvent added to the dry cleaning process (gal/yr)
VWS = Volume of waste solvent removed from the process (gal/yr)
D = Density of solvent (lb/gal) [note - density of perchloroethylene is 13.5 lb/gal]
VCS = Mass of solvent which is captured via carbon adsorption and not reintroduced back into the process (lb/yr)

b. Emission Factor Method

EPA emission factors are available for certain specific types of dry cleaning processes. These emission factors are listed in Table 6-1 below. Emissions are calculated by multiplying the mass of clothes cleaned times the appropriate emission factor.

$$E_{solvent} = MC * EF$$

Where,

$E_{solvent}$ = Emissions of solvent (lb/yr)
MC = Mass of clothes cleaned (10^2 lb/yr) [note - the annual amount (mass) of clothes cleaned in each machine can be estimated by multiplying the machine's capacity times the number of loads washed in the machine during the year]
EF = Emission factor (lb/10^2 lb)

Table 6-1. Emission Factors for Dry Cleaning Processes

Solvent Type (Process Used)	Source	Emission Rate[a] Typical System ($lb/10^2$ lb)	Emission Rate[a] Well-Controlled System ($lb/10^2$ lb)
Petroleum (transfer process)	Washer/dryer	18	2[b]
	Filter disposal		
	Uncooked (drained)	8	
	Centrifuged		0.75
	Still residue disposal	1	0.75
	Miscellaneous[c]	1	1
	Total for process	**28**	**4.5**
Perchloroethylene (transfer process)	Washer/dryer/still/muck cooker	8[d]	0.3[b]
	Filter disposal		
	Uncooked muck	14	
	Cooked muck	1.3	0.9
	Cartridge filter	1.1	0.8
	Still residue disposal	1.6	1.05
	Miscellaneous[c]	1.5	1
	Total for process	**27.5**	**4.05**
Trichlorotrifluoroethane (dry-to-dry process)	Washer/dryer/still[e]	0	0
	Cartridge filter disposal	1	1
	Still residue disposal	0.5	0.5
	Miscellaneous[c]	2	2
	Total for process	**3.5**	**3.5**

[a] Units are in terms of pounds solvent emitted per 100 pounds of clothes cleaned.
[b] Emissions from washer, dryer, still and muck cooker are passed collectively through a carbon adsorber.
[c] Miscellaneous sources include fugitives from flanges, pumps, pipes, and storage tanks, and fixed losses such as opening and closing dryers, etc.
[d] About 15% of solvent emitted is from washer, 75% from dryer, 5% each from still and muck cooker.
[e] Based on the typical refrigeration system installed in fluorocarbon plants.

6.3 Information Resources: All information required to calculate the emissions from dry cleaning operations should be available from the personnel (e.g., contractor) who operate the dry cleaning machines.

6.4 Example Problem:

a. Problem # 1

A dry cleaning facility on base has a single dry-to-dry machine which uses perchloroethylene. According to records maintained by the contractor who operates the dry cleaning machine, 250 gallons of fresh perchloroethylene were purchased and added to the process during the year while approximately 200 gallons of waste solvent were removed from the process and sent off-site for recycling. Emissions from the machine are controlled by a refrigerated condenser followed by a carbon adsorber. All liquid solvent recovered by the refrigerated condenser is put back into the machine's pure solvent supply tank. However, the carbon adsorption material is shipped off base for regeneration and solvent recovery. According to the dry cleaning operator, approximately 400 pounds of perchloroethylene were captured by the carbon adsorption material during the year and shipped off-site for reclamation. Calculate the perchloroethylene emissions.

The emissions can be calculated using the mass balance method described above.

$E_{solvent}$ = [(VFS -VWS) * D] - VCS
E_{perc} = [(250 gal/yr -200 gal/yr) * 13.5 lb/gal] - 400 lb/yr = **275 lb/yr**

b. Problem # 2

A dry cleaning facility on base has a single transfer machine which uses perchloroethylene. There are currently no emission controls associated with the transfer machine. Unfortunately, the contractor which operates the dry cleaning facility was unable to provide reliable data as to the quantity of fresh solvent added and quantity of waste solvent removed from the machine during the year. However, the contractor's records did show that there were 75 loads of laundry cleaned in the transfer machine during the year. According to the operator, the typical size of each load was about 40 pounds. Calculate the perchloroethylene emissions.

Although the data necessary to calculate emissions via the mass balance method are not available, the emissions can be calculated using the emission factor method instead.

(1) The first step is to calculate the mass of clothes (in hundreds of pounds) cleaned in the machine during the year:

MC = 75 loads/yr * 40 lb/load = $\underline{30 \times 10^2 \text{ lb/yr}}$

(2) The next step is to calculate the emissions using the mass of clothes cleaned and the appropriate emission factor:

$E_{solvent}$ = MC * EF
E_{perc} = (30×10^2 lb clothes/yr) * 27.5 lb perc/10^2 lb clothes) = **825 lb perc/yr**

6.5 References

1. U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources* (AP-42), Section 4.1, April 1981 (Reformatted January 1995).

2. Emissions Inventory Improvement Program (EIIP), *Volume III: Chapter 4, "Dry Cleaning,"* May 1996.

SECTION 7

EQUIPMENT LEAKS
(Revised December 2003)

7.1 Background: Most Air Force installations have elaborate fuel transfer systems consisting of several types of equipment such as pump houses, pipelines, fill stands, hydrants, loading and unloading racks, etc. Included with fuel transfer equipment are various components in which fugitive emission leaks may occur. These components include, but are not limited to, the following: valves, pump seals, connectors, flanges, compressor seals, open-ended lines, pressure relief valves, and sample connections. The primary emissions associated with equipment leaks are total VOC emissions. However, organic HAP emissions also occur if the fuel in the system contains HAP constituents.

VOC emission factors for equipment leaks can be found in the EPA document titled "Protocol for Equipment Leak Emission Estimates" (EPA-453/R-95-017, Nov 95). The EPA document addresses equipment leak emissions associated with four different industries/operations including the synthetic organic chemical manufacturing industry (SOCMI), petroleum refineries, marketing terminals, and oil and gas production operations. The emission factors listed in this report (Table 7-1 below) are based on the emission factors for marketing terminals since this operation is considered to most closely resemble fuel operations at an Air Force installation.

Emission factors for equipment leaks are specific as to the type of equipment component (valves, pump seals, flanges, etc.) and to the service category (fuel/chemical type). The three service categories include gas/vapor, light liquid, and heavy liquid. The definitions for these service types include the following:

Gas/vapor - material in a gaseous state at operating conditions;

Light liquid - material in a liquid state in which the sum of the concentration of individual constituents with a vapor pressure over 0.0435 pounds per square inch (psi) at 68 °F is greater than or equal to 20 percent by weight; and

Heavy liquid - not in gas/vapor service or light liquid service.

Based on the above definitions, gasoline and JP-4 would be considered light liquids while diesel fuel and JP-8 would be considered in both the light and heavy liquids depending on the flash point and liquid temperature.

7.2 Emission Calculations: Calculating the VOC leak emissions from a specific fuel equipment component consists of multiplying the time (hours) the component was in operation during the year by the appropriate emission factor. In most cases, fuel equipment and associated components are in operation all year long (8,760 hr/yr). Similar component types which are used for the same fuel and which are operated the same amount of time during the year can be grouped together and then multiplied by the appropriate emission factor. The following equation is used to calculate the VOC emissions from each specific type of component:

$$E_{VOC} = NC * t * EF$$

Where,

E_{VOC} = VOC Emissions (lb/yr)
NC = Number of similar components located on base (# of similar emission sources)
t = Time during the year in which all similar components were in operation (hr/yr)
EF = Emission Factor (lb/hr/source)

Table 7-1. VOC Emission Factors for Equipment Leaks[a]

Component type	Service[b]	VOC Emission factor (lb/hr/source)
Valves (except pressure relief valves)	Gas/Vapor	2.9×10^{-5}
	Liquid	9.5×10^{-5}
Pump seals	Gas/Vapor	1.4×10^{-4}
	Liquid	1.2×10^{-3}
Connectors (not including flanges or sampling connections)	Gas/Vapor	9.3×10^{-5}
	Liquid	1.8×10^{-5}
Flanges	Gas/Vapor	9.3×10^{-5}
	Liquid	1.8×10^{-5}
Compressor seals	Gas/Vapor	2.6×10^{-4}
Open-ended lines	Gas/Vapor	2.6×10^{-4}
	Liquid	2.9×10^{-4}
Pressure relief valves	Gas/Vapor	2.6×10^{-4}
	Liquid	2.9×10^{-4}
Sampling Connections	Gas/Vapor	2.6×10^{-4}
	Liquid	2.9×10^{-4}
Others[c]	Gas/Vapor	2.6×10^{-4}
	Liquid	2.9×10^{-4}

[a] Based on average emission factors for marketing terminals
[b] Emission factors for liquid service are based on light liquids (i.e., liquids with a vapor pressure over 0.0435 psi at 68 °F). However, since no data on heavy liquids is available for marketing terminals, the liquid emission factors should also be used for heavy liquids (note - this provides a worst-case scenario).
[c] The “other” equipment type should be applied to any equipment except valves, pump seals, connectors, or flanges.

Once the total VOC emissions are calculated, emissions of individual HAP constituents can be calculated by multiplying the VOC emissions by the vapor weight fraction of each HAP constituent.

$$E_{HAP} = E_{VOC} * (\%HAP/100)$$

Where,

E_{HAP} = Emissions of a HAP constituent in the fuel (lb/yr)
E_{VOC} = VOC Emissions (lb/yr)
%HAP = Weight percent of the HAP constituent in the fuel vapor*

*__Note__ - Vapor-phase speciation of gasoline can be found in the "Gasoline Service Stations" section of this report while vapor-phase speciation of JP-8 and diesel can be found in the "Fuel Storage" section.

7.3 Information Resources: Base Supply Fuels Management is responsible for the operation of fuel transfer systems and they should be contacted for the information required to estimate equipment leaks. The Civil Engineering Liquid Fuels shop, who usually performs maintenance on fuel transfer systems, should be contacted for information not available from Fuels Management.

7.4 Example Problem: An Air Force base uses JP-8 to fuel its aircraft. Information provided by Base Supply Fuels Management indicates that the following type and number of components are associated with the JP-8 fuel transfer equipment: 590 connectors, 460 flanges, 325 valves, 42 open-ended lines, 35 pressure relief valves, and 28 pump seals. The components were in operation at all times during the year. Calculate the annual VOC emissions.

$$E_{VOC} = NC * t * EF$$

Component Type	Number of Components		Time in Operation (hr/yr)		Emission Factor (lb/hr/source)		VOC Emissions (lb/yr)
Connectors	590	x	8,760	x	1.8×10^{-5}	=	93.0
Flanges	460	x	8,760	x	1.8×10^{-5}	=	72.5
Valves	325	x	8,760	x	9.5×10^{-5}	=	270.5
Open-ended lines	42	x	8,760	x	2.9×10^{-4}	=	106.7
Relief Valves	35	x	8,760	x	2.9×10^{-4}	=	88.9
Pump Seals	28	x	8,760	x	1.2×10^{-3}	=	294.3
					Total	=	**925.9**

7.5 References

1. U.S. Environmental Protection Agency, *Protocol for Equipment Leak Emission Estimates,* EPA 453/R-95-017, November 1995.

2. Emissions Inventory Improvement Program (EIIP), *Volume II: Chapter 4, "Preferred and Alternative Methods for Estimating Fugitive Emissions from Equipment Leaks,"* November 1996.

3. JP-8 Volatility Study", Southwest Research Institute, March 2003.

SECTION 8

ETHYLENE OXIDE STERILIZERS

8.1 Background: Ethylene oxide (EO), which is both a VOC and a HAP, is commonly used (either in pure form or in a mixture) as a sterilant. Ethylene oxide sterilization of medical equipment and surgical materials is performed at many hospitals/clinics in the Air Force. Ethylene oxide sterilization is usually performed using either a vacuum chamber or an atmospheric chamber.

Vacuum chambers are pressure vessels with a vacuum pump to remove air from the chamber before sterilization begins and to remove the sterilant from the chamber after sterilization is complete. Typical operating procedures for vacuum chamber sterilizers are as follows: 1) contaminated material is loaded into the chamber; 2) the chamber door is closed and hermetically sealed; 3) air is vacuumed from the chamber; 4) the sterilant (either 100 percent EO, 12 percent EO with 88 percent Freon, or 10 percent ethylene oxide with 90 percent carbon dioxide) is introduced into the chamber to a set pressure or concentration and for a specified time period (note - 100 percent EO is used with a negative pressure while EO mixtures are used with positive pressure); 5) an exhaust vacuum removes the sterilant from the chamber; 6) the sterilant is exhausted (through a vent line) either directly to the atmosphere, or through a control device and then to the atmosphere; 7) fresh air is drawn into the chamber until atmospheric pressure is reached; 8) the chamber door is opened and the treated material removed; 9) the treated material may be transferred to an aeration cabinet which circulates heated air around the material in order to drive-off any residual EO.

Atmospheric chambers are enclosed vessels in which the air inside is not evacuated prior to sterilization. For this reason, a longer exposure time is usually necessary. The sterilant used in atmospheric chamber type sterilizers is supplied as a gas mixture in cartridges. Some units introduce the EO mixture into the chamber under pressure, and then (after treatment) flush out the EO mixture with pressurized air. As with the vacuum chamber type sterilizer, the sterilant in an atmospheric chamber sterilizer is exhausted (through a vent line) either directly to the atmosphere, or through a control device and then to the atmosphere.

As mentioned above, the emissions from ethylene oxide sterilizers may be passed through a control device prior to being vented into the atmosphere. Some possible control techniques include thermal oxidation (incineration), catalytic oxidation, wet scrubbing, charcoal adsorption, and refrigeration/reclamation.

8.2 Emission Calculations: Emissions from ethylene oxide sterilizers can be estimated using a mass balance approach. Basically, the amount of ethylene oxide used for sterilization is assumed to be emitted, except for the amount estimated to be captured by a control device (if applicable).

$$E_{EO} = QS * WP_{EO}/100 * [1-(Eff/100)]$$

Where,

E_{EO} = Emissions of ethylene oxide (lb/yr)
QS = Quantity (mass) of sterilant used (lb/yr)
WP_{EO} = Weight percent or ethylene oxide in sterilant (%)
Eff = Efficiency of control device (%) [note - use zero if no control device is used]

8.3 Information Resources: The base medical facilities (e.g., hospitals and/or clinics) which use ethylene oxide sterilizers should have all the information needed to calculate emissions. This includes the type and quantity of each sterilant used, type of sterilizing equipment used, and type of control device used.

8.4 Example Problem: The base hospital has a vacuum chamber sterilizer for sterilizing heat sensitive medical equipment. The only type of sterilant used in this sterilizer is a gas mixture containing 12% ethylene oxide and 88% dichlorodifluoromethane (CFC-12), by weight. According to hospital records, 185 pounds of sterilant were used in the sterilizer during the year. The exhaust from the sterilizer is vented to a stack and then directly into the atmosphere (no control device is used). Calculate the annual emissions of ethylene oxide.

E_{EO} = QS * WP_{EO}/100 * [1-(Eff/100)]
E_{EO} = 185 lb/yr * (12%/100) * [1-(0%/100)] = **<u>22.2 lb/yr</u>**

8.5 References

1. U.S. Environmental Protection Agency, *Locating and Estimating Air Emissions from Sources of Ethylene Oxide*, EPA-450/4-84-007L, September 1986.

SECTION 9

EXTERNAL COMBUSTION SOURCES

9.1 Background: External combustion sources include boilers, furnaces, and heaters used for heating and/or power production purposes. Most smaller external combustion units are located at individual buildings on base (e.g., in building mechanical rooms), while larger boilers are usually located at the base heat (or heat/power) plant. As with any combustion source, emissions from external combustion units include the criteria pollutants and a variety of HAPs (both organic and inorganic). The emissions from external combustion units depend on a variety of factors including the size/type of the combustor, firing configuration, fuel type, control devices used, operating capacity, and whether the system is properly operated/maintained.

a. Size and Classification

Boilers/heaters which combust a certain type of fuel are usually further categorized according to their size and/or classification. In regards to size, boilers are categorized according to their heat input capacities. For emission factor purposes, the following size categories are typically used:

> 100 MMBtu/hr
10 to 100 MMBtu/hr
0.3 to < 10 MMBtu/hr
< 0.3 MMBtu/hr

In regards to classification, boilers are categorized according to their designed function. For emission factor purposes, the following classification categories are typically used:

Utility Boilers
Industrial Boilers
Commercial/Institutional Boilers
Residential Furnace

b. Heat Transfer Methods

There are four major types of heat transfer methods associated with boilers: watertube, firetube, cast iron, and tubeless. Watertube boilers are designed to pass water through the inside of heat transfer tubes while the outside of the tubes is heated by direct contact with the hot combustion gases. The watertube design is the most common mechanism used for heat transfer in utility and large industrial boilers. Watertube boilers are used for a variety of applications, ranging from the provision of large amounts of process steam, to providing hot water or steam for space heating, to the generation of high-temperature /high-pressure steam for electricity production.

In firetube boilers, the hot combustion gases flow through the tubes, and the water being heated circulates outside of the tubes. These boilers are used primarily for heating systems, industrial process steam, and portable power boilers. Firetube boilers are almost exclusively packaged units.

In cast iron boilers, as in firetube boilers, the hot gases are contained inside the tubes and the water being heated circulates outside the tubes. However, the units are constructed of cast iron rather than steel. Virtually all cast iron boilers are constructed as package boilers. These boilers are used to

produce either low-pressure steam or hot water, and are most commonly used in small commercial applications.

Another type of heat transfer configuration used on smaller boilers is the tubeless design. This design incorporates nested pressure vessels with water in between the shells. Combustion gases are fired into the inner pressure vessel and are then sometimes recirculated outside the second vessel.

c. Fuel and Combustor Types

In general, there are five primary categories of fuels used in external combustion units. These fuel categories include coal, fuel oil, natural gas, liquid petroleum gas (LPG), and waste oil. The following are brief descriptions of each fuel type and of the combustion units which burn each fuel:

(1) *Coal*

Coal is a complex combination of organic matter and inorganic ash formed over centuries of successive layers of fallen vegetation. Coals are classified by rank according to their progressive formation. Coal rank depends on the volatile matter, fixed carbon, inherent moisture, and oxygen content. Typically, coal rank increases as the amount of fixed carbon increases and the amount of volatile matter decreases. The specific types of coal, listed in order of formation, include lignite, subbituminous, bituminous, and anthracite.

Anthracite is the highest ranking coal with more fixed carbon and less volatile matter than the other three coal types. Nearly all anthracite in the United States (U.S.) is mined in northeastern Pennsylvania and is consumed in Pennsylvania and its surrounding states. Anthracite currently accounts for only a small portion of the total quantity of coal combusted in the U.S. The heating value of anthracite ranges from approximately 12,000 to 14,000 British thermal units per pound (Btu/lb).

Bituminous coal is by far the largest group of coal and is characterized as having lower fixed carbon and higher volatile matter than anthracite. Generally, bituminous coals have heating values ranging from 10,500 to 14,000 Btu/lb on a wet, mineral-matter-free basis. Subbituminous coal has a higher moisture and volatile matter content and lower sulfur content than bituminous coal and may be used as an alternative fuel in some boilers originally designed to burn bituminous coals. The heating values of subbituminous coals range from 8,300 to 11,500 Btu/lb on a wet, mineral-matter-free basis.

Lignite is a coal in the early stages of coalification which is characterized by a high moisture content and low heating value (5,000 to 7,500 Btu/lb on a wet basis). These properties make shipping lignite unfeasible; consequently, it is usually only burned where it is mined. Due to the uncommon use of lignite, emission factors for this type of coal are not included in this document.

Coal-fired boilers can be classified by type, fuel, and method of construction. Coal-fired boiler types are identified by the heat transfer method (watertube, firetube, or cast iron), the arrangement of the heat transfer surfaces (horizontal or vertical, straight or bent tube), and the firing configuration (suspension, stoker, or fluidized bed). The most common heat transfer method for coal-fired boilers is the watertube method in which the hot combustion gases contact the outside of the heat transfer tubes, while the boiler water and steam are contained within the tubes. Coal-fired watertube boilers include pulverized coal, cyclone, stoker, fluidized bed, and handfed units. In stoker-fired systems and most handfed units, the fuel is primarily burned on the bottom of the furnace or on a grate. In a fluidized bed combustor (FBC), the coal is introduced to a bed of either sorbent or inert material (usually sand) which is fluidized by an upward flow of air. In pulverized coal-fired (PC-fired) boilers, the fuel is pulverized to the

consistency of talcum powder (i.e., at least 70 percent of the particles will pass through a 200-mesh sieve) and pneumatically injected through the burners into the furnace. Combustion in PC-fired units takes place almost entirely while the coal is suspended in the furnace volume.

PC-fired boilers are classified as either dry bottom or wet bottom (also referred to as slag tap furnaces), depending on whether the ash is removed in a solid or molten state. In dry bottom furnaces, coals with high fusion temperatures are burned, resulting in dry ash. In wet bottom furnaces, coals with low fusion temperatures are used, resulting in molten ash or slag. Depending upon the type and location of the burners and the direction of coal injection into the furnace, PC-fired boilers can also be classified into two different firing types: wall and tangential. Wall-fired boilers can be either single wall-fired (with burners on only one wall of the furnace firing horizontally), or opposed wall-fired (with burners mounted on two opposing walls). Tangential (or corner-fired) boilers have burners mounted in the corners of the furnace. The fuel and air are injected tangent to an imaginary circle in the plane of the boilers.

Cyclone furnaces are often categorized as PC-fired systems even though the coal is crushed to a maximum size of about 4-mesh. The coal is fed tangentially, with primary air, into a horizontal cylindrical furnace. Smaller coal particles are burned in suspension while larger particles adhere to the molten layer of slag on the combustion chamber wall. Cyclone furnaces are high-temperature, wet-bottom type systems.

Stoker-fired systems account for the vast majority of coal-fired watertube boilers for industrial, commercial, and institutional applications. Most packaged stoker units designed for coal firing are small and can be divided into three groups: underfeed stokers, overfeed stokers, and spreader stokers. Underfeed stokers are generally either the horizontal-feed, side-ash-discharge type, or the gravity-feed, rear-ash-discharge type. An overfeed stoker uses a moving grate assembly in which coal is fed from a hopper onto a continuous grate which conveys the fuel into the furnace. In a spreader stoker, mechanical or pneumatic feeders distribute coal uniformly over the surface of a moving grate.

There are two major categories of FBC systems: 1) atmospheric (operating at or near ambient pressures), and 2) pressurized (operating from 60 to 450 psig). Currently, atmospheric FBCs are more commercialized than pressurized FBCs. The two principal types of atmospheric FBCs are bubbling bed and circulating bed. The feature that varies most fundamentally between these two types is the fluidization velocity. In the bubbling bed design, the fluidation velocity is relatively low in order to minimize solids carryover or elutriation from the combustor. Circulating FBCs, however, employ high fluidization velocities to promote the carryover or circulation of the solids. High-temperature cyclones are used in circulating FBCs and in some bubbling FBCs to capture the solid fuel and bed material for return to the primary combustion chamber. The circulating FBC maintains a continuous, high-volume recycle rate which increases the residence time compared to the bubbling bed design. Because of this feature, circulating FBCs often achieve higher combustion efficiencies and better sorbent utilization than bubbling bed units.

(2) *Fuel Oils*

Two major categories of fuel oil are burned by combustion sources: distillate oils and residual oils. These oils are further distinguished by grade numbers. No. 1 and No. 2 fuel oils are considered distillate oils while No. 4, No. 5 and No. 6 fuel oils are considered residual oils. No. 6 fuel oil is sometimes referred to as Bunker C.

Distillate oils are more volatile and less viscous than residual oils. They have negligible nitrogen and ash contents and usually contain less than 0.3 percent sulfur (by weight). Distillate oils are used mainly in domestic and small commercial applications, and include kerosene and diesel fuels. Distillate oils have an average heating value of around 140,000 British thermal units per gallon (Btu/gal).

Residual oils are produced from the residue remaining after the lighter fractions (gasoline, kerosene, and distillate oils) have been removed from the crude oil. For this reason, residual fuels contain significant quantities of ash, nitrogen, and sulfur. Because of their high viscosity and low volatility, the heavier residual oils (No. 5 and No. 6) may need to be heated for ease of handling and to facilitate proper atomization. Residual oils are used mainly in utility, industrial, and large commercial applications. Residual oils have an average heating value of around 150,000 Btu/gal.

All four major boiler configurations (watertube, firetube, cast iron, and tubeless design) are used for fuel oil-fired combustors. Fuel oil boilers are classified according to design and orientation of heat transfer surfaces, burner configuration, and size. These factors can all strongly influence emissions as well as the potential for controlling emissions.

(3) *Natural Gas*

Natural gas is one of the major fuels used in the United States. It is used mainly for industrial process steam and heat production, for residential and commercial space heating, and for electric power generation. Natural gas consists of a high percentage of methane (generally above 85 percent) and varying amounts of ethane, propane, butane, and inerts (typically nitrogen, carbon dioxide, and helium). The average gross heating value of natural gas is approximately 1,020 British thermal units per standard cubic foot (Btu/scf), usually varying from 950 to 1050 Btu/scf.

Watertube, firetube, and cast iron are the three major types of boilers used for natural gas combustion in the industrial, commercial, and utility sectors. Natural gas is also used in residential furnaces. In residential furnaces, natural gas and air are combined in a burner and mixed to promote efficient combustion. Combustion air is supplied by a small fan in forced air furnaces. Hot combustion gases exchange heat with circulating air before being exhausted from a vent or chimney. A variety of burner types may be used in residential furnaces, including single port, multiport, inshot, ribbon, and slotted. Heat exchangers are typically of the sectional or drum types.

Natural gas is considered to be one of the cleanest of the commonly used fossil fuels. Nitrogen oxides are the major pollutants of concern when burning natural gas. NO_X formed in combustion processes are due either to thermal fixation of atmospheric nitrogen in the combustion air, resulting in the formation of thermal NO_X, or to the conversion of chemically bound nitrogen in the fuel, resulting in fuel NO_X. Due to its characteristically low fuel nitrogen content, nearly all NO_X emissions from natural gas combustion are thermal NO_X. The formation of thermal NO_X is affected by four furnace-zone factors: 1) nitrogen concentration; 2) oxygen concentration; 3) peak temperature; and 4) time of exposure at peak temperature. The emission trends due to changes in these factors are fairly consistent for all types of natural gas-fired boilers and furnaces. Emission levels vary considerably with the type and size of combustor and with operating conditions (particularly combustion air temperature, load, and excess air level in boilers).

(4) *Liquid Petroleum Gas (LPG)*

LPG consists of propane, propylene, butane, and butylenes. The product used for domestic heating is composed primarily of propane. This gas, obtained mostly from gas wells (but also, to a lesser

extent, as a refinery by-product) is stored as a liquid under moderate pressures. There are three grades of LPG available as heating fuels: commercial-grade propane, engine fuel-grade propane (also known as HD-5 propane), and commercial-grade butane. Specifications for the various LPG grades are available from the American Society for Testing and Materials and the Gas Processors Association. A typical heating value for commercial-grade propane and HD-5 propane is 90,500 British thermal units per gallon (Btu/gal), after vaporization. A typical heating value for commercial-grade butane is 97,400 Btu/gal.

The combustion processes that use LPG are very similar to those that use natural gas. Use of LPG in commercial and industrial applications may require a vaporizer to provide the burner with the proper mix of air and fuel. The burner itself will usually have different fuel injector tips as well as different fuel-to-air ratio controller settings than a natural gas burner since the LPG stoichiometric requirements are different than natural gas requirements. LPG is fired as a primary and backup fuel in small commercial and industrial boilers and in space heating equipment, and can be used to generate heat and process steam for industrial facilities and in most domestic appliances that typically use natural gas.

(5) *Waste Oil*

Waste oil includes used crankcase oils from automobiles and trucks, used industrial lubricating oils (such as metal working oils), and other used industrial oils (such as heat transfer fluids). When discarded, these oils become waste oils due to a breakdown of physical properties and contamination by the materials they come in contact with. The different types of waste oils may be burned as mixtures or as single fuels where supplies allow. Waste (or used) oil can be burned in a variety of combustion systems including industrial boilers, commercial/institutional boilers, and space heaters. Space heaters are small combustion units (generally less than 0.25 MMBtu/hr) that are common in automobile service stations and automotive repair shops where supplies of waste crankcase oil are available.

Waste oil typically serves as a substitute fuel for combustors (e.g., boilers/heaters) designed to burn residual or distillate oil. In some cases, modifications to the combustor are necessary in order to optimize combustion. As an alternative to boiler/heater modification, the properties of waste oil can be modified by blending it with fuel oil, to the extent required to achieve a clean-burning fuel mixture.

d. Control Techniques

A variety of techniques are used to control pollutant emissions from external combustion sources. These techniques may be classified into three broad categories: fuel treatment, combustion modification, and postcombustion control. A listing of the most common types of control techniques for external combustion is provided in Table 9-1 below.

Table 9-1. Common Control Techniques for External Combustion Units

Pollutant	Control Techniques
Coal Combustion	
PM, Inorganic HAPs (e.g., metals), some low-volatile organic HAPs	Electrostatic Precipitator (ESP), Fabric Filter (bag house), Wet Scrubber, Cyclone or Multiclone Collector, Side Stream Separator, Combustion modifications (applicable to small stoker-fired boilers).
SO_X	Change to lower sulfur coal, Coal Cleaning, Flue Gas Desulfurization (e.g., wet scrubbing, spray drying, furnace injection, duct injection).
NO_X	Low Excess Air (LEA), Burners out of Service (BOOS), Biased Burner Firing, Overfire Air (OFA), Low NO_X Burners (LNBs), Reburn, Selective Noncatalytic Reduction (SNCR), Selective Catalytic Reduction (SCR).
Fuel Oil Combustion	
PM, Inorganic HAPs (e.g., metals), some low-volatile organic HAPs	Improving oil atomization and combustion aerodynamics, Electrostatic Precipitator, Fabric Filter (bag house), Wet Scrubber, Cyclone or Multiclone Collector.
SO_X	Flue Gas Desulfurization (e.g., wet, semi-dry, or dry scrubbers)
NO_X	Low Excess Air, Burners out of Service, Biased Burner Firing, Overfire Air, Flue Gas Recirculation (FGR), Low NO_X Burners, Selective Noncatalytic Reduction, Selective Catalytic Reduction.
Natural Gas Combustion	
NO_X	Low NO_X Burners, Flue Gas Recirculation
LPG Combustion	
NO_X	Low NO_X Burners, Flue Gas Recirculation, Water or steam injection into flame zone.
Waste Oil Combustion	
Pollutants listed above for Fuel Oil Combustion	Same as for Fuel Oil Combustion
Metals	Demetallization of the fuel (prior to combustion) via acid, solvent, or chemical contacting.
Miscellaneous Pollutants	Removing large particles and water in the fuel (prior to combustion) via sedimentation followed by filtration.
Miscellaneous Pollutants	Blending of waste oil with a virgin fuel oil prior to combustion.

9.2 Emission Calculations: Emissions from external combustion units can be estimated by multiplying the amount of fuel combusted by the appropriate emission factor.

$$E_{pol} = FC * EF$$

Where,

E_{pol} = Emissions of a particular pollutant (lb/yr)
FC = Quantity of fuel consumed per year (e.g., "tons/yr" for coal; "10^3 gal/yr" for fuel oils and LPG; "10^6 ft^3/yr" for natural gas)
EF = Emission factor in units of pounds pollutant per quantity of fuel burned (e.g., "lb/ton" for coal; "lb/10^3 gal" for fuel oils and LPG; "lb/10^6 ft^3" for natural gas)

It's important to note that some EPA emission factors for external combustion sources are in units of pounds pollutant per million British thermal units heat input (lb/MMBtu) instead of in pounds pollutant

per quantity of fuel burned. To make it easier (and less confusing) to calculate emissions, for this document all EPA emission factors in units of lb/MMBtu were converted into one of the following units, as appropriate: lb/ton, lb/10^3 gal, or lb/10^6 ft^3. The conversion was accomplished by multiplying the lb/MMBtu emission factor times the applicable fuel heating value. Typical fuel heating values used in the conversion calculations are listed in Table 2 below.

Table 9-2. Typical Heating Values of External Combustion Fuels

Fuel Type	Heating Value
Anthracite Coal	25 MMBtu/ton
Bituminous Coal	26 MMBtu/ton
Subbituminous Coal	20 MMBtu/ton
Residual Fuel Oil	150 MMBtu/10^3 gal
Distillate Fuel Oil	140 MMBtu/10^3 gal
Natural Gas	1,020 MMBtu/10^6 ft^3
Butane	97 MMBtu/10^3 gal
Propane	91 MMBtu/10^3 gal

Emission factors for external combustion units are found in Tables 9-3 through 9-29 below. It's important to emphasize that emissions of some pollutants (especially NO_X and CO) are very dependent on individual boiler operation. Therefore, whenever possible emission factors derived from actual source (stack) sampling results should be used in lieu of the emission factors provided below.

The emission factors provided in the Tables below are for uncontrolled units and for some controlled units. If a combustion source is controlled but a controlled emission factor is not available in the Tables below, the emissions can still be estimated by using the uncontrolled emission factor and the efficiency of the control device.

$$E_{pol} = FC * UEF * [1-(CE/100)]$$

Where,

E_{pol} = Emissions of a particular pollutant (lb/yr)
FC = Quantity of fuel consumed per year (e.g., "tons/yr" for coal; "10^3 gal/yr" for fuel oils and LPG; "10^6 ft^3/yr" for natural gas)
UEF = Uncontrolled emission factor in units of pounds pollutant per quantity of fuel burned (e.g., "lb/ton" for coal; "lb/10^3 gal" for fuel oils and LPG; "lb/10^6 ft^3" for natural gas)
CE = Efficiency of the control device (%)

9.3 Information Resources: Civil Engineering is usually responsible for operating/maintaining external combustion units on base and should be contacted to obtain the information (e.g., type and size of combustor, type of control equipment, type and quantity of fuel burned, etc.) required to calculate emissions. Additionally, base Supply Fuels Maintenance may also be a point of contact for information pertaining to fuel consumption.

9.4 Example Problem: A base has a 12 MMBtu/hr commercial boiler which is fueled with No 2. distillate oil. Flue gas recirculation is used to control NO_X emissions from the boiler. The estimated NO_X reduction efficiency of the FGR system is 60%. According to Civil Engineering, approximately 18,200 gallons of fuel oil was combusted in the boiler during the year. According to the fuel supplier, the distillate oil has a maximum sulfur content of 0.05%. Calculate the criteria pollutant and HAP emissions from the boiler.

a. The first step is to calculate the emissions of NO_X (the only controlled pollutant).

E_{pol} = FC * UEF * [1-(CE/100)]
E_{NOx} = (18.2 x 10^3 gal/yr) * 20 lb/10^3 gal * [1-(60%/100)] = **146 lb/yr**

b. The next step is to calculate emissions of the uncontrolled pollutants.

E_{pol} = FC * EF

Pollutant	**Fuel Consumed (10^3 gal/yr)**		**Emission Factor (lb/10^3 gal)**		**Emissions (lb/yr)**
Criteria Pollutants					
PM	18.2	x	(2 + 1.5)[a]	=	**64**
PM_{10}	18.2	x	(1.08 + 1.5)[a]	=	**47**
VOC	18.2	x	0.34	=	**6.2**
CO	18.2	x	5	=	**91**
SO_X	18.2	x	143.6(0.05)	=	**131**
HAPs					
Beryllium	18.2	x	4.2 x 10^{-4}	=	**7.6 x 10^{-3}**
Cadmium	18.2	x	4.2 x 10^{-4}	=	**7.6 x 10^{-3}**
Chromium	18.2	x	4.2 x 10^{-4}	=	**7.6 x 10^{-3}**
Formaldehyde	18.2	x	4.8 x 10^{-2}	=	**0.9**
Lead	18.2	x	1.26 x 10^{-3}	=	**0.023**
Manganese	18.2	x	8.4 x 10^{-4}	=	**0.015**
Mercury	18.2	x	4.2 x 10^{-4}	=	**7.6 x 10^{-3}**
Nickel	18.2	x	4.2 x 10^{-4}	=	**7.6 x 10^{-3}**
POM	18.2	x	3.3 x 10^{-3}	=	**0.06**
Selenium	18.2	x	2.1 x 10^{-3}	=	**0.038**

[a] Note - Both filterable and condensable particulate are included for PM and PM_{10}.

Table 9-3. Criteria Pollutant (except NO_X) Emission Factors for Uncontrolled Bituminous and Subbituminous Coal Combustion[a]

Firing Configuration	SCC[c]	Emission Factor (lb/ton)[b]					
		CO	SO_X[d]	VOC[e]	PM[f,g]	PM_{10}[f,g]	$PM_{2.5}$[f,g]
Pulverized coal, dry bottom, wall-fired	1-01-002-02/22 1-02-002-02/22 1-03-002-06/22	0.5	38S (35S)	0.06	10A	2.3A	0.6A
Pulverized coal, dry bottom, tangentially fired	1-01-002-12/26 1-02-002-12/26 1-03-002-16/26	0.5	38S (35S)	0.06	10A	2.3A	0.6A
Pulverized coal, wet bottom	1-01-002-01/21 1-02-002-01/21 1-03-002-05/21	0.5	38S (35S)	0.04	7A	2.6A	1.48A
Pulverized coal, dry bottom, cell burner fired	1-01-002-15/35	0.5	38S (35S)	ND	ND	ND	ND
Cyclone Furnace	1-01-002-03/23 1-02-002-03/23 1-03-002-03/23	0.5	38S (35S)	0.11	2A	0.26A	0
Spreader Stoker	1-01-002-04/24 1-02-002-04/24 1-03-002-09/24	5	38S (35S)	0.05	66	13.2	4.6
Overfeed Stoker[h]	1-01-002-05/25 1-02-002-05/25 1-03-002-07/25	6	38S (35S)	0.05	16	6	2.2
Underfeed stoker	1-02-002-06 1-03-002-08	11	31S	1.3	15	6.2	3.8
Hand-fed units	1-03-002-14	275	31S	10	15	6.2	ND
Fluidized bed combustor, circulating bed	1-01-002-18 1-02-002-18 1-03-002-18	18	[i]	0.05	17	12	1.4
Fluidized bed combustor, bubbling bed	1-01-002-17 1-02-002-17 1-03-002-17	18	[i]	0.05	17	12	1.4

[a] Emission factors are from Section 1.1 of AP-42. ND = No Data
[b] Emission factors are in units of pounds pollutant per ton of coal burned (lb/ton).
[c] SCC = Source Classification Code
[d] Factors in parentheses should be used to estimate gaseous SO_X emissions for subbituminous coal. In all cases, S is the weight % sulfur content of the coal as fired. The emission factor is calculated by multiplying the weight percent sulfur in the coal by the numerical value preceding S.
[e] VOC values are based on the emission factors for Total Nonmethane Organic Compounds (TNMOC).
[f] Emission factors are for filterable particulate matter [i.e., particulate collected on or prior to the filter of an EPA Method 5 (or equivalent) sampling train]. Condensable particulate matter emission factors are found in Table 9-5.
[g] A is weight % ash content of coal as fired. Emission factor would be calculated by multiplying the weight percent ash in the coal by the numerical value preceding A.
[h] Includes traveling grate, vibrating grate, and chain grate stokers.
[i] SO_X emission factors for fluidized bed combustion are a function of fuel sulfur content and calcium-to-sulfur ratio. For both bubbling bed and circulating bed design, use: lb SO_X/ton coal = $39.6(S)(Ca/S)^{-1.9}$. In this equation, S is the weight percent sulfur in the fuel and Ca/S is the molar calcium-to-sulfur ratio in the bed. This equation may be used when the Ca/S is between 1.5 and 7. When no calcium-based sorbents are used and the bed material is inert with respect to sulfur capture, the emission factor for underfeed stokers should be used to estimate SO_X emissions.

Table 9-4. NO_X Emission Factors for Bituminous and Subbituminous Coal Combustion[a]

Firing Configuration	SCC[b]	NO_X Emission Factor (lb/ton)[c]
Pulverized coal, dry bottom, wall-fired, bituminous	1-01-002-02 1-02-002-02 1-03-002-06	22[d]
Pulverized coal, dry bottom, wall-fired, bituminous, with low-NO_X burner	1-01-002-02 1-02-002-02 1-03-002-06	11[d]
Pulverized coal, dry bottom, wall-fired, subbituminous	1-01-002-22 1-02-002-22 1-03-002-22	12[d]
Pulverized coal, dry bottom, cell burner fired, bituminous	1-01-002-15	31
Pulverized coal, dry bottom, cell burner fired, subbituminous	1-01-002-35	14
Pulverized coal, dry bottom, tangentially fired, bituminous	1-01-002-12 1-02-002-12 1-03-002-16	15[d]
Pulverized coal, dry bottom, tangentially fired, bituminous, with low-NO_X burner	1-01-002-12 1-02-002-12 1-03-002-16	9.7[d]
Pulverized coal, dry bottom, tangentially fired, subbituminous	1-01-002-26 1-02-002-26 1-03-002-26	8.4[d]
Pulverized coal, wet bottom, wall-fired, bituminous	1-01-002-01 1-02-002-01 1-03-002-05	31[d]
Pulverized coal, wet bottom, wall-fired, subbituminous	1-01-002-21 1-02-002-21 1-03-002-21	24
Cyclone Furnace, bituminous	1-01-002-03 1-02-002-03 1-03-002-03	33
Cyclone Furnace, subbituminous	1-01-002-23 1-02-002-23 1-03-002-23	17
Spreader Stoker, bituminous	1-01-002-04 1-02-002-04 1-03-002-09	11

Table 9-4. NO_X Emission Factors for Bituminous and Subbituminous Coal Combustion[a] (Cont'd)

Firing Configuration	SCC[b]	NO_X Emission Factor (lb/ton)[c]
Spreader Stoker, subbituminous	1-01-002-24 1-02-002-24 1-03-002-24	8.8
Overfeed Stoker[e]	1-01-002-05/25 1-02-002-05/25 1-03-002-07/25	7.5
Underfeed stoker	1-02-002-06 1-03-002-08	9.5
Hand-fed units	1-03-002-14	9.1
Fluidized bed combustor, circulating bed	1-01-002-18 1-02-002-18 1-03-002-18	5.0
Fluidized bed combustor, bubbling bed	1-01-002-17 1-02-002-17 1-03-002-17	15.2

[a] Emission factors are from Section 1.1 of AP-42.
[b] SCC = Source Classification Code
[c] Emission factors are in units of pounds pollutant per ton of coal burned (lb/ton).
[d] A different emission factor (found in Table 1.1-3 of AP-42) must be used for boilers > 250 MMBtu/hr which are subject to a New Source Performance Standard (NSPS) under 40 CFR 60 Subpart D or Da.
[e] Includes traveling grate, vibrating grate, and chain grate stokers.

Table 9-5. Condensable Particulate Matter Emission Factors for Bituminous and Subbituminous Coal Combustion[a]

Firing Configuration	Emission Factor (lb/ton)[b,c,d]
All pulverized coal-fired boilers, except those controlled with FGD[e]	2.6S – 0.78 (2.0S – 0.60)
All pulverized coal-fired boilers controlled with FGD[e]	0.52 (0.40)
Spreader stoker, travelling grate overfeed stoker, underfeed stoker	1.04 (0.80)
Cyclone boilers	2.6S – 0.78 (2.0S – 0.60)
Atmospheric Fluidized Bed Combustion (AFBC) boilers	0.52 (0.40)

[a] All condensable particulate matter is assumed to be less than 1.0 micron in diameter.
[b] Emission factors are from Section 1.1 of AP-42 and are in units of pounds pollutant per ton of coal burned (lb/ton).
[c] Values not in parenthesis are for bituminous coal while values in parenthesis are for subbituminous coal.
[d] S = weight % sulfur content of the coal. For example, for a cyclone boiler burning subbituminous coal with a sulfur content of 0.5%, the emission factor is: 2.0(0.5) – 0.60 = 0.4 lb/ton
[e] FGD = Flue gas desulfurization

Table 9-6. Particulate Matter Emission Factors for Controlled Bituminous and Subbituminous Coal Combustion[a]

Firing Configuration	Emission Factor (lb/ton)[b]											
	Multiple Cyclone			Scrubber			Electrostatic Precipitator			Baghouse		
	PM	PM_{10}	$PM_{2.5}$	PM	PM_{10}	$PM_{2.5}$	PM	PM_{10}	$PM_{2.5}$	PM	PM_{10}	$PM_{2.5}$
Pulverized coal, dry bottom	2A	0.58A	0.06A	0.6A	0.42A	0.3A	0.08A	0.054A	0.024A	0.02A	0.02A	0.01A
Pulverized coal, wet bottom	1.4A	1.3A	0.86A	ND	ND	ND	0.056A	0.042	0.022A	ND	ND	ND
Cyclone Furnace	0.12A	0.112A	0.11A	ND	ND	ND	0.016A	0.011A	0.006A	ND	ND	ND
Spreader Stoker	17.0 or 12.0[c]	12 or 7.8[c]	1.4 or 3.2[c]	ND	ND	ND	0.48	0.44	0.30	0.12	0.072	0.032
Overfeed Stoker	9.0	5.0	3.8	ND	ND	ND	ND	ND	ND	ND	ND	ND
Underfeed Stoker	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

[a] Emission factors are from Section 1.1 of AP-42. The emission factors are for filterable particulate matter [i.e., particulate collected on or prior to the filter of an EPA Method 5 (or equivalent) sampling train]. Condensable particulate matter emission factors are found in Table 9-5.

[b] Emission factors are in units of pounds pollutant per ton of coal burned (lb/ton). "A" is weight % ash content of coal as fired. Emission factor would be calculated by multiplying the weight percent ash in the coal by the numerical value preceding A.

[c] The first number is for systems with flyash reinjection while the second number is for systems without flyash reinjection.

Table 9-7. Emission Factors for Metals, Polycyclic Organic Matter (POM), and Formaldehyde (HCOH) from Uncontrolled Bituminous and Subbituminous Coal Combustion[a]

Firing Configuration	Emission Factor (lb/ton)[b]									
	Arsenic	Beryllium	Cadmium	Chromium	Lead	Manganese	Mercury	Nickel	POM	HCOH
Pulverized coal, wet bottom	1.40×10^{-2} (1.08×10^{-2})	2.11×10^{-3} (1.62×10^{-3})	1.48×10^{-3} (1.14×10^{-3})	3.37×10^{-2} (2.59×10^{-2})	1.32×10^{-2} (1.01×10^{-2})	4.92×10^{-2} (3.79×10^{-2})	4.16×10^{-4} (3.20×10^{-4})	2.77×10^{-2} (2.13×10^{-2})	ND	ND
Pulverized coal, dry bottom	1.78×10^{-2} (1.37×10^{-2})	2.11×10^{-3} (1.62×10^{-3})	1.15×10^{-3} (8.88×10^{-4})	3.67×10^{-2} (2.82×10^{-2})	1.32×10^{-2} (1.01×10^{-2})	4.17×10^{-2} (3.21×10^{-2})	4.16×10^{-4} (3.20×10^{-4})	3.02×10^{-2} (2.32×10^{-2})	5.41×10^{-5} (4.16×10^{-5})	ND
Pulverized coal, dry bottom, tangential	ND	ND	ND	ND	ND	ND	ND	ND	6.24×10^{-5} (4.80×10^{-5})	ND
Cyclone Furnace	2.99×10^{-3} (2.30×10^{-3})	2.11×10^{-3} (1.62×10^{-3})	7.28×10^{-4} (5.60×10^{-4})	2.23×10^{-2} (1.71×10^{-2})	1.32×10^{-2} (1.01×10^{-2})	1.99×10^{-2} (l.53 $\times 10^{-2}$)	4.16×10^{-4} (3.20×10^{-4})	1.90×10^{-2} (1.46×10^{-2})	ND	ND
Spreader Stoker	1.05×10^{-2} (8.06×10^{-3})	ND	8.32×10^{-4} (6.40×10^{-4})	3.27×10^{-2} (2.51×10^{-2})	1.32×10^{-2} (1.01×10^{-2})	ND	ND	ND	ND	5.75×10^{-3} (4.42×10^{-3})
Overfeed Stoker, traveling grate	2.04×10^{-2} (1.57×10^{-2})	ND	1.63×10^{-3} (1.25×10^{-3})	ND	1.32×10^{-2} (1.01×10^{-2})	ND	ND	ND	ND	3.64×10^{-3} (2.80×10^{-3})
Underfeed Stoker	2.05×10^{-1} (1.58×10^{-1})	ND	1.20×10^{-2} (9.20×10^{-3})	ND	ND	ND	ND	ND	5.10×10^{-3} (3.92×10^{-3})	ND

[a] Emission factors are from Section 1.1 of AP-42. Values not in parenthesis are for bituminous coal while values in parenthesis are for subbituminous coal.
[b] Emission factors are in units of pounds pollutant per ton of coal burned. The values listed in AP-42 were converted from "lb/MMBtu" to "lb/ton" by multiplying times the applicable fuel heating value listed in Table 9-2.

Table 9-8. Organic HAP Emission Factors for Controlled Bituminous and Subbituminous Coal Combustion[a]

Pollutant	Emission Factor (lb/ton)[b]
Acetaldehyde	5.7×10^{-4}
Acetophenone	1.5×10^{-5}
Acrolein	2.9×10^{-4}
Benzene	1.3×10^{-3}
Benzyl chloride	7.0×10^{-4}
Biphenyl	1.7×10^{-6}
Bis(2-ethylhexyl)phthalate (DEHP)	7.3×10^{-5}
Bromoform	3.9×10^{-5}
Carbon disulfide	1.3×10^{-4}
2-Chloroacetophenone	7.0×10^{-6}
Chlorobenzene	2.2×10^{-5}
Chloroform	5.9×10^{-5}
Cumene	5.3×10^{-6}
Cyanide	2.5×10^{-3}
2,4-Dinitrotoluene	2.8×10^{-7}
Dimethyl sulfate	4.8×10^{-5}
Ethyl benzene	9.4×10^{-5}
Ethyl chloride	4.2×10^{-5}
Ethylene dichloride	4.0×10^{-5}
Ethylene dibromide	1.2×10^{-6}
Formaldehyde	2.4×10^{-4}
Hexane	6.7×10^{-5}
Isophorone	5.8×10^{-4}
Methyl bromide	1.6×10^{-4}
Methyl chloride	5.3×10^{-4}
Methyl ethyl ketone	3.9×10^{-4}
Methyl hydrazine	1.7×10^{-4}
Methyl methacrylate	2.0×10^{-5}
Methyl tert butyl ether	3.5×10^{-5}
Methylene chloride	2.9×10^{-4}
Naphthalene	1.3×10^{-5}
Phenol	1.6×10^{-5}
Propionaldehyde	3.8×10^{-4}
Tetrachloroethylene	4.3×10^{-5}
Toluene	2.4×10^{-4}
1,1,1-Trichloroethane	2.0×10^{-5}
Styrene	2.5×10^{-5}
Xylenes	3.7×10^{-5}
Vinyl acetate	7.6×10^{-6}

[a] Emission factors are from Section 1.1 of AP-42.
[b] Emission factors are in units of pounds pollutant per ton of coal burned (lb/ton). The emission factors are applicable to boilers using both wet limestone scrubbers or spray dryers and an electrostatic precipitator (ESP) or fabric filter (FF). In addition, the factors apply to boilers using only an ESP or FF.

Table 9-9. Emission Factors for Metal HAPs from Controlled Bituminous and Subbituminous Coal Combustion[a]

Pollutant	Emission Factor (lb/ton)[b]
Antimony	1.8×10^{-5}
Arsenic	4.1×10^{-4}
Beryllium	2.1×10^{-5}
Cadmium	5.1×10^{-5}
Chromium	2.6×10^{-4}
Cobalt	1.0×10^{-4}
Lead	4.2×10^{-4}
Manganese	4.9×10^{-4}
Mercury	8.3×10^{-5}
Nickel	2.8×10^{-4}
Selenium	1.3×10^{-3}

[a] Emission factors are from Section 1.1 of AP-42. The factors apply to boilers utilizing either venturi scrubbers, spray dryer absorbers, or wet limestone scrubbers with an electrostatic precipitator (ESP) or fabric filter (FF).
[b] Emission factors are in units of pounds pollutant per ton of coal burned (lb/ton).

Table 9-10. Emission Factors for Dioxins and Furans from Controlled Bituminous and Subbituminous Coal Combustion[a]

	Emission Factor (lb/ton)[b]	
Pollutant	**FGD-SDA with FF[c]**	**ESP or FF[d]**
2,3,7,8-Tetrachlorodibenzo-p-dioxin	No Data	1.43×10^{-11}
Dibenzofurans	2.01×10^{-7}	1.09×10^{-9}

[a] Emission factors are from Section 1.1 of AP-42.
[b] Emission factors are in units of pounds pollutant per ton of coal burned (lb/ton).
[c] Factors apply to boilers equipped with both flue gas desulfurization spray dryer adsorber (FGD-SDA) and a fabric filter (FF).
[d] Factors apply to boilers equipped with an electrostatic precipitator (ESP) or a fabric filter (FF).

Table 9-11. Emission Factors for Hydrogen Chloride (HCl) and Hydrogen Fluoride (HF) from Bituminous and Subbituminous Coal Combustion[a]

Firing Configuration	Emission Factor (lb/ton)[b]	
	Hydrogen Chloride	Hydrogen Fluoride
Pulverized coal, dry bottom, wall fired	1.2	0.15
Pulverized coal, dry bottom, tangential fired	1.2	0.15
Pulverized coal, wet bottom	1.2	0.15
Cyclone furnace	1.2	0.15
Spreader stoker	1.2	0.15
Overfeed stoker	1.2	0.15
Underfeed stoker	1.2	0.15
Fluidized bed combustor, bubbling bed	1.2	0.15
Fluidized bed combustor, circulating bed	1.2	0.15
Hand-fired	1.2	0.15

[a] Emission factors are from Section 1.1 of AP-42. The factors apply to both controlled and uncontrolled sources.
[b] Emission factors are in units of pounds pollutant per ton of coal burned (lb/ton).

Table 9-12. Emission Factors for Polycyclic Organic Matter (POM) from Controlled Bituminous and Subbituminous Coal Combustion[a]

Firing Configuration	Control Device	Emission Factor (lb/ton)[b]
Pulverized coal, dry bottom, wall fired	Wet Scrubber	2.22×10^{-4} (1.71×10^{-4})
	Multiple Cyclones and ESP	4.81×10^{-4} (3.70×10^{-4})
Pulverized coal, wet bottom	Wet Scrubber	1.47×10^{-2} (1.13×10^{-2})
	ESP	2.31×10^{-4} (1.78×10^{-4})
Pulverized coal, dry bottom, tangentially fired	Multiple Cyclones and ESP	5.72×10^{-5} (4.40×10^{-5})
Cyclone furnace	Wet Scrubber	4.21×10^{-4} (3.24×10^{-4})
	ESP	5.30×10^{-5} (4.08×10^{-5})
Overfeed Stoker	Multiple Cyclones	7.64×10^{-6} (5.88×10^{-6})

[a] Emission factors are from EPA's FIRE program. Values not in parenthesis are for bituminous coal while values in parenthesis are for subbituminous coal.
[b] Emission factors are in units of pounds pollutant per ton of coal burned. The values listed in FIRE were converted from "lb/MMBtu" to "lb/ton" by multiplying times the applicable fuel heating value listed in Table 9-2.

Table 9-13. Criteria Pollutant Emission Factors for Uncontrolled Anthracite Coal Combustion[a]

Firing Configuration	SCC[c]	Emission Factor (lb/ton)[b]						
		CO	NO_X	SO_X[d]	VOC	PM[e]	PM_{10}[e]	$PM_{2.5}$[e]
Stoker-fired	1-01-001-02 1-02-001-04 1-03-001-02	0.6	9.0	39S	0.3	0.88A	4.8	ND
Fluidized bed combustor	No SCC	0.6	1.8	2.9	ND	ND	ND	ND
Pulverized coal	1-01-001-01 1-02-001-01 1-03-001-01	0.6	18	39S	0.07	10A	2.3A	0.6A
Residential space heaters	A2104001000	ND	3	39S	ND	ND	ND	ND
Hand-fired units	1-02-001-07 1-03-001-03	90	3	39S	10	10.0	5.2	ND

[a] Emission factors are from Section 1.2 of AP-42 and from the EPA's FIRE program.
[b] Emission factors are in units of pounds pollutant per ton of coal burned (lb/ton).
[c] SCC = Source Classification Code
[d] S is the weight % sulfur content of the coal as fired. The emission factor is calculated by multiplying the weight percent sulfur in the coal by the numerical value preceding S.
[e] A is weight % ash content of coal as fired. Emission factor would be calculated by multiplying the weight percent ash in the coal by the numerical value preceding A.

Table 9-14. Particulate Matter Emissions from Controlled Pulverized Coal Boilers Burning Anthracite Coal[a]

Control Device	Emission Factor (lb/ton)[b]		
	PM	PM_{10}	$PM_{2.5}$
Multiple Cyclones	2A	1.10A	0.48A
Baghouse	0.02A	0.013A	0.006A

[a] Emission factors are from Section 1.2 of AP-42.
[b] A is weight % ash content of coal as fired. Emission factor would be calculated by multiplying the weight percent ash in the coal by the numerical value preceding A. Emission factors are in units of pounds pollutant per ton of coal burned (lb/ton).

Table 9-15. HAP Emission Factors for Uncontrolled Anthracite Coal Combustion[a]

Pollutant	Emission Factors per Type of Firing Configuration (lb/ton)[b]			
	Stoker-fired	Pulverized Coal	Residential Space Heaters	Hand-fired
Inorganic HAPs				
Arsenic	1.9×10^{-4}	ND	ND	ND
Beryllium	3.1×10^{-4}	ND	ND	ND
Cadmium	7.1×10^{-5}	ND	ND	ND
Chromium	2.8×10^{-2}	ND	ND	ND
Lead	8.9×10^{-3}	8.9×10^{-3}	ND	8.9×10^{-3}
Manganese	3.6×10^{-3}	ND	ND	ND
Mercury	1.3×10^{-4}	ND	ND	ND
Nickel	2.6×10^{-2}	ND	ND	ND
Selenium	1.3×10^{-3}	ND	ND	ND
Organic HAPs				
Biphenyl	2.5×10^{-2}	ND	ND	ND
Dibenzofurans	ND	ND	1.1×10^{-6}	ND
Naphthalene	1.3×10^{-1}	ND	0.3	ND
POM[c]	ND	ND	ND	1.44×10^{-3} [d]
2,3,7,8-TCDD[e]	ND	ND	3.2×10^{-9}	ND

[a] Emission factors obtained from the EPA's FIRE program. ND = No Data
[b] Emission factors are in units of pounds of pollutant per ton of coal burned.
[c] POM = Polycyclic Organic Matter
[d] This emission factor was obtained by multiplying the "lb/MMBtu" emission factor listed in the FIRE program times the typical heating value of anthracite coal (25 MMBtu/ton).
[e] 2,3,7,8-Tetrachlorodibenzo-p-dioxin

Table 9-16. HAP Emission Factors for Controlled Anthracite Coal Combustion

Firing Configuration	Control Device	Emission Factor (lb/ton)[a]
		Selenium
Stoker-fired	Multiple Cyclones	2.09×10^{-3}
Pulverized Coal	Electrostatic Precipitator	7.53×10^{-4}

[a] Emission factors are in units of pounds pollutant per ton of coal burned. These values were obtained by multiplying the "lb/MMBtu" emission factors listed in EPA's FIRE program times the typical heating value of anthracite coal (25 MMBtu/ton).

Table 9-17. CO, SO_X, and PM Emission Factors for Uncontrolled Fuel Oil Combustion[a]

Firing Configuration	SCC[c]	Emission Factor ($lb/10^3$ gal)[b]		
		CO	SO_X[d]	PM[e,f]
Boilers > 100 MMBtu/hr				
No. 6 oil, normal firing	1-01-004-01, 1-02-004-01, 1-03-004-01	5	161.6S	9.19(S) + 4.72
No. 6 oil, tangential firing	1-01-004-04	5	161.6S	9.19(S) + 4.72
No. 5 oil, normal firing	1-01-004-05, 1-02-004-04	5	161.6S	11.5
No. 5 oil, tangential firing	1-01-004-06	5	161.6S	11.5
No. 4 oil, normal firing	1-01-005-04, 1-02-005-04	5	154.6S	8.5
No. 4 oil, tangential firing	1-01-005-05	5	154.6S	8.5
No. 2 oil fired	1-01-005-01, 1-02-005-01, 1-03-005-01	5	146.6S	3.3
Boilers < 100 MMBtu/hr				
No. 6 oil fired	1-02-004-02/03, 1-03-004-02/03	5	158.6S	9.19(S) + 4.72
No. 5 oil fired	1-03-004-04	5	158.6S	11.5
No. 4 oil fired	1-03-005-04	5	151.6S	8.2
Distillate oil fired[g]	1-02-005-02/03, 1-03-005-02/03	5	143.6S	3.3
Residential furnace[h]	A2104004/A2104011	5	143.6S	1.7

[a] Emission factors obtained from Section 1.3 of AP-42.
[b] Emission factors are in units of pounds pollutant per thousand gallons of fuel burned.
[c] SCC = Source Classification Code
[d] Includes both SO_2 and SO_3 (reported as SO_2). S is the weight % sulfur content of the fuel oil. For example, if the fuel oil contains 0.5% sulfur, then S = 0.5. The emission factor is calculated by multiplying the weight percent sulfur in the fuel oil by the numerical value preceding S.
[e] Each particulate matter emission factor was derived by adding together the applicable filterable particulate matter emission factor and the applicable condensable particulate emission factor found in Section 1.3 of AP-42.
[f] Particulate emission factors for No. 6 fuel oil combustion are a function of fuel oil sulfur content where S is the weight % sulfur in the oil. For example, if the fuel oil contains 0.5% sulfur, then S = 0.5.
[g] Distillate oil includes both No. 1 and No. 2 fuel oils.
[h] Residential furnaces are typically considered to be units < 0.3 MMBtu/hr.

Table 9-18. VOC, PM_{10}, and $PM_{2.5}$ Emission Factors for Uncontrolled Fuel Oil Combustion[a]

Firing Configuration	SCC[c]	Emission Factor (lb/10^3 gal)[b]		
		VOC[d]	PM_{10}[e,f]	$PM_{2.5}$[e,f]
Utility Boilers				
No. 6, normal firing	1-01-004-01	0.76	6.6(S) + 3.7	4.8(S) + 3.1
No. 6, tangential firing	1-01-004-04	0.76	6.6(S) + 3.7	4.8(S) + 3.1
No. 5, normal firing	1-01-004-05	0.76	8.6	6.7
No. 5, tangential firing	1-01-004-06	0.76	8.6	6.7
No. 4, normal firing	1-01-005-04	0.76	6.5	5.1
No. 4, tangential firing	1-01-005-05	0.76	6.5	5.1
Industrial Boilers				
No. 6 oil fired	1-02-004-01/02/03	0.28	8.03(S) + 4.15	5.2(S) + 3.23
No. 5 oil fired	1-02-004-04	0.28	10.1	7.1
No. 4 oil fired	1-02-005-04	0.2	7.52	5.42
Distillate oil fired[g]	1-02-005-01/02/03	0.2	2.3	1.55
Commercial/Institutional Boilers				
No. 6 oil fired	1-03-004-01/02/03	1.13	5.79(S) + 3.41	2.15(S) + 2.21
No. 5 oil fired	1-03-004-04	1.13	7.7	3.8
No. 4 oil fired	1-03-005-04	0.34	5.84	3.11
Distillate oil fired[g]	1-03-005-01/02/03	0.34	2.38	2.13
Residential furnace[h]	A2104004/A2104011	0.713	ND[i]	ND[i]

[a] Emission factors obtained from Section 1.3 of AP-42.
[b] Emission factors are in units of pounds pollutant per thousand gallons of fuel burned.
[c] SCC = Source Classification Code
[d] VOC values are for Nonmethane Total Organic Compounds (NMTOC).
[e] Each particulate matter emission factor was derived by adding together the applicable filterable particulate matter emission factor and the applicable condensable particulate emission factor found in Section 1.3 of AP-42.
[f] Particulate emission factors for No. 6 fuel oil combustion are a function of fuel oil sulfur content where S is the weight % sulfur in the oil. For example, if the fuel oil contains 0.5% sulfur, then S = 0.5.
[g] Distillate oil includes both No. 1 and No. 2 fuel oils.
[h] Residential furnaces are typically considered to be units < 0.3 MMBtu/hr.
[i] ND = No data

Table 9-19. NO_X Emission Factors for Fuel Oil Combustion[a]

Firing Configuration	SCC[b]	NO_X Emission Factor ($lb/10^3$ gal)[c]
Boilers > 100 MMBtu/hr		
No. 6 oil, normal firing	1-01-004-01, 1-02-004-01, 1-03-004-01	47
No. 6 oil, normal firing, low NO_X burner	1-01-004-01, 1-02-004-01, 1-03-004-01	40
No. 6 oil, tangential firing	1-01-004-04	32
No. 6 oil, tangential firing, low NO_X burner	1-01-004-04	26
No. 5 oil, normal firing	1-01-004-05, 1-02-004-04	47
No. 5 oil, tangential firing	1-01-004-06	32
No. 4 oil, normal firing	1-01-005-04, 1-02-005-04	47
No. 4 oil, tangential firing	1-01-005-05	32
No. 2 oil fired	1-01-005-01, 1-02-005-01, 1-03-005-01	24
No. 2 oil fired, LNB/FGR[d]	1-01-005-01, 1-02-005-01, 1-03-005-01	10
Boilers < 100 MMBtu/hr		
No. 6 oil fired	1-02-004-02/03, 1-03-004-02/03	55
No. 5 oil fired	1-03-004-04	55
No. 4 oil fired	1-03-005-04	20
Distillate oil fired[e]	1-02-005-02/03, 1-03-005-02/03	20
Residential furnace[f]	A2104004/A2104011	18

[a] Emission factors obtained from Section 1.3 of AP-42.
[b] SCC = Source Classification Code
[c] Emission factors are in units of pounds pollutant per thousand gallons of fuel burned.
[d] LNB/FGR = low NO_X burner with flue gas recirculation.
[e] Distillate oil includes both No. 1 and No. 2 fuel oils.
[f] Residential furnaces are typically considered to be units < 0.3 MMBtu/hr.

Table 9-20. HAP Emission Factors for Uncontrolled Fuel Oil Combustion (lb/10^3 gal)[a]

Pollutant	Utility Boilers			Industrial Boilers				Commercial/Institutional		
	No. 6 Fuel[b] (1-01-004-01, 1-01-004-04)[c]	**No. 5 Oil, Normal Firing[d] (1-01-004-05)[c]**	**Distillate Oil[e] (1-01-005-01)[c]**	**No. 6 Oil[d] (1-02-004-01)[c]**	**No. 5 Oil[d] (1-02-004-04)[c]**	**Distillate Oil[b] (1-02-005-01)[c]**	**Distillate Oil[d] (1-02-005-02, 1-02-005-03)[c]**	**No. 6 Oil[d] (1-03-004-01)[c]**	**Distillate Oil[f] (1-03-005-01)[c]**	**Distillate Oil[d] (1-03-005-02, 1-03-005-03)[c]**
Antimony	5.25×10^{-3}	ND	ND	5.25×10^{-3}	ND	ND	ND	5.25×10^{-3}	ND	ND
Arsenic	1.32×10^{-3}	1.01×10^{-3}	5.6×10^{-4}	1.01×10^{-2}	ND	5.6×10^{-4}	ND	1.01×10^{-2}	5.6×10^{-4}	ND
Beryllium	2.78×10^{-5}	3.21×10^{-5}	4.2×10^{-4}	6.30×10^{-4}	ND	4.2×10^{-4}	ND	6.30×10^{-4}	4.2×10^{-4}	ND
Cadmium	3.98×10^{-4}	1.04×10^{-4}	4.2×10^{-4}	1.71×10^{-2}	ND	4.2×10^{-4}	ND	1.71×10^{-2}	4.2×10^{-4}	ND
Chromium	8.45×10^{-4}	6.06×10^{-4}	4.2×10^{-4}	1.12×10^{-2}	ND	4.2×10^{-4}	ND	1.12×10^{-2}	4.2×10^{-4}	ND
Cobalt	6.02×10^{-3}	ND	ND	1.49×10^{-2}	ND	ND	ND	1.49×10^{-2}	ND	ND
Lead	1.51×10^{-3}	2.4×10^{-3}	1.26×10^{-3}	ND	ND	1.26×10^{-3}	1.25×10^{-3}	ND	1.26×10^{-3}	1.25×10^{-3}
Manganese	3.0×10^{-3}	2.61×10^{-3}	8.4×10^{-4}	7.28×10^{-3}	ND	8.4×10^{-4}	ND	7.28×10^{-3}	8.4×10^{-4}	ND
Mercury	1.13×10^{-4}	ND	4.2×10^{-4}	2.51×10^{-3}	ND	4.2×10^{-4}	ND	2.51×10^{-3}	4.2×10^{-4}	ND
Nickel	8.45×10^{-2}	5.55×10^{-2}	4.2×10^{-4}	2.38×10^{-1}	ND	4.2×10^{-4}	ND	2.38×10^{-1}	4.2×10^{-4}	ND
Selenium	6.83×10^{-4}	5.67×10^{-4}	2.1×10^{-3}	5.70×10^{-3}	ND	2.1×10^{-3}	ND	5.70×10^{-3}	2.1×10^{-3}	ND
Benzene	2.14×10^{-4}	ND	ND	1.1×10^{-3}	ND	ND	ND	1.1×10^{-3}	2.75×10^{-3}	ND
Ethylbenzene	6.36×10^{-5}	ND	ND	ND	ND	ND	ND	ND	ND	ND
Formaldehyde	3.30×10^{-2}	7.05×10^{-3} [g]	4.8×10^{-2}	4.25×10^{-2}	7.05×10^{-3}	4.8×10^{-2}	ND	4.25×10^{-2}	4.8×10^{-2}	ND
Methyl Chloroform	2.36×10^{-4}	ND	ND	ND	ND	ND	ND	ND	ND	ND
Naphthalene	1.13×10^{-3}	6.27×10^{-4}	4.66×10^{-2}	6.45×10^{-2}	5.04×10^{-5}	ND	ND	6.45×10^{-2}	ND	ND
Polycyclic Organic Matter	1.2×10^{-3}	ND	3.3×10^{-3}	1.2×10^{-3}	ND	3.3×10^{-3}	ND	1.2×10^{-3}	3.3×10^{-3}	ND
Toluene	6.20×10^{-3}	ND	ND	8.8×10^{-3}	ND	ND	ND	8.8×10^{-3}	ND	ND
o-Xylene	1.09×10^{-4}	ND	ND	ND	ND	ND	ND	ND	ND	ND
Xylene, mixed isomers	ND	ND	ND	7.5×10^{-3}	ND	ND	ND	7.5×10^{-3}	ND	ND

[a] Emission factors are in units of pounds pollutant per thousand gallons of fuel burned. EPA emission factors listed in units of "lb/MMBtu" were converted into units of "lb/10^3 gal" by multiplying times the applicable fuel heating value listed in Table 9-2. ND = No Data
[b] All emission factors in the column are from Section 1.3 of AP-42.
[c] Numbers in parenthesis are the applicable Source Classification Codes (SCCs).
[d] All emission factors in the column are from the EPA's FIRE Program.
[e] With the exception of naphthalene, emission factors in this column are from Section 1.3 of AP-42. The naphthalene emission factor is from FIRE.
[f] With the exception of benzene, emission factors in this column are from Section 1.3 of AP-42. The benzene emission factor is from FIRE.
[g] The formaldehyde value listed in FIRE for a Utility Boiler burning No.5 fuel oil is 4.7×10^{-1} lb/MMBtu. Since this is obviously incorrect (much too high), the value in FIRE for an Industrial Boiler burning No. 5 fuel oil (4.7×10^{-5} lb/MMBtu) was used instead.

Table 9-21. Particulate Matter Emission Factors for Controlled Residual Fuel Oil Combustion[a]

Firing Configuration	Emission Factor (lb/10^3 gal)[b]								
	Electrostatic Precipitator			Scrubber			Multiple Cyclone		
	PM	PM_{10}	$PM_{2.5}$	PM	PM_{10}	$PM_{2.5}$	PM	PM_{10}	$PM_{2.5}$
Utility Boilers									
No. 6 fuel oil fired (SCCs 1-01-004-01/04)	0.075(S) + 0.025	0.047(S) + 0.016	0.031(S) + 0.010	0.56(S) + 0.19	0.56(S) + 0.19	0.54(S) + 0.18	ND	ND	ND
No. 5 fuel oil fired (SCCs 1-01-004-05/06)	0.08	0.05	0.03	0.60	0.60	0.58	ND	ND	ND
No. 4 fuel oil fired (SCCs 1-01-005-04/05)	0.06	0.04	0.02	0.42	0.42	0.40	ND	ND	ND
Industrial Boilers									
No. 6 fuel oil, normal firing (SCCs 1-02-004-01/02/03)	ND	ND	ND	ND	ND	ND	1.87(S) + 0.62	1.77(S) + 0.58	0.37(S) + 0.12
No. 5 fuel oil, normal firing (SCC 1-02-004-04)	ND	ND	ND	ND	ND	ND	2.00	1.90	0.40
No. 4 fuel oil, normal firing (SCC 1-02-005-04)	ND	ND	ND	ND	ND	ND	1.40	1.33	0.28

[a] Emission factors are from Section 1.3 of AP-42. ND = No Data

[b] Emission factors are in units of pounds pollutant per thousand gallons of fuel burned (lb/10^3 gal). For No. 6 fuel oil, particulate emissions are a function of fuel oil sulfur content where S is the weight % sulfur in the oil. For example, if the fuel oil contains 0.5% sulfur, then S = 0.5.

Table 9-22. HAP Emission Factors for Controlled Fuel Oil Combustion (lb/10^3 gal)[a,b]

Pollutant	Utility Boilers				Industrial Boilers
	No. 6 Fuel Oil – Normal Firing, Controlled with Flue Gas Recirculation	No. 6 Fuel Oil - Tangential Firing, Controlled with Flue Gas Recirculation	No. 5 Fuel Oil – Normal Firing, Controlled with Flue Gas Recirculation	No. 5 Fuel Oil - Normal Firing, Controlled with Multiple Cyclones	No. 6 Fuel Oil, Controlled with Low NO_X Burner and Flue Gas Recirculation
Cadmium	ND	ND	4.31×10^{-4}	ND	ND
Chromium	9.63×10^{-4}	ND	1.51×10^{-3}	1.51×10^{-3}	ND
Lead	ND	ND	ND	ND	ND
Manganese	3.84×10^{-3}	ND	8.08×10^{-3}	8.08×10^{-3}	ND
Nickel	4.52×10^{-2}	ND	3.3×10^{-2}	3.30×10^{-2}	ND
Ethylbenzene	ND	ND	ND	ND	1.4×10^{-3}
Formaldehyde	ND	ND	5.16×10^{-2}	5.17×10^{-2}	ND
Naphthalene	4.01×10^{-4}	ND	7.18×10^{-3}	7.18×10^{-3}	ND
Polycyclic Organic Matter (POM)	ND	8.69×10^{-4}	1.41×10^{-2}	1.41×10^{-2}	ND

[a] Emission factors obtained from the EPA's FIRE program. ND = No Data

[b] Emission factors are in units of pounds pollutant per thousand gallons of fuel burned. EPA emission factors listed in units of "lb/MMBtu" were converted into units of "lb/10^3 gal" by multiplying times the typical heating value of residual fuel (150 MMBtu/10^3 gal).

Table 9-23. NO_X and CO Emission Factors from Natural Gas Combustion[a]

Combustor Type	SCC[c]	Emission Factor ($lb/10^6 ft^3$)[b]	
		NO_X[d]	CO
Large Wall-Fired Boilers (> 100 MMBtu/hr)	1-01-006-01, 1-02-006-01, 1-03-006-01		
Uncontrolled (Pre-NSPS)[e]		280	84
Uncontrolled (Post-NSPS)[e]		190	84
Controlled – LNB[f]		140	84
Controlled – FGR[g]		100	84
Small Wall-Fired Boilers (< 100 MMBtu/hr)	1-01-006-02, 1-02-006-02, 1-03-006-02, 1-03-006-03		
Uncontrolled		100	84
Controlled – LNB[f]		50	84
Controlled – LNB/FGR[h]		32	84
Tangential-Fired Boilers (all sizes)	1-01-006-04		
Uncontrolled		170	24
Controlled – FGR[g]		76	98
Residential Furnaces (< 0.3 MMBtu/hr)	No SCC		
Uncontrolled		94	40

[a] Emission Factors are from Section 1.4 of AP-42. It's important to note that CO and NO_X emissions are very dependent on boiler operation. Therefore, whenever possible emission factors derived from actual source sampling should be used instead of the emission factors in this table.
[b] Emission Factors are in units of pounds pollutant emitted per million cubic feet of natural gas burned.
[c] SCC = Source Classification Code
[d] For large and small wall-fired boilers with selective noncatalytic reduction (SNCR) control, apply a 24 percent reduction to the applicable NO_X emission factor. For tangential-fired boilers with SNCR control, apply a 13 percent reduction to the applicable NO_X emission factor.
[e] NSPS = New Source Performance Standard as defined in 40 CFR 60 Subparts D and Db. Post-NSPS units are boilers with greater than 250 MMBtu/hr heat input that commenced construction modification, or reconstruction, after 17 August 1971; and units with heat input capacities between 100 and 250 MMBtu/hr that commenced construction modification, or reconstruction, after 19 June 1984.
[f] LNB = Low NO_X burner
[g] FGR = flue gas recirculation
[h] LNB/FGR = low NO_X burner with flue gas recirculation.

Table 9-24. SO_X, VOC, and Particulate Matter Emission Factors from Natural Gas Combustion[a]

Pollutant	Emission Factor ($lb/10^6 ft^3$)[b]
SO_X[c]	0.6
VOC	5.5
PM[d]	7.6

[a] Emission Factors are from Section 1.4 of AP-42. Data are for all natural gas combustion sources.
[b] Emission Factors are in units of pounds pollutant emitted per million cubic feet of natural gas burned.
[c] Based on 100% conversion of fuel sulfur to SO_2 and a fuel sulfur content of 2,000 grains/10^6 scf. If the site-specific sulfur content is known, the SO_X emission factor in this table may be adjusted by multiplying it times the ratio of the site-specific sulfur content (grains/10^6 scf) to 2,000 grains/10^6 scf.
[d] Combination of both filterable and condensable particulate matter. All particulate matter is assumed to be less than 1.0 micrometer in diameter (i.e., the emission factor applies to Total PM, PM_{10}, and $PM_{2.5}$).

Table 9-25. HAP Emission Factors from Natural Gas Combustion[a]

Pollutant	Emission Factor ($lb/10^6 ft^3$)[b]
Inorganic HAPs	
Arsenic	2.0×10^{-4}
Beryllium	1.2×10^{-5}
Cadmium	1.1×10^{-3}
Chromium	1.4×10^{-3}
Cobalt	8.4×10^{-5}
Lead	5.0×10^{-4}
Manganese	3.8×10^{-4}
Mercury	2.6×10^{-4}
Nickel	2.1×10^{-3}
Selenium	2.4×10^{-5}
Organic HAPs	
Benzene	2.1×10^{-3}
Formaldehyde	7.5×10^{-2}
Hexane	1.8
Naphthalene	6.1×10^{-4}
Polycyclic Organic Matter (POM)[c]	8.8×10^{-5}
Toluene	3.4×10^{-3}

[a] Emission Factors are from Section 1.4 of AP-42. Data are for all natural gas combustion sources.
[b] Emission Factors are in units of pounds pollutant emitted per million cubic feet of natural gas burned.
[c] Total of all individual POM pollutants.

Table 9-26. Criteria Pollutant Emission Factors for Uncontrolled Liquid Petroleum Gas (LPG) Combustion[a]

Pollutant	Butane Emission Factor ($lb/10^3$ gal)[b]		Propane Emission Factor ($lb/10^3$ gal)[b]	
	Industrial Boilers[c] (SCC 1-02-010-01)	Commercial Boilers[d] (SCC 1-03-010-01)	Industrial Boilers[c] (SCC 1-02-010-02)	Commercial Boilers[d] (SCC 1-03-010-02)
PM/PM_{10}[e]	0.6	0.5	0.6	0.4
SO_X[f]	0.09S	0.09S	0.10S	0.10S
NO_X	21	15	19	14
CO	3.6	2.1	3.2	1.9
VOC	0.26	0.50	0.25	0.47

[a] With the exception of VOC, all pollutant emission factors were obtained from Section 1.5 of AP-42. VOC emission factors were obtained from the EPA's FIRE program.
[b] Emission factors are in units of pounds pollutant per thousand gallons of fuel burned.
[c] Heat input capacities generally between 10 and 100 million Btu per hour (10 to 100 MMBtu/hr).
[d] Heat input capacities generally between 0.3 and 10 million Btu per hour (0.3 to < 10 MMBtu/hr).
[e] Based on filterable particulate matter. All PM is assumed to be less than 10 μm in size (i.e., $PM = PM_{10}$).
[f] S equals the sulfur content expressed in grains per hundred cubic feet of gas vapor (gr/100 ft^3). For example, if the butane sulfur content is 0.18 gr/100 ft^3, the emission factor would be (0.09 x 0.18) = 0.016 lb of $SO_X/10^3$ gal butane burned.

Table 9-27. Criteria Pollutant Emission Factors for Uncontrolled Waste Oil Combustion[a]

	Emission Factor ($lb/10^3$ gal)[b]		
Pollutant	**Small Boilers (SCC 1-03-013-02)**	**Space Heaters, Vaporizing Burner (SCC 1-05-001-14, 1-05-002-14)**	**Space Heaters, Atomizing Burner (SCC 1-05-001-13, 1-05-002-13)**
CO	5	1.7	2.1
NO_X	19	11	16
SO_X[c]	147S	100	107
PM[d]	64A	2.8A	66A
PM_{10}[d]	51A	ND	57A
VOC[e]	1.0	1.0	1.0

[a] Emission factors are from Section 1.11 of AP-42. ND = No Data
[b] Emission factors are in units of pounds pollutant per thousand gallons of fuel burned ($lb/10^3$ gal).
[c] S is the weight % sulfur content of the fuel. For example, if the fuel contains 0.5% sulfur, then S = 0.5. The emission factor is calculated by multiplying the weight percent sulfur in the fuel by the numerical value preceding S.
[d] A is the weight % ash content of the fuel. For example, if the fuel contains 0.1% ash, then A = 0.1. The emission factor is calculated by multiplying the weight percent ash in the fuel by the numerical value preceding A.
[e] VOC emission factor is based on the value for Total Organic Compounds (TOC).

Table 9-28. HAP Emission Factors for Uncontrolled Waste Oil Combustion[a]

	Emission Factor (lb/10^3 gal)[b]		
Pollutant	**Small Boilers (SCC 1-03-013-02)**	**Space Heaters, Vaporizing Burner (SCC 1-05-001-14, 1-05-002-14)**	**Space Heaters, Atomizing Burner (SCC 1-05-001-13, 1-05-002-13)**
Inorganic HAPs			
Antimony	BDL	3.4×10^{-4}	4.5×10^{-3}
Arsenic	0.11	2.5×10^{-3}	6.0×10^{-2}
Beryllium	BDL	BDL	1.8×10^{-3}
Cadmium	9.3×10^{-3}	1.5×10^{-4}	1.2×10^{-2}
Chromium	2.0×10^{-2}	0.19	0.18
Cobalt	2.1×10^{-4}	5.7×10^{-3}	5.2×10^{-3}
Hydrogen Chloride (HCl)	66Cl[c]	ND	ND
Lead[d]	55L	0.41L	50L
Manganese	6.8×10^{-2}	2.2×10^{-3}	5.0×10^{-2}
Nickel	1.1×10^{-2}	5.0×10^{-2}	0.16
Selenium	BDL	BDL	BDL
Phosphorous	ND	3.6×10^{-2}	ND
Organic HAPs			
Bis(2-ethylhexyl)phthalate	ND	2.2×10^{-3}	ND
Dibutylphthalate	ND	ND	3.4×10^{-5}
Dichlorobenzene	ND	8.0×10^{-7}	ND
Naphthalene	ND	1.3×10^{-2}	9.2×10^{-5}
Phenol	ND	2.4×10^{-3}	2.8×10^{-5}
Polycyclic Organic Matter[e]	ND	2.6×10^{-2}	1.1×10^{-4}

[a] Emission factors are from Section 1.11 of AP-42. ND = No Data. BDL = Below Detection Limit
[b] Emission factors are in units of pounds pollutant per thousand gallons of fuel burned (lb/10^3 gal).
[c] Cl = weight % chlorine in the fuel. The emission factor is calculated by multiplying the weight percent chlorine in the fuel by the numerical value preceding Cl.
[d] L = weight % lead in the fuel. The emission factor is calculated by multiplying the weight percent lead in the fuel by the numerical value preceding L.
[e] The emission factor for Polycyclic Organic Matter (POM) was derived by adding together the emission factors for the following pollutants: phenanthrene/anthracene, pyrene, benz(a)anthracene/chrysene, and benzo(a)pyrene.

9.5 References

1. U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources* (AP-42), Sections 1.1 and 1.3, September 1998.

2. U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources* (AP-42), Section 1.4, March 1998.

3. U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources* (AP-42), Sections 1.2, 1.5, and 1.11, October 1996.

4. U.S. Environmental Protection Agency, *Factor Information Retrieval System* (FIRE), Version 6.01, May 1998.

5. Emissions Inventory Improvement Program (EIIP), *Volume II: Chapter 2, "Preferred and Alternative Methods for Estimating Air Emissions from Boiler,"* June 1996.

SECTION 10

FIRE FIGHTER TRAINING

10.1 Background: Training of Air Force (and other military) fire fighters involves the use of live fires. Most training (including all initial training) of Air Force fire fighters is accomplished at the Air Force fire fighter training school located at Goodfellow AFB TX. However, a few other Air Force installations have smaller scale fire fighter training facilities which are used for periodic refresher training. The training performed at Goodfellow and the other Air Force installations is performed in live fire training pits which usually include a mock-up metal structure, such as an aircraft, vehicle, or building. The purpose of these structures is to create a more realistic fire scenario. The primary fuel currently used for fire fighter training is liquid propane. However, JP-8 fuel is used (along with liquid propane) in some aircraft and vehicle fire scenarios, while vegetable oil is used in some building fire scenarios.

The emissions of concern from fire fighter training include both criteria pollutants and HAPs resulting from the open combustion of the fuels mentioned above.

10.2 Emission Calculations: Emissions from fire fighter training operations using propane and/or JP-8 fuel can be calculated using emission factors derived from the study performed at Goodfellow AFB. The emissions are calculated by simply multiplying the quantity of fuel burned by the appropriate emission factor.

$$E_{pol} = QF * EF$$

Where,

E_{pol} = Emissions of a particular pollutant (lb/yr)
QF = Quantity of fuel burned (gal/yr)
EF = Emission factor (lb/gal)

The emission factors associated with fire fighter training fires using liquid propane and JP-8 fuels are provided in Tables 10-1 and 10-2 respectively. Unfortunately, no emission factors for vegetable oil fires could be found.

Table 10-1. Emission Factors for Fire Fighter Training using Liquid Propane Fuel[a]

Pollutant	Emission Factor (lb/gal)[b]
Criteria Pollutants	
CO	0.0154
NO_X	0.0557
PM[c]	0.0095
VOC[d]	0.0240
Hazardous Air Pollutants[e]	
Formaldehyde	0.0007

[a] Emission factors are based on sampling performed at Goodfellow AFB.
[b] Emission factors are in units of pounds pollutant per gallon of fuel burned.
[c] Based on sampling results for total particulate matter.
[d] Based on sampling results for Total Hydrocarbons (THC), as methane.
[e] The only HAP sampled for was formaldehyde.

Table 10-2. Emission Factors for Fire Fighter Training using JP-8 Fuel[a]

Pollutant	Emission Factor (lb/gal)[b]
Criteria Pollutants	
CO	0.2961
NO_X	0.0100
PM[c]	0.1939
VOC[d]	0.5845
Hazardous Air Pollutants[e]	
Formaldehyde	0.0070

[a] Emission factors are based on sampling performed at Goodfellow AFB.
[b] Emission factors are in units of pounds pollutant per gallon of fuel burned.
[c] Based on sampling results for total particulate matter.
[d] Based on sampling results for Total Hydrocarbons (THC), as methane.
[e] The only HAP sampled for was formaldehyde.

10.3 Information Resources: The quantity of each fuel type burned during fire fighter training operations can be obtained from the base fire department. For Goodfellow AFB, this information can be obtained from the training school.

10.4 Example Problem: A base has two live fire training pits which are used for periodic refresher training of fire department personnel. According to fire department officials, the base used approximately 24,000 gallons of liquid propane and approximately 800 gallons of JP-8 during the year at the two training pits. Calculate the emission of both criteria pollutants and HAPs.

a. First calculate the emissions associated with the propane fires:

$$E_{pol} = QF * EF$$

Pollutant	Quantity of Fuel Burned (gal/yr)		Emission Factor (lb/gal)		Emissions (lb/yr)
CO	24,000	x	0.0154	=	370
NO_X	24,000	x	0.0557	=	1,337
PM	24,000	x	0.0095	=	228
VOC	24,000	x	0.0240	=	576
Formaldehyde	24,000	x	0.0007	=	17

b. The next step is to calculate the emissions associated with the JP-8 fires:

Epol = QF * EF

Pollutant	Quantity of Fuel Burned (gal/yr)		Emission Factor (lb/gal)		Emissions (lb/yr)
CO	800	x	0.2961	=	237
NO_X	800	x	0.0100	=	8
PM	800	x	0.1939	=	155
VOC	800	x	0.5845	=	468
Formaldehyde	800	x	0.0070	=	6

c. The final step is to add the propane and JP-8 emissions together to obtain the total fire fighter training emissions:

Pollutant	Propane Fire Emissions (lb/yr)		JP-8 Fire Emissions (lb/yr)		Total Emissions (lb/yr)
CO	370	+	237	=	**607**
NO_X	1,337	+	8	=	**1,345**
PM	228	+	155	=	**383**
VOC	576	+	468	=	**1,044**
Formaldehyde	17	+	6	=	**23**

10.5 References

1. Environmental Quality Management, *Emissions Testing of Fire Fighter Training Facility - Goodfellow AFB TX*, January 1998.

SECTION 11

FUEL CELL MAINTENANCE
(Revised December 2003)

11.1 Background: Air Force personnel occasionally enter aircraft fuel cells (tanks) to perform necessary maintenance and repairs as well as routine inspections. Although the procedures for performing fuel cell maintenance vary depending on the aircraft type, typical procedures include the following: 1) the fuel cell is defueled and the fuel loaded into bowsers and/or approved containers; 2) the fuel cell is purged with either fresh air or an approved fluid (note - fluid purging is usually only performed at Depots); 3) oxygen and lower explosive limit (LEL) readings are taken and purging is re-accomplished if oxygen/LEL levels are not within acceptable limits; 4) the explosion suppression foam (if applicable) is removed from the fuel cell; 5) the fuel cell is depuddled to remove any remaining liquid fuel; 6) the fuel cell is purged again with fresh air; 7) the fuel cell is entered and maintenance performed. (Note - mechanical ventilation is performed constantly during all fuel cell entries)

The emissions of concern from fuel cell maintenance include VOCs and organic HAPs. Based on the procedures listed above, there are three potential emission sources associated with fuel cell maintenance. These include loading of the liquid fuel into bowsers, air purging of the fuel vapors from the tank, and removal/drying of the explosion suppression foam (if applicable). Emissions associated with loading fuel into bowsers are covered under the "Fuel Transfer" section of this report and therefore are not addressed in this section. As for fuel cell air purging, the vapors which are removed from the cell are typically exhausted directly to the atmosphere. Depending on the type of aircraft, some fuel cells contain explosion suppression foam while others do not. If foam is present in a fuel cell, it is typically removed prior to maintenance. The foam removed from a fuel cell may or may not be an emission source, depending on how it is handled. In most cases the foam blocks are placed into closed containers, in which case they are not an emissions source. However, there may be some situations in which the saturated foam blocks are air dried, in which case they are an emissions source. Depending on their condition, the foam blocks are either reused in the aircraft fuel cell or they are disposed of. According to section 2-9.7 of Technical Order 1-1-3, "Inspection and Repair of Aircraft Integral Tanks and Fuel Cells," foam which is to be reused shall be placed in clean electro-static free plastic bags or canvas bags, or placed on a clean electro-static free plastic or canvas ground cloth and covered with clean electro-static free plastic or canvas. T.O. 1-1-3 also states that foam which is not to be reused shall be stored and disposed of in accordance with applicable environmental regulations. Based on this, the only possible situations in which air emissions from the explosion suppression foam may need to be addressed are those in which the foam is not being reused. Applicable environmental regulations allow the foam to be air dried.

11.2 Emission Calculations:

a. <u>VOC Emissions</u>

The VOC emissions associated with fuel cell purging can be conservatively estimated by assuming that two completely saturated volumes of fuel cell air are purged from the fuel cell prior to performing maintenance. In general, the emissions from purging a fuel cell are calculated by multiplying the saturation vapor density of JP-8 times twice the volume capacity of the fuel cell. The following equation should be used to calculate the annual emissions associated with maintenance of all fuel cells of a particular size:

$$E_{VOC(purge)} = W_V * V * 0.134 * 2 * NFC$$

Where,

$E_{VOC(purge)}$ = Annual VOC emissions associated with the purging of a specific size fuel cell (lb/yr)

W_V = $M_V P_{VA} / RT_{LA}$

M_V is the vapor molecular weight, P_{VA} is the vapor pressure at the daily average liquid surface temperature in psia, R is the ideal gas constant (10.731 psia*ft3/lb-mole*R), and T_{LA} is the daily average liquid surface temperature °R (°F+460). Vapor molecular weights and vapor pressures can be found in Section 14, Table 14-2 and 14-3.

V = Volume capacity of the fuel cell (gallons/cell)

0.134 = Conversion factor (ft^3/gal)

2 = Number of saturated volumes of fuel cell air which are assumed to be purged prior to maintenance

NFC = Number of fuel cells with a volume equal to V which were entered for maintenance during the year (cells/yr)

VOC emissions associated with the air drying of the fire-suppressant foam are calculated using a mass balance approach. This is done by weighing a typical foam block when it is saturated with JP-8 fuel and then weighing the same foam block again after it is air dried. The difference in the weight is the amount of JP-8 which evaporated, which in turn is equal to the VOC emissions.

$$E_{VOC(foam)} = [WFB_{(sat)} - WFB_{(dried)}] * NFB$$

Where,

$E_{VOC(foam)}$ = Annual VOC emissions associated with air drying fuel cell foam blocks (lb/yr)

$WFB_{(sat)}$ = Weight of a typical foam block when saturated with liquid JP-8 (lb/block)

$WFB_{(dried)}$ = Weight of a typical foam block after it is air dried (lb/block) [note - the foam is usually not completely dried]

NFB = Number of foam blocks which are air dried during the year (blocks/yr)

b. <u>HAP Emissions</u>

HAP emissions associated with evaporative losses from fuel cell purging are calculated the same way as HAP emissions from fuel storage tanks. In summary, HAP emissions are calculated by multiplying the corresponding VOC emissions by the <u>vapor-phase</u> weight fraction (weight percent divided by 100) of each HAP in the fuel:

$$E_{HAP} = E_{VOC} * (VWP_{HAP}/100)$$

Where,

E_{HAP} = Emissions of a specific HAP (lb/yr)

E_{VOC} = VOC emissions (lb/yr)

VWP_{HAP} = Weight percent of the HAP in the fuel vapor (%)

This same equation/procedure is also used to calculate the HAP emissions associated with the air drying of the fire-suppressant foam (note - the vapor-phase speciation is used because the foam is usually not completely dried).

Both vapor-phase and liquid-phase HAP speciations of JP-8 can be found in the "Fuel Storage" section of this report.

11.3 Information Resources: The fuels maintenance shop should be able to provide all information needed to calculate emissions from fuel cell maintenance operations. In some cases it may be necessary to contact the aircraft manufacturer to obtain the fuel volume capacity.

11.4 Example Problem: The base fuels maintenance shop performs maintenance on C-17 aircraft fuel cells. The C-17 is equipped with two outboard fuel tanks and two inboard fuel tanks. According to the fuels maintenance shop, 43 outboard fuel cells and 49 inboard fuel cells were entered during the year for routine maintenance and repairs. Each fuel cell was purged twice prior to entry (once after defueling and once after depuddling). All explosion suppression foam removed from the fuel tanks is placed into closed containers (none are air dried). According to the aircraft manufacturer (Boeing), the fuel capacities for the outboard and the inboard tanks are 5,637 gallons and 7,857 gallons, respectively. JP-8 temperature was 70 °F.with a flash point of 110 °F. Calculate the annual VOC and organic HAP emissions associated with purging of the C-17 fuel cells prior to maintenance.

a. First calculate the VOC emissions from the outboard fuel cells:

$E_{VOC(purge)} = W_V * V * 0.134 * 2 * NFC$
$E_{VOC(purge)} = 0.0011\ lb/ft^3 * 5{,}637\ gal/cell * 0.134\ ft^3/gal * 2 * 43\ cells/yr = \underline{71.45\ lb/yr}$

b. Second, calculate the VOC emissions from the inboard fuel cells:

$E_{VOC(purge)} = W_V * V * 0.134 * 2 * NFC$
$E_{VOC(purge)} = 0.0011\ lb/ft^3 * 7{,}857\ gal/cell * 0.134\ ft^3/gal * 2 * 49\ cells/yr = \underline{113.5\ lb/yr}$

c. Next, add the VOC emissions associated with both the outboard and inboard fuel cells to obtain the total VOC emissions associated with the purging of the C-17 fuel cells.

Total $E_{VOC(purge)}$ = 71.45 lb/yr + 113.5 lb/yr = **184.95 lb/yr**

d. Finally, calculate the organic HAP emissions using the vapor-phase speciation found in the "Fuel Storage" section of this document.

$E_{HAP} = E_{VOC} * (VWP_{HAP} / 100)$
$E_{benzene}$ = 184.95 lb/yr * (0.20% / 100) = **0.37 lb/yr**
E_{cumene} = 184.95 lb/yr * (0.29% / 100) = **0.54 lb/yr**
$E_{ethylbenzene}$ = 184.95lb/yr * (0.86% / 100) = **1.59 lb/yr**
$E_{naphthalene}$ = 184.95 lb/yr * (0.38% / 100) = **0.7 lb/yr**
$E_{toluene}$ = 184.95 lb/yr * (1.65% / 100) = **3.05 lb/yr**
$E_{2,2,4\text{-trimethylpentane}}$ = 184.95 lb/yr * (0.02% / 100) = **0.04 lb/yr**
$E_{xylenes\ (mixed\ isomers)}$ = 184.95 lb/yr * (4.74% / 100) = **8.77 lb/yr**

11.5 References

1. U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors Volume I: Stationary Point and Area Sources* (AP-42), Chapter 7, February 1996.

2. Parsons Engineering Science, *VOC and Hazardous Air Pollutant Emission Factors for Military Aircraft Fuel Cell Inspection, Maintenance, and Repair Operations*, Paper presented at the 90th annual Air & Waste Management Association Meeting, June 1997.

3. U.S. Air Force, *Inspection and Repair of Aircraft Integral Tanks and Fuel Cells*, Technical Order 1-1-3, 30 November 1994 (Change 6 - 23 January 1998).

4. American Petroleum Institute, *Manual of Petroleum Measurements Standards: Chapter 19.4 - Recommended Practice for Speciation of Evaporative Losses*, First Edition, November 1997.

5. U.S. Air Force Armstrong Laboratory, Environmental Research Division (AL/EQL), *JP-8 Composition and Variability*, Report # AL/EQ-TR-1996-0006, May 1996.

SECTION 12

FUEL SPILLS
(Revised December 2003)

12.1 Background: The accidental spillage of fuel occasionally occurs at Air Force installations, usually during transfer operations. Most fuel spills occur on the flightline during the transfer of jet fuel. When spills occur, most of the fuel is recovered (picked-up) by base personnel. The quantity which is not recovered is assumed to evaporate into the atmosphere. The emissions of concern from fuel spills include VOC and organic HAPs.

12.2 Emission Calculations:

a. VOC Emissions

VOC Emissions from fuel spills are calculated using a simple material balance approach. Basically, the difference between the total quantity of fuel spilled minus the quantity of fuel recovered is assumed to equal the VOC emissions.

$$E_{VOC} = (QS - QR) * D$$

Where,

E_{VOC} = Emissions of VOC (lb/yr)
QS = Quantity of fuel spilled (gal/yr)
QR = Quantity of fuel recovered (gal/yr)
D = Density of the fuel (lb/gal) [note - typical fuel densities are 6.8 for JP-8, 7.1 for diesel, and 6.0 for gasoline]

b. HAP Emissions

Since all the fuel which is not recovered is assumed to evaporate, organic HAP emissions can be calculated based on the liquid-phase speciation of the fuel. This is accomplished by multiplying the total VOC emissions by the weight fraction (weight percent divided by 100) of each HAP in the liquid fuel.

$$E_{HAP} = E_{VOC} * (LWP_{HAP} / 100)$$

Where,

E_{HAP} = Emissions of a specific HAP (lb/yr)
E_{VOC} = VOC emissions (lb/yr)
LWP_{HAP} = Weight percent of the HAP in the liquid fuel (%)
100 = Factor for converting weight percent into weight fraction

Liquid-phase HAP speciations of JP-8 and diesel are found in the “Fuel Storage” section of this report while a vapor-phase speciation of gasoline is provided in the “Gasoline Service Stations” section of this report.

12.3 Information Resources: Information pertaining to fuel spills (e.g., type and quantity of fuel spilled, quantity of fuel recovered, etc.) are usually kept by the base Environmental Management (or Civil Engineering environmental) office. Other organizations which may have historical information on fuel spills include the Fire Department, Fuels Management, and the base Hazardous Materials (HAZMAT) Response Team.

12.4 Example Problem: Records maintained by the base Environmental Management office show there were five significant (defined by the base as being over 10 gallon) JP-8 fuel spills during the year. According to the records, an estimated total of 625 gallons of JP-8 were spilled during the year while an estimated 450 gallons were recovered. Calculate the VOC and the organic HAP emissions.

a. The first step is to calculate the VOC emissions

E_{VOC} = (QS - QR) * D
E_{VOC} = (625 gal/yr - 450 gal/yr) * 6.8 lb/gal = **1,190 lb/yr**

b. The next step is to calculate the organic HAP emissions using the liquid-phase speciation found in the "Fuel Storage" section of this document.

E_{HAP} = E_{VOC} * (LWP_{HAP} / 100)
$E_{benzene}$ = 1,190 lb/yr * (0.033% / 100) = **0.4 lb/yr**
E_{cumene} = 1,190 lb/yr * (0.179% / 100) = **2.1 lb/yr**
$E_{ethylbenzene}$ = 1,190 lb/yr * (0.157% / 100) = **1.9 lb/yr**
$E_{naphthalene}$ = 1,190 lb/yr * (0.264% / 100) = **3.1 lb/yr**
$E_{toluene}$ = 1,190 lb/yr * (0.216% / 100) = **2.6 lb/yr**
$E_{2,2,4\text{-trimethylpentane}}$ = 1,190 lb/yr * (0.001% / 100) = **0.01 lb/yr**
$E_{xylenes\ (mixed\ isomers)}$ = 1,190 lb/yr * (1.173% / 100) = **14 lb/yr**

12.5 References

1. American Petroleum Institute, *Manual of Petroleum Measurements Standards: Chapter 19.4 - Recommended Practice for Speciation of Evaporative Losses*, First Edition, November 1997.

2. U.S. Air Force Armstrong Laboratory, Environmental Research Division (AL/EQL), *JP-8 Composition and Variability*, Report # AL/EQ-TR-1996-0006, May 1996.

SECTION 13

FUEL STORAGE
(Revised December 2003)

13.1 Background: Air Force installations typically employ numerous tanks for the storage of various types of fuel. These fuel storage tanks may range in size from a few hundred gallons to over a million gallons. The three common types of liquid fuels stored on Air Force installations include JP-8 (jet fuel), gasoline (mogas), and diesel (distillate oil # 2). Each of these fuels is composed of a mixture of numerous hydrocarbon compounds, some of which are on the list of HAPs. Therefore, emissions of concern from fuel storage tanks include VOCs and organic HAPs. There are three major types of storage tanks, including fixed roof tanks, external floating roof tanks, and internal floating roof tanks. The following is a summary of each tank type:

a. Fixed Roof Tanks: This type of tank consists of a cylindrical steel shell with a permanently affixed roof, which may vary in design from cone- or dome-shaped to flat. Emissions from fixed roof tanks are caused by changes in temperature, pressure, and liquid level. The amount of emissions varies as a function of vessel capacity, vapor pressure of the stored liquid, utilization rate of the tank, and atmospheric conditions at the tank location. In general, there are two types of emissions from fixed roof tanks, "storage losses" and "working losses." Storage loss from a fixed roof tank is in the form of "breathing loss" which is the expulsion of vapor from a tank as a result of vapor expansion and contraction caused by changes in temperature and barometric pressure. This occurs without any liquid level change in the tank. Working loss is the combined loss from filling and emptying the tank. Evaporation during filling operations is a result of an increase in the liquid level in the tank. As the liquid level increases, the pressure inside the tank exceeds the relief pressure and vapors are expelled from the tank. Evaporative loss during emptying occurs when air drawn into the tank during liquid removal becomes saturated with organic vapor and expands, thus exceeding the capacity of the vapor space.

Fixed roof tanks may be either vertical or horizontal. Horizontal fixed roof tanks are constructed for both above-ground and underground service and are designed such that the length of the tank is not greater than six times the diameter to ensure structural integrity. Emissions from underground storage tanks are associated mainly with changes in the liquid level in the tank. Losses due to changes in temperature or barometric pressure are minimal for underground tanks because the surrounding earth limits the diurnal temperature change, and changes in the barometric pressure result in only small evaporative emission losses.

Fixed roof tanks are either freely vented or equipped with a pressure/vacuum vent. The latter allows the tanks to operate at a slight internal pressure or vacuum to prevent the release of vapors during very small changes in temperature, pressure, or liquid level. Of current tank designs, the fixed roof tank design is the least expensive to construct but is also the least efficient regarding emissions.

b. External Floating Roof Tanks: A typical external floating roof tank consists of an open-topped cylindrical steel shell equipped with a roof that floats on the surface of the stored liquid. The floating roof consists of a deck, fittings, and rim seal system. Floating decks currently in use are constructed of welded steel plate and are of two general types: pontoon or double-deck. With all types of external floating roof tanks, the roof rises and falls with the liquid level in the tank. External floating decks are equipped with a rim seal system, which is attached to the deck perimeter and contacts the tank wall. The purpose of the floating roof and rim seal system is to reduce evaporative loss of the stored liquid. Some annular space remains between the seal system and the tank wall. The seal system slides against the tank

wall as the roof is raised and lowered. The floating deck is also equipped with fittings that penetrate the deck and serve operational functions.

There are two types of emissions associated with external floating roof tanks, "withdrawal losses" and "standing storage losses." Withdrawal losses occur as the liquid level, and thus the floating roof, is lowered. When this occurs, some liquid remains on the inner tank wall surface and evaporates. Standing storage losses from external floating roof tanks primarily include rim seal and deck fitting losses, although some breathing losses may also occur as a result of temperature and pressure changes. For external floating roof tanks, the majority of rim seal vapor losses have been found to be wind induced. These wind-induced emissions usually come from the annular space between the seal system and the tank wall. Rim seal losses can also occur due to permeation of the rim seal material by the vapor or via a wicking effect of the liquid. Testing has indicated that breathing, permeation, and wicking loss mechanisms are small in comparison to the wind-induced loss. The deck fitting losses from floating roof tanks can be explained by the same mechanisms as the rim seal losses. However, the relative contribution of each mechanism is not known. Numerous fittings pass through or are attached to floating roof decks to accommodate structural support components or allow for operational functions. Deck fittings can be a source of evaporative loss when they require openings in the deck. Some common components that require openings in the deck include access hatches, gauge-floats, gauge-hatch/sample ports, rim vents, deck drains, deck legs, guidepoles and wells, vacuum breakers, etc.

c. Internal Floating Roof Tanks: An internal floating roof tank has both a permanent fixed roof and a floating roof inside. There are two basic types of internal floating roof tanks: tanks in which the fixed roof is supported by vertical columns within the tank, and tanks with a self-supporting fixed roof and no internal support columns. Internal floating roof tanks are the most efficient of the three designs discussed here. The emissions from internal floating roof tanks are similar to the emissions from external floating roof tanks with the following exceptions:

(1) In addition to rim seal and deck fitting losses, standing storage losses associated with internal floating roof tanks may also include deck seam losses (for those tanks which do not have welded decks).

(2) Unlike external floating roof tanks, wind is not a predominant factor affecting rim seal losses from internal floating roof tanks

(3) For internal floating roof tanks that have a column supported fixed roof, some of the withdrawal loss includes liquid clinging to the columns and evaporating.

13.2 Emission Calculations:

a. VOC Emissions

The methodologies and step-by-step procedures used to calculate VOC emissions from storage tanks can be found in section 7.1.3 of AP-42. Since these manual procedures involve a comprehensive set of equations and data, it is highly recommended that the EPA's TANKS program be used to calculate the VOC emissions from liquid storage tanks. The latest version of this program is Version 3.1, referred to hereafter as TANKS3.1. Due to the comprehensive nature of the manual methods and the availability of the EPA's TANKS program, the manual calculation procedures are not addressed in this document.

The EPA's TANKS3.1 program may be obtained by either downloading from the internet (http://www.epa.gov/ttn/chief/tanks.html) or by contacting the EPA's "Info CHIEF" hotline at (919) 541-

5285. The TANKS3.1 program enables the user to calculate emissions from the following four tank types: vertical fixed roof, horizontal fixed roof (including USTs), external floating roof, and internal floating roof. Although the TANKS program is relatively easy to use, a significant amount of input data is still needed. Table 13-1 below lists the data elements required to calculate storage tank VOC emissions using the EPA's TANKS program.

Table 13-1. Data Elements Required by the EPA's TANKS Program

Tank Type	Data Elements
Vertical Fixed Roof Tanks	Data elements are based on EPA's TANKS program. The following information is required for each tank: 1. Shell Height (ft) 2. Diameter (ft) 3. Maximum Liquid Height (ft) 4. Average Liquid Height (ft) 5. Working Volume (gal) 6. Turnovers per Year (i.e., annual fuel throughput divided by tank volume) 7. Is Tank Heated (yes or no) 8. If tank is heated, then the following additional information will be required: • Average Liquid Surface Temperature (° F) • Minimum Liquid Surface Temperature (° F) • Maximum Liquid Surface Temperature (° F) 9. Shell Color/Shade (choose one of the following: white/white, aluminum/specular, aluminum/diffuse, gray/light, gray/medium, or red/primer) 10. Shell Condition (good or poor) 11. Roof Color/Shade (same options as for shell color/shade) 12. Roof Condition (good or poor) 13. Roof Type (cone or dome) 14. Roof Height (ft) 15. Roof Radius (ft) [for dome roof only] 16. Roof Slope (ft/ft) [for cone roof only] 17. Breather Vent Vacuum Setting (TANKS default is -0.03 psig) 18. Breather Vent Pressure Setting (TANKS default is 0.03 psig) 19. Nearest Major City (choose from list in TANKS Program)[a] 20. Chemical Category of Liquid Stored in Tank (choose one of the following: organic liquid, petroleum distillates, or crude oil) 21. Is Liquid a Single or Multi-Component Liquid (note – fuels are considered "Single" component liquids) 22. Name of Liquid or Liquid Components (note - TANKS contains listings of various chemicals and fuels to choose from. For JP-8, the "Jet Kerosene" option is typically used) 23. Weight Percent of Components (for multi-component liquids)

Table 13-1. Data Elements Required by the EPA's TANKS Program (Cont'd)

Tank Type	Data Elements
Horizontal Fixed Roof Tanks (Including USTs) **Note**: Gasoline USTs are covered under the "Gasoline Service Stations" section of this report.	Data elements are based on EPA's TANKS program. The following information is required for each tank: 1. Shell Length (ft) 2. Diameter (ft) 3. Working Volume (gal) 4. Turnovers per Year (i.e., annual fuel throughput divided by tank volume) 5. Is Tank Underground (yes or no) 6. Is Tank Heated (yes or no) 7. If tank is heated, then the following additional information will be required: • Average Liquid Surface Temperature (° F) 8. Shell Color/Shade (choose one of the following: white/white, aluminum/specular, aluminum/diffuse, gray/light, gray/medium, or red/primer) 9. Shell Condition (good or poor) 10. Breather Vent Vacuum Setting (TANKS default is -0.03 psig) 11. Breather Vent Pressure Setting (TANKS default is 0.03 psig) 12. Nearest Major City (choose from list in TANKS Program)[a] 13. Chemical Category of Liquid Stored in Tank (choose one of the following: organic liquid, petroleum distillates, or crude oil) 14. Is Liquid a Single or Multi-Component Liquid (note – fuels are considered "Single" component liquids) 15. Name of Liquid or Liquid Components (note - TANKS contains listings of various chemicals and fuels to choose from. For JP-8, the "Jet Kerosene" option is typically used) 16. Weight Percent of Components (for multi-component liquids)

Table 13-1. Data Elements Required by the EPA's TANKS Program (Cont'd)

Tank Type	Data Elements
External Floating Roof	Data elements are based on EPA's TANKS program. The following information is required for each tank: 1. Tank Diameter (ft) 2. Tank Volume (gal) 3. Turnovers per Year (i.e., annual fuel throughput divided by tank volume) 4. Shell Condition (choose one of the following: light rust, dense rust, or gunite lining) 5. Paint Color/Shade (choose one of the following: white/white, aluminum/specular, aluminum/diffuse, gray/light, gray/medium, or red/primer) 6. Paint Condition (good or poor) 7. Roof Type (pontoon or double deck) 8. Roof Fitting Category (typical or detail) 9. Tank Construction (welded or riveted) 10. Primary Rim-seal (liquid-mounted, mechanical shoe, or vapor mounted) 11. Secondary Seal (none, rim-mounted, or shoe-mounted) 12. Nearest Major City (choose from list in TANKS Program)[a] 13. Chemical Category of Liquid Stored in Tank (choose one of the following: organic liquid, petroleum distillates, or crude oil) 14. Is Liquid a Single or Multi-Component Liquid (note – fuels are considered "Single" component liquids) 15. Name of Liquid or Liquid Components (note - TANKS contains listings of various chemicals and fuels to choose from. For JP-8, the "Jet Kerosene" option is typically used) 16. Weight Percent of Components (for multi-component liquids)

Table 13-1. Data Elements Required by the EPA's TANKS Program (Cont'd)

Tank Type	Data Elements
Internal Floating Roof	Data elements are based on EPA's TANKS program. The following information is required for each tank: 1. Tank Diameter (ft) 2. Tank Volume (gal) 3. Turnovers per Year (i.e., annual fuel throughput divided by tank volume) 4. Self-Supporting Roof (yes or no) 5. Number of Columns 6. Effective Column Diameter (ft) 7. Shell Condition (light rust, dense rust, or gunite lining) 8. Shell Color/Shade (choose one of the following: white/white, aluminum/specular, aluminum/diffuse, gray/light, gray/medium, or red/primer) 9. Shell Paint Condition (good or poor) 10. Roof Color/Shade (same options as for shell color/shade) 11. Roof Paint Condition (good or poor) 12. Primary Rim-seal (liquid-mounted, mechanical shoe, or vapor mounted) 13. Secondary Seal (none or rim-mounted) 14. Deck Type (bolted or welded) 15. Deck Fitting Category (typical or detail) 16. Deck Construction (for bolted decks only) [choose one of the following: 5 ft wide continuous sheet, 6 ft wide continuous sheet, 7 ft wide continuous sheet, 5 x 7.5 rectangular panel, or 5 x 12 ft rectangular panel) 17. Nearest Major City (choose from list in TANKS Program)[a] 18. Chemical Category of Liquid Stored in Tank (choose one of the following: organic liquid, petroleum distillates, or crude oil) 19. Is Liquid a Single or Multi-Component Liquid (note – fuels are considered "Single" component liquids) 20. Name of Liquid or Liquid Components (note – TANKS contains listings of various chemicals and fuels to choose from. For JP-8, the "Jet Kerosene" option is typically used) 21. Weight Percent of Components (for multi-component liquids)

[a] The EPA's TANKS program contains meteorological data for numerous cities in the United States. However, it does not contain meteorological data for any cities outside the United States. Therefore, for installations not located in the United States, local meteorological data (if available) should be inputted into the TANKS program before it is used. This is done by going to the TANKS program's main menu, clicking on "Database Utilities," then clicking on "Meteorological Database," and finally clicking on "Add Meteorological Data." The following local meteorological information must then be entered: daily ambient average temperature for the site, average atmospheric pressure, daily minimum and maximum ambient temperatures for each month of the year, daily minimum and maximum ambient temperatures during an average year, solar insolation factor (Btu/ft^2•day) for each month of the year, solar insolation factor during an average year, average wind speed for each month of the year, and the average annual wind speed. If the above information is not available, then a U.S. city with similar meteorological conditions may be selected instead.

b. <u>HAP Emissions</u>

Liquid fuels such as jet fuel (JP-8), diesel, and gasoline are a mixture of various hydrocarbon compounds, some of which are on the list of HAPs. Therefore, as fuel vapors are emitted into the atmosphere, these HAP component compounds are also emitted. Since the individual compounds which make up liquid fuel have different vapor pressures, the evaporative emissions coming from a tank will be composed mainly of the those compounds with the highest vapor pressure. For this reason, the concentration of individual compounds in the fuel vapor will be different than the concentrations of these compounds in the liquid fuel. Therefore, the HAP emissions associated with fuel evaporative losses from storage tanks are calculated by multiplying the corresponding VOC emissions by the vapor-phase weight fraction (weight percent divided by 100) of each HAP in the fuel:

$$E_{HAP} = E_{VOC} * (VWP_{HAP}/100)$$

Where,

E_{HAP} = Emissions of a specific HAP (lb/yr)
E_{VOC} = VOC emissions (lb/yr)
VWP_{HAP} = Weight percent of the HAP in the fuel vapor (%)

Tables 13-2 and 13-3 below provide a typical vapor-phase HAP speciation of JP-8 and diesel fuel respectively. A vapor-phase speciation of gasoline is provided in Table 15-2 which is found in the "Gasoline Service Stations" section of this report.

Table 13-2. Liquid-phase and Vapor-phase Speciation of JP-8

HAP Component	Weight Percent in Liquid-Phase[a]	Weight Percent in Vapor-Phase[b]
Benzene	0.033	0.613
Cumene	0.179	0.330
Ethylbenzene	0.157	0.271
Naphthalene	0.264	0.003
Toluene	0.216	1.143
2,2,4-Trimethylpentane	0.001	0.010
Xylenes (mixed isomers)	1.173	1.877

[a] The liquid-phase speciation is based on average values listed in the Air Force AL/EQ report entitled "JP-8 Composition and Variability." A typical JP-8 density of 0.81 Kg/L (6.8 lb/gal) was used to convert the average "mg/L" values found in the AL/EQ report into units of mg/Kg (ppm).
[b] The vapor-phase speciation was calculated using the liquid-phase speciation values and the procedures found in Section 7.1.4 of AP-42. Specific data (e.g., molecular weights, vapor pressures, etc.) used in the calculations can be found in Appendix E.

Table 13-3. Liquid-phase and Vapor-phase Speciation of Diesel Fuel

HAP Component	Weight Percent in Liquid-Phase[a]	Weight Percent in Vapor-Phase[b]
Benzene	0.2	7.2
Cumene	0.1	0.4
Ethylbenzene	0.2	0.7
Hexane (*n*-hexane)	0.04	2.3
Naphthalene	0.2	Negligible
Toluene	0.4	4.1
Xylenes (mixed isomers)	0.8	2.5

[a] With the exception of naphthalene, the liquid-phase speciation is based on "typical" values obtained from Table 3 of API's Manual of Petroleum Measurement Standards, Chapter 19.4. The naphthalene liquid-phase percentage was obtained by averaging the sample results found in the draft version of EPA's report entitled "Technical Support Document for Development of a Comparable Fuel Exemption"

[b] The vapor-phase speciation was calculated using the liquid-phase speciation values and the procedures found in Section 7.1.4 of AP-42. Specific data (e.g., molecular weights, vapor pressures, etc.) used in the calculations can be found in Appendix E.

13.3 Information Resources: Base Supply Fuels Management should be contacted for a listing of storage tanks located on base, for information concerning the fuels stored in each tank (e.g., fuel type, annual throughput, etc.) and for the physical information required on each tank (e.g., tank type, volume, dimensions, color/shade, condition, etc.). The Civil Engineering Liquid Fuels shop should be contacted for physical tank information not available from Fuels Management.

13.4 Example Problem:

a. <u>VOC Emissions</u>

The EPA's TANKS3.1 program includes an example for each of the four types of storage tanks addressed by the program.

b. <u>HAP Emissions</u>

A base has eight above ground tanks and six underground tanks used for the storage of JP-8 jet fuel. After running the EPA's TANKS3.1 program for each of the 14 tanks, the total VOC emissions from all 14 tanks combined was determined to be 1,475 lb/yr. Calculate the annual HAP emissions associated with the JP-8 storage tanks.

HAP Compound	HAP Weight Fraction in JP-8 Vapor-phase*		VOC Emissions from JP-8 Tanks (lb/yr)		HAP Emissions from JP-8 Tanks (lb/yr)
Benzene	0.00613	x	1,475	=	**9.04**
Cumene	0.00330	x	1,475	=	**4.87**
Ethylbenzene	0.00271	x	1,475	=	**4.00**
Naphthalene	0.00003	x	1,475	=	**0.04**
Toluene	0.01143	x	1,475	=	**16.86**
2,2,4-Trimethylpentane	0.00010	x	1,475	=	**0.15**
Xylenes (mixed isomers)	0.01877	x	1,475	=	**27.69**

*Weight fraction equals weight percent divided by 100.

13.5 References

1. U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources* (AP-42), Section7.1, September 1997.

2. U.S. Environmental Protection Agency, *TANKS Program* (Storage Tank Emissions Calculation Software), Version 3.1, September 1997.

3. American Petroleum Institute, *Manual of Petroleum Measurements Standards: Chapter 19.4 - Recommended Practice for Speciation of Evaporative Losses*, First Edition, November 1997.

4. U.S. Air Force Armstrong Laboratory, Environmental Research Division (AL/EQL), *JP-8 Composition and Variability*, Report # AL/EQ-TR-1996-0006, May 1996.

5. U.S. Environmental Protection Agency, *Technical Support Document for Development of a Comparable Fuel Exemption*, Draft Version, February 1996.

SECTION 14

FUEL TRANSFER
(Revised December 2003)

14.1 Background: Fuel transfer operations involves the loading of fuel into tanker trucks, aircraft, vehicles/equipment, and into bowsers. It's important to note that the loading of fuel into storage tanks is addressed in the "Fuels Storage" section of this report and is therefore not covered under this section. On an Air Force installation, the filling of tanker trucks is performed at fuel loading docks and involves the transfer of fuel from large storage tanks into the tanker trucks. Typical types of vehicles/equipment located on Air Force installations include, but are not limited to; automobiles, heavy duty equipment, aerospace ground support equipment (AGSE), etc. The fuel that is loaded into aircraft and into vehicles/equipment may come from storage tanks or directly from tanker trucks. Loading fuel into bowsers is usually performed during defueling of aircraft. Since gasoline automobile refueling is addressed under the "Gasoline Service Stations" section of this report, it is not covered under this section.

The emissions of concern from fuel transfer operations include both VOCs and organic HAPs. As liquid fuel is loaded into a source (e.g., into a tanker truck cargo tank, an aircraft tank, a vehicle/equipment tank, or a bowser), vapors are displaced and emitted into the atmosphere. The amount of emissions released is dependent of several factors such as the type of fuel being transferred, temperature, and the loading method. The amount of emissions is also influenced by the recent history of the tank/bowser being loaded. If the tank/bowser has just been cleaned and vented, it will contain vapor-free air. However, if the tank truck has just carried fuel and has not been vented, it will contain vapors which are expelled during the loading operation along with newly generated vapors.

There are two primary methods associated with fuel loading: splash loading and submerged loading. In the splash loading method, the fill pipe dispensing the fuel is lowered only partway into the tank, above the liquid level. Significant turbulence and vapor/liquid contact occur during splash loading, resulting in high levels of vapor generation and loss. Two types of submerged loading currently exist, the submerged fill pipe method and the bottom loading method. In the submerged fill pipe method, the fill pipe extends almost to the bottom of the tank. In the bottom loading method, a permanent fill pipe is attached to the bottom of the tank. For both types of submerged loading, the fill pipe opening is below the liquid surface level. Liquid turbulence is controlled significantly during submerged loading, resulting in much lower vapor generation than encountered during splash loading. Schematics of splash loading, submerged fill pipe loading, and bottom loading are shown in Figures 14-1, 14-2, and 14-3, respectively.

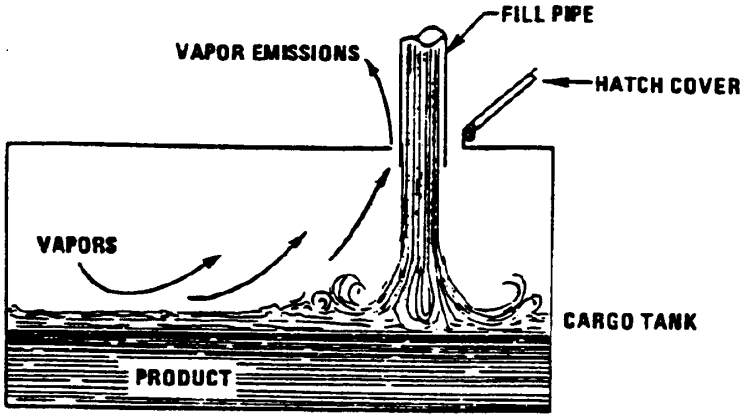

Figure 14-1. Tank Filling Using Splash Loading Method

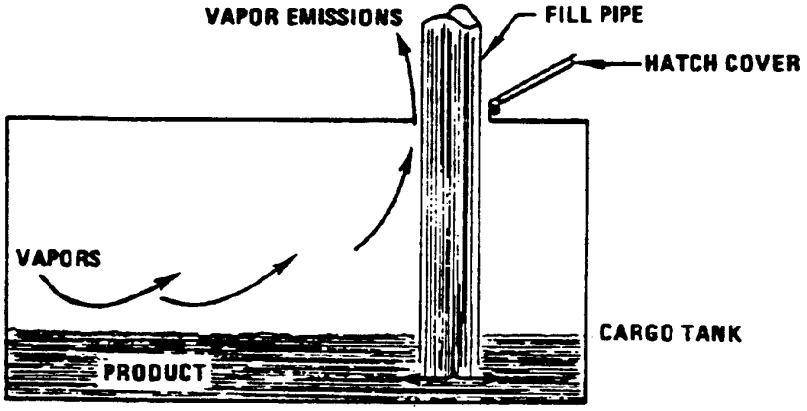

Figure 14-2. Tank Filling Using Submerged Fill Pipe Method

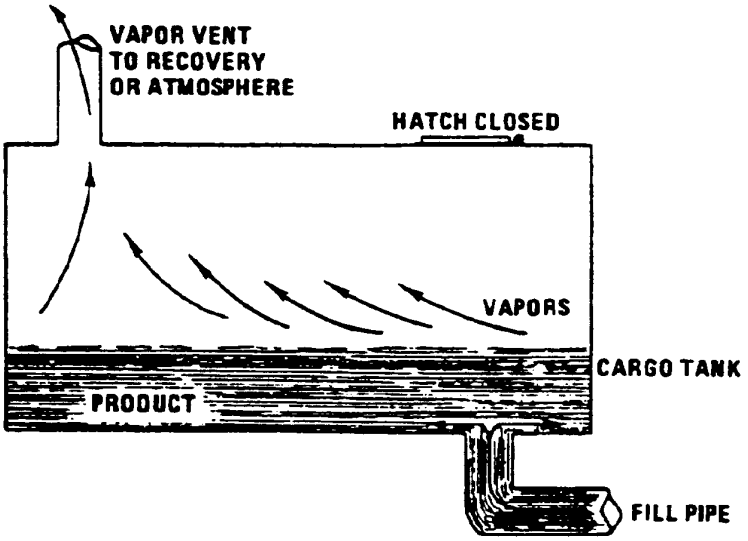

Figure 14-3. Tank Filling Using Bottom Loading Method

For the loading of fuel into a tanker truck, emissions can be significantly reduced by using a vapor recovery system. As liquid fuel is added to the tanker truck, the displaced vapors are captured and routed to a vapor recovery unit. Control efficiencies for the recovery units range from 90 to over 99 percent, depending on both the nature of the vapors and the type of control equipment used. However, only 70 to 90 percent of the displaced vapors reach the control device, because of leakage from both the tank truck and collection system. The capture efficiency should be assumed to be 90 percent for tanker trucks required to pass an annual leak test, otherwise, 70 percent should be assumed. A schematic of tank truck loading using vapor recovery is shown in Figure 14-4 below.

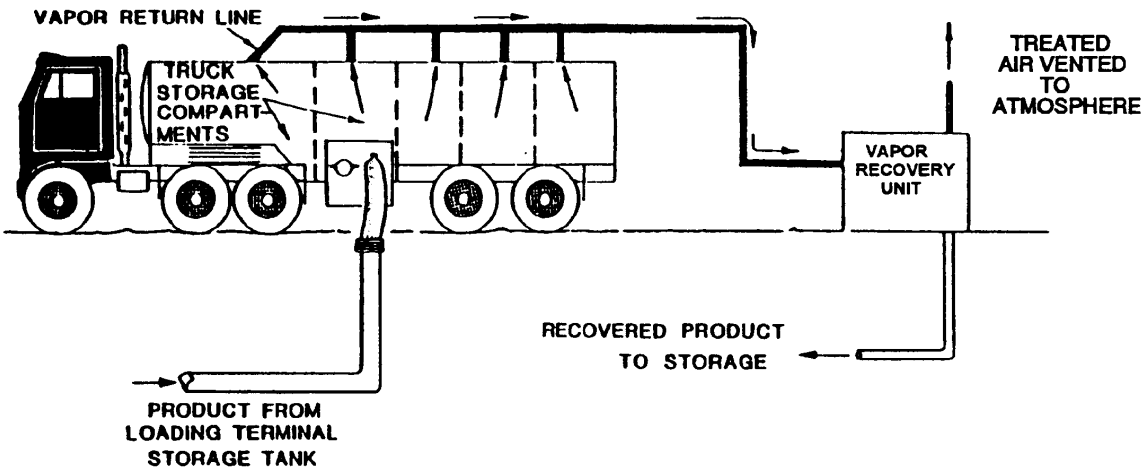

Figure 14-4. Tank Truck Loading with Vapor Recovery

14.2 Emission Calculations:

a. VOC Emissions

VOC emissions from fuel transfer operations can be calculated by the multiplying the amount of fuel loaded into a tank/bowser times the loading loss associated with the tank/bowser:

$$E_{VOC} = F_T * L_L$$

Where,

E_{VOC} = VOC emissions from the transfer of fuel into a tank or bowser (lb/yr)
F_T = Quantity of fuel transferred into the tank or bowser during year (10^3 gal/yr)
L_L = Loading loss associated with the tank or bowser (lb/10^3 gal)

The loading loss (L_L) associated with a tank or bowser can be calculated using the following equation:

$$L_L = 12.46 * [(S * P * M)/T] * [1 - (Cap_{eff}/100 * Con_{eff}/100)]$$

Where,

12.46 = constant

S = Saturation Factor [see Table 14-1 below]
P = True vapor pressure of liquid loaded (psia) [use the temperature of the bulk liquid loaded and Table 14-2 below]
M = Molecular weight of vapors (lb/lb-mole) [see Table 14-2 below]
T = Temperature of bulk liquid loaded (°R) [note: °R equals °F + 460]
Cap_{eff} = Capture efficiency of vapor control system (%) [note: applies only to those tanker trucks equipped with a control system. Assume 90% for tanker trucks required to pass an annual leak test. Otherwise, assume 70%.]
Con_{eff} = Control efficiency of vapor recovery unit (%) [note: applies only to those tanker trucks equipped with a control system.]

Table 14-1. Saturation (S) Factors For Calculating Petroleum Liquid Loading Losses[a]

Mode of Operation	S Factor
Submerged loading of a clean (vapor-free) cargo tank	0.50
Submerged loading: dedicated normal service	0.60
Submerged loading: dedicated vapor balance service	1.00
Splash loading of a clean (vapor-free) cargo tank	1.45
Splash loading: dedicated normal service	1.45
Splash loading: dedicated vapor balance service	1.00

[a] Data is from Section 5.2 of AP-42.

Table 14-2. Properties of Selected Petroleum Liquids[a]

Petroleum Liquid	Vapor Molecular Weight at 60° F (lb/lb-mole)	Liquid Density at 60° F (lb/gal)	True Vapor Pressure (psi)						
			40° F	50° F	60° F	70° F	80° F	90° F	100° F
Gasoline RVP 13	62	5.6	4.7	5.7	6.9	8.3	9.9	11.7	13.8
Gasoline RVP 10	66	5.6	3.4	4.2	5.2	6.2	7.4	8.8	10.5
Gasoline RVP 7	68	5.6	2.3	2.9	3.5	4.3	5.2	6.2	7.4
Crude oil RVP 5	50	7.1	1.8	2.3	2.8	3.4	4.0	4.8	5.7
Jet naphtha (JP-4)	80	6.4	0.8	1.0	1.3	1.6	1.9	2.4	2.7
Jet kerosene	130	7.0	0.0041	0.0060	0.0085	0.011	0.015	0.021	0.029
Distillate fuel oil No. 2	130	7.1	0.0031	0.0045	0.0074	0.0090	0.012	0.016	0.022
Residual oil No 6	190	7.9	0.00002	0.00003	0.00004	0.00006	0.00009	0.00013	0.00019

[a] Data is from Section 7.1 of AP-42.

b. HAP Emissions

HAP emissions associated with evaporative losses from fuel transfer operations are calculated the same way as HAP emissions from fuel storage tanks (see Section 13). In summary, HAP emissions are calculated by multiplying the corresponding VOC emissions by the vapor-phase weight fraction (weight percent divided by 100) of each HAP in the fuel:

$$E_{HAP} = E_{VOC} * (VWP_{HAP}/100)$$

Where,

E_{HAP} = Emissions of a specific HAP (lb/yr)
E_{VOC} = VOC emissions (lb/yr)
VWP_{HAP} = Weight percent of the HAP in the fuel vapor (%)
100 = Factor for converting weight percent into weight fraction

Vapor-phase HAP speciations of JP-8 and diesel are found in the "Fuel Storage" section of this report while a vapor-phase speciation of gasoline is provided in the "Gasoline Service Stations" section of this report.

14.3 Information Resources: Base Supply Fuels Management is the primary point of contact for information concerning fuel transfer operations. For operations involving the transfer of fuel into vehicles/equipment, the shops which are responsible for the vehicles/equipment may also need to be contacted. Similarly, the aircraft fuels maintenance shop may need to be contacted for information pertaining to defueling of aircraft. Finally, if a vapor recovery system is used for the loading of fuel into tanker trucks, then base Civil Engineering or the applicable manufacturer will need to be contacted to obtain the control efficiency of the vapor recovery unit.

14.4 Example Problem: Calculate the annual VOC emissions associated with aircraft fueling and defueling operations on base. Approximately 4,450,000 gallons of JP-8 per year is used to refuel aircraft. The fuel is transferred from storage tanks to the aircraft via tank trucks. The transfer of fuel from storage tanks to tank trucks is accomplished using the submerged fill pipe method and a vapor recovery system. The control efficiency of the vapor recovery unit is 95%. The tanker trucks are not required to pass an annual leak test, therefore, the vapor capture efficiency can be assumed to be 70%. The transfer from tank trucks to aircraft is accomplished using the submerged loading method and no vapor recovery. Additionally, approximately 175,000 gallons of JP-8 per year are defueled from aircraft into bowsers. The transfer from aircraft to bowsers is accomplished using the splash loading method and no vapor recovery. The annual average bulk JP-8 temperature is assumed to be about the same as the annual average ambient temperature at the base which is approximately 60° F (520° R). The tank trucks, aircraft tanks, and bowsers are typically not cleaned/vented prior to fuel transfers.

a. First calculate the VOC emissions associated with loading fuel into the fuel trucks as follows:

$L_L = 12.46 * [(S * P * M)/T] * [1 - (Cap_{eff}/100 * Con_{eff}/100)]$
$L_{L(trucks)} = 12.46 * [(1.00 * 0.0085 * 130)/520] * [1 - (70/100 * 95/100)] = 0.0089 lb/10^3 gal$

$E_{VOC} = F_T * L_L$
$E_{VOC(trucks)} = (4{,}450 \times 10^3 gal/yr) * (0.0089 lb/10^3 gal) = \underline{39.6 lb/yr}$

b. Second, calculate the VOC emissions associated with loading fuel into the aircraft tanks as follows:

$L_L = 12.46 * [(S * P * M)/T] * [1 - (Cap_{eff}/100 * Con_{eff}/100)]$
$L_{L(aircraft)} = 12.46 * [(0.60 * 0.0085 * 130)/520] * [1 - (0/100 * 0/100)] = 0.016 lb/10^3 gal$

$E_{VOC} = F_T * L_L$
$E_{VOC(aircraft)} = (4{,}450 \times 10^3 gal/yr) * (0.016 lb/10^3 gal) = \underline{71.2 lb/yr}$

c. Next, calculate the VOC emissions associated with aircraft defueling (loading fuel into bowsers) as follows:

$$L_L = 12.46 * [(S * P * M)/T] * [1 - (Cap_{eff}/100 * Con_{eff}/100)]$$
$$L_{L(bowsers)} = 12.46 * [(1.45 * 0.0085 * 130)/520] * [1 - (0/100 * 0/100)] = 0.038 \text{ lb}/10^3 \text{ gal}$$

$$E_{VOC} = F_T * L_L$$
$$E_{VOC(bowsers)} = (175 \times 10^3 \text{ gal/yr}) * (0.038 \text{ lb}/10^3 \text{ gal}) = \underline{6.7 \text{ lb/yr}}$$

d. Finally, add up the VOC emissions from steps 1 through 3 above to get the total VOC emissions associated with JP-8 fuel transfer.

$$E_{VOC(total\ JP\text{-}8)} = E_{VOC(trucks)} + E_{VOC(aircraft)} + E_{VOC(bowsers)}$$
$$E_{VOC(total\ JP\text{-}8)} = 39.6 \text{ lb/yr} + 71.2 \text{ lb/yr} + 6.7 \text{ lb/gal} = \mathbf{117.5\ lb/yr}$$

14.5 References

1. U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources* (AP-42), Section 5.2, January 1995.

2. U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources* (AP-42), Section 7.1, September 1997.

3. American Petroleum Institute, *Manual of Petroleum Measurements Standards: Chapter 19.4 - Recommended Practice for Speciation of Evaporative Losses*, First Edition, November 1997.

4. U.S. Environmental Protection Agency, *Technical Support Document for Development of a Comparable Fuel Exemption*, Draft Version, February 1996

SECTION 15

GASOLINE SERVICE STATIONS

15.1 Background: Most Air Force installations have multiple gasoline service stations used to refuel both privately owned vehicles (POVs) and government owned vehicles (GOVs). Typically, each installation will have at least one Army Air Force Exchange Service (AAFES) service station for refueling of POVs and at least one military service station (operated by either the base Supply Squadron or the base Logistics Squadron) for refueling of GOVs. The emissions of concern from gasoline service stations include VOCs and organic HAPs. These emissions originate from filling the underground storage tanks, breathing and emptying losses from the underground storage tanks (USTs), and vehicle refueling operations. The following is a brief description of each of these emission sources:

a. Filling Underground Tanks: When an UST is filled by a tanker truck, the vapors in the UST are displaced to the atmosphere as the liquid level in the UST increases. The amount of emissions is dependent on a variety of factors including the method and rate of filling, the tank configuration, and properties associated with the gasoline (e.g., temperature, vapor pressure, and composition). The two methods of filling an UST are submerged filling and splash filling. With submerged filling the end of the pipe used to fill the UST is below the surface level of the gasoline. With splash spilling, the end of the fill pipe is above the surface level of the gasoline. Using the submerged fill method results in approximately 35 to 40% less VOC emissions than the splash fill method. Emissions from the filling of USTs can also be greatly reduced by using a vapor balance system known as Stage I vapor control. The vapor balance system employs a hose that returns gasoline vapors displaced from the underground tank to the tank truck cargo compartments being emptied. The control efficiency of the balance system ranges from 93 to 100 percent. A schematic which illustrates Stage I vapor control is provided in Figure 15-1.

b. Underground Tank Breathing and Emptying: Breathing losses occur daily and are attributable to gasoline evaporation resulting from temperature and barometric pressure changes. Breathing losses for underground storage tanks are minimal because the surrounding earth limits the diurnal temperature change, and changes in the barometric pressure result in only small losses. Emptying losses occur due to fresh air entering the tank to replace the withdrawn fuel. The fresh air enhances evaporation as it becomes saturated with vapors and expands.

c. Vehicle Refueling Operations: Vehicle refueling losses come primarily from vapors displaced from the automobile tank by dispensed gasoline. The quantity of displaced vapors depends on gasoline temperature, auto tank temperature, gasoline Reid Vapor Pressure (RVP), and dispensing rate. These emissions can also be greatly reduced through the use of a control system known as Stage II vapor control. Controlling vehicle refueling emissions is based on conveying the vapors displaced from the vehicle fuel tank to the underground storage tank vapor space through the use of a special hose and nozzle, as depicted in Figure 15-2. Stage II vapor control is accomplished using either a “balance” vapor control system or a “vacuum assist” vapor control system. In "balance" vapor control systems, the vapors are conveyed by natural pressure differentials established during refueling. In "vacuum assist" systems, the conveyance of vapors from the auto fuel tank to the underground storage tank is assisted by a vacuum pump. Tests on State II control systems have indicated overall control efficiencies in the range of 88 to 92 percent. In addition to vapors displaced from the automobile tank, some emissions from vehicle refueling operations are a result of fuel spillage. Spillage loss is made up of contributions from prefill and postfill nozzle drip and from spit-back and overflow from the vehicle’s fuel tank filler pipe during filling. The amount of spillage loss is dependent on several variables, including service station business characteristics, tank configuration, and operator techniques.

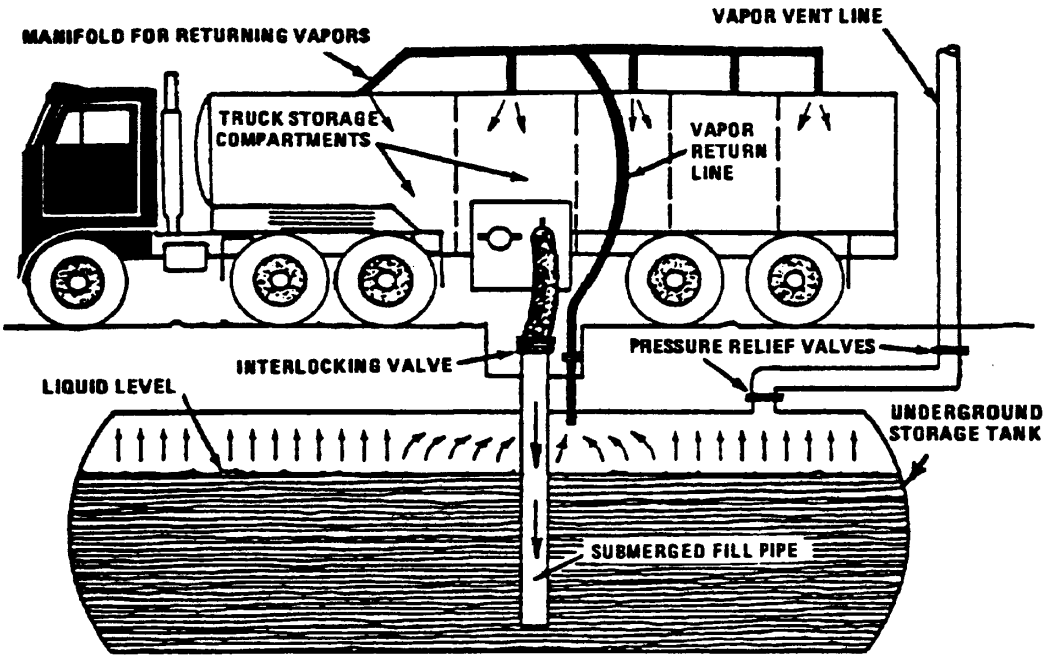

Figure 15-1. Schematic of Stage I Vapor Control

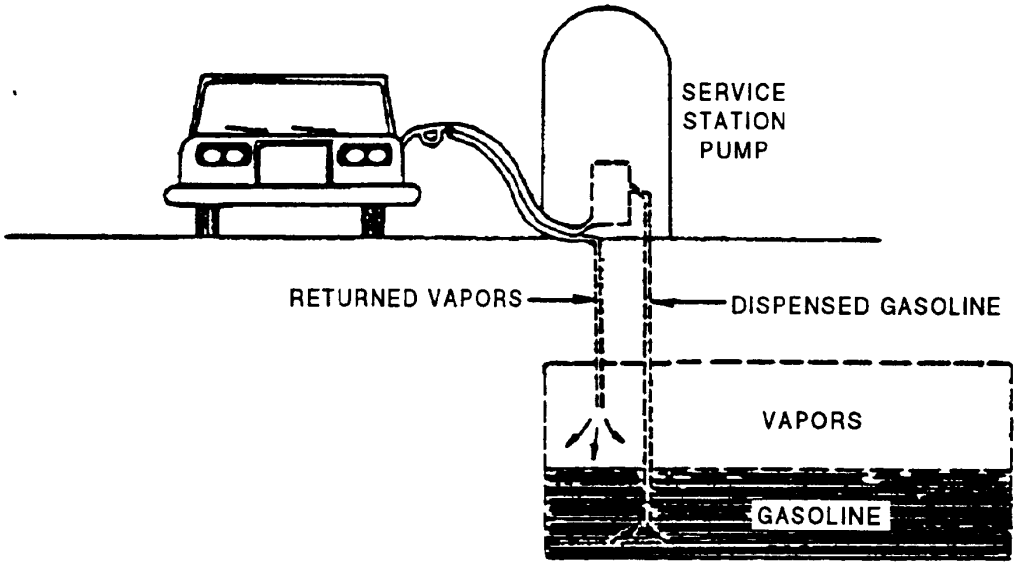

Figure 15-2. Schematic of Stage II Vapor Control

15.2 Emission Calculations:

a. VOC Emissions

VOC emissions from gasoline service stations are estimated by calculating the emissions from each different source type (i.e., filling of the USTs, breathing and emptying losses from the USTs, vapor displacement from automobile tanks during refueling, and spillage during automobile refueling) and then adding the emissions together.

$$E_{VOC\text{-}Total} = E_{VOC\text{-}Fill} + E_{VOC\text{-}B\&E} + E_{VOC\text{-}VD} + E_{VOC\text{-}S}$$

Where,

$E_{VOC\text{-}Total}$ = Total VOC emissions from a gasoline service station (lb/yr)
$E_{VOC\text{-}Fill}$ = VOC emissions associated with filling of the USTs (lb/yr)
$E_{VOC\text{-}B\&E}$ = VOC emissions associated with breathing and emptying losses from the USTs (lb/yr)
$E_{VOC\text{-}VD}$ = VOC emissions associated with vapor displacement from automobile tanks during refueling (lb/yr)
$E_{VOC\text{-}S}$ = VOC emissions associated with spillage during automobile refueling (lb/yr)

The emissions from each source type are calculated by multiplying the gasoline throughput by the appropriate emission factor. Therefore, the total VOC emissions can be calculated as follows:

$$E_{VOC\text{-}Total} = [GT * EF_{VOC\text{-}Fill}] + [GT * EF_{VOC\text{-}B\&E}] + [GT * EF_{VOC\text{-}VD}] + [GT * EF_{VOC\text{-}S}]$$

Where,

$E_{VOC\text{-}Total}$ = Total VOC emissions from a gasoline service station (lb/yr)
GT = Gasoline throughput in thousands of gallons per year (1000 gal/yr)
$EF_{VOC\text{-}Fill}$ = VOC emission factor associated with filling USTs (lb/1000 gal)
$EF_{VOC\text{-}B\&E}$ = VOC emission factor associated with breathing and emptying losses from USTs (lb/1000 gal)
$EF_{VOC\text{-}VD}$ = VOC emission factor associated with vapor displacement from automobile tanks during refueling (lb/1000 gal)
$EF_{VOC\text{-}S}$ = VOC emission factor associated with spillage during automobile refueling (lb/1000 gal)

The VOC emission factors associated with gasoline service stations are listed in Table 15-1 below.

Table 15-1. VOC Emission Factors for Gasoline Service Stations[a]

Emission Source	VOC Emission Factor (lb/1000 gal)[b]
Filling underground tank[c]	
Submerged filling	7.3
Splash filling	11.5
Balanced submerged filling (Stage I controls)	0.3
Underground tank breathing and emptying[c]	1.0
Vehicle refueling operations[d]	
Displacement losses (uncontrolled)	11.0
Displacement losses (Stage II controls)	1.1
Spillage	0.7

[a] Emission factors are from Section 5.2 of AP-42 and are based on average conditions (e.g., average temperatures, average gasoline vapor pressure, average dispensing rate, etc.).
[b] Emission factors are in units of pounds VOC emitted per thousand gallons of fuel throughput.
[c] If needed, more specific values for the tank emissions can be calculated using the EPA's TANKS3.1 program (see the "Fuel Storage" section of this document). Also, the TANKS3.1 program should be used if the gasoline storage tanks are above ground instead of underground.
[d] If needed, more specific values for the vehicle refueling operations can be calculated using procedures found in section 5.2.2.3 of AP-42.

b. HAP Emissions

Gasoline is a mixture of various hydrocarbon compounds, some of which are on the list of HAPs. Therefore, as gasoline vapors are emitted into the atmosphere, these HAP component compounds are also emitted. As mentioned above, gasoline service station emissions come from four different sources: 1) filling of the USTs, 2) breathing and emptying losses from the USTs, 3) vapor displacement from automobile tanks during refueling, and 4) spillage during automobile refueling. The emissions from the first three source types are in the form of evaporative emissions from a tank (i.e., either the UST or automobile tank). Since the individual compounds which make up gasoline have different vapor pressures, the evaporative emissions coming from a tank will be composed mainly of the those compounds with the highest vapor pressure. For this reason, the concentration of individual compounds in the fuel vapor will be different than the concentrations of these compounds in the liquid fuel. Therefore, the HAP emissions associated with the first three sources are calculated by multiplying the corresponding VOC emissions by the vapor-phase weight fraction of each HAP in gasoline. Since all the gasoline spilled during automobile refueling completely evaporates, calculating the HAP emissions associated with spillage is accomplished by simply multiplying the spillage VOC emissions by the liquid-phase weight percent of each HAP in gasoline. Table 15-2 below provides both a typical liquid-phase and a typical vapor-phase HAP speciation of gasoline.

Table 15-2. Liquid-phase and Vapor-phase HAP Speciation of Gasoline

HAP Component	Weight Percent in Liquid-Phase[a]	Weight Percent in Vapor-Phase[b]
Benzene	1.8	0.6
Cumene	0.5	0.02
Ethylbenzene	1.4	0.04
Hexane (*n*-hexane)	1	0.5
Methyl tert-butyl ether	4.5	4.6
Naphthalene	0.3	Negligible
Toluene	7	0.7
2,2,4-Trimethylpentane	4	0.7
Xylenes (mixed isomers)	7	0.2

[a] With the exception of naphthalene, the liquid-phase speciation is based on "typical" values obtained from Table 3 of API's Manual of Petroleum Measurement Standards, Chapter 19.4. The naphthalene liquid-phase percentage was obtained by averaging the sample results found in the draft version of EPA's report entitled "Technical Support Document for Development of a Comparable Fuel Exemption."

[b] The vapor-phase speciation was calculated using the liquid-phase speciation values and the procedures found in Section 7.1.4 of AP-42. Specific data (e.g., molecular weights, vapor pressures, etc.) used in the calculations can be found in Appendix E.

15.3 Information Resources: The gasoline service station supervisor should be contacted for information such as the annual gasoline throughput and whether or not Stage II vapor recovery controls are being used. Although the supervisor may also have the required information pertaining to filling of the USTs, in some cases the gasoline supplier(s) will need to be contacted. The required UST information includes the method in which the USTs are filled (submerged filling or splash spilling) and whether or not Stage I vapor recovery controls are being used.

15.4 Example Problem: A base has an AAFES service station located at the shoppette. According to the service station supervisor, a total of a 172,000 gallons of gasoline was dispensed at the service station during the year and no Stage II vapor recovery controls were used. The shop supervisor also stated that only one fuel supplier was used during the year. When contacted, the fuel supplier stated that the USTs were filled using the submerged filling technique and that no Stage I vapor controls were used. Calculate both the VOC and HAP emissions.

a. First calculate the VOC emissions as follows:

$E_{VOC\text{-}Total}$ = [GT * $EF_{VOC\text{-}Fill}$] + [GT * $EF_{VOC\text{-}B\&E}$] + [GT * $EF_{VOC\text{-}VD}$] + [GT * $EF_{VOC\text{-}S}$]

$E_{VOC\text{-}Total}$ = [(172 x 10^3 gal/yr) * 7.3 lb/10^3 gal] + [(172 x 10^3 gal/yr) * 1.0 lb/10^3 gal] + [(172 x 10^3 gal/yr) * 11.0 lb/10^3 gal] + [(172 x 10^3 gal/yr) * 0.7 lb/10^3 gal]

$E_{VOC\text{-}Total}$ = 1,255.6 lb/yr + 172 lb/yr + 1,892 lb/yr + 120.4 lb/yr = **3,440 lb/yr**

b. Next, calculate the HAP emissions associated with the evaporative losses from the USTs and automobile tanks. This is done by multiplying the VOC emissions associated with evaporation from the USTs and automobile tanks times the weight fraction of each HAP in the vapor-phase.

(1) The VOC emissions associated with evaporation from the USTs and automobile tanks are equal to:

1,255.6 lb/yr + 172 lb/yr + 1,892 lb/yr = <u>3,319.6 lb/yr</u>

(2) The HAP emissions associated with evaporation from the USTs and automobile tanks are then calculated as follows:

HAP Compound	HAP Weight Fraction in Vapor-phase*		VOC Emissions from USTs & Automobile Tanks (lb/yr)		HAP Emissions from USTs & Automobile Tanks (lb/yr)
Benzene	0.006	x	3,319.6	=	19.9
Cumene	0.0002	x	3,319.6	=	0.7
Ethylbenzene	0.0004	x	3,319.6	=	1.3
Hexane	0.005	x	3,319.6	=	16.6
Methyl tert-butyl ether	0.046	x	3,319.6	=	152.7
Naphthalene	----	x	3,319.6	=	---
Toluene	0.007	x	3,319.6	=	23.2
2,2,4-Trimethylpentane	0.007	x	3,319.6	=	23.2
Xylenes (mixed isomers)	0.002	x	3,319.6	=	6.6

*Weight fraction equals weight percent divided by 100.

c. The next step is to calculate the HAP emissions associated with the gasoline spillage during automobile refueling. This is done by multiplying the VOC emissions associated with spillage times the weight fraction of each HAP in the liquid-phase.

HAP Compound	HAP Weight Fraction in Liquid-phase*		VOC Emissions from Spillage (lb/yr)		HAP Emissions from Spillage (lb/yr)
Benzene	0.018	x	120.4	=	2.2
Cumene	0.005	x	120.4	=	0.6
Ethylbenzene	0.014	x	120.4	=	1.7
Hexane	0.01	x	120.4	=	1.2
Methyl tert-butyl ether	0.045	x	120.4	=	5.4
Naphthalene	0.003	x	120.4	=	0.4
Toluene	0.07	x	120.4	=	8.4
2,2,4-Trimethylpentane	0.04	x	120.4	=	4.8
Xylenes (mixed isomers)	0.07	x	120.4	=	8.4

*Weight fraction equals weight percent divided by 100.

d. The final step is to calculate the total HAP emissions by adding the HAP emissions associated with evaporation from the USTs and automobile tanks with the emissions associated with gasoline spillage during refueling.

HAP Compound	HAP Emissions from USTs & Automobile Tanks (lb/yr)		HAP Emissions from Spillage (lb/yr)		Total HAP Emissions (lb/yr)
Benzene	19.9	+	2.2	=	**22.1**
Cumene	0.7	+	0.6	=	**1.3**
Ethylbenzene	1.3	+	1.7	=	**3.0**
Hexane	16.6	+	1.2	=	**17.8**
Methyl tert-butyl ether	152.7	+	5.4	=	**158.1**
Naphthalene	---	+	0.4	=	**0.4**
Toluene	23.2	+	8.4	=	**31.6**
2,2,4-Trimethylpentane	23.2	+	4.8	=	**28.0**
Xylenes (mixed isomers)	6.6	+	8.4	=	**15.0**

15.5 References

1. U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources* (AP-42), Section 5.2, January 1995.

2. U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources* (AP-42), Section 7.1.4, February 1996.

3. American Petroleum Institute, *Manual of Petroleum Measurements Standards: Chapter 19.4 - Recommended Practice for Speciation of Evaporative Losses*, First Edition, November 1997.

4. U.S. Environmental Protection Agency, *Technical Support Document for Development of a Comparable Fuel Exemption*, Draft Version, February 1996.

5. U.S. Environmental Protection Agency, *TANKS Program* (Storage Tank Emissions Calculation Software), Version 3.1, September 1997.

6. Emissions Inventory Improvement Program (EIIP), *Volume III: Chapter11, "Gasoline Marketing (Stage I and Stage II),"* September 1997.

SECTION 16

HEAVY CONSTRUCTION OPERATIONS

16.1 Background: Heavy construction operations involve the construction of buildings and/or roads. These operations can be expected to occur during the year at virtually all Air Force installations. Although much of the emissions from heavy construction operations come from the exhaust of motorized equipment/vehicles, these emissions are considered "mobile source emissions" and therefore are not addressed in this document. Only those emissions which fall under the definition of "stationary source emissions" are addressed. The pollutant of concern from the stationary source portion of heavy construction operations is fugitive dust (particulate matter).

In general, heavy construction operations can be broken down into three major phases; demolition and debris removal, site preparation (earth moving), and general construction. However, since most of the fugitive dust emissions can be expected to come from the first two phases, these will be the only ones addressed in this document. These two phases can be further broken down into more specific activities. Some of the specific activities are listed in Table 16-1 below.

Table 16-1. Specific Activities Associated with Typical Heavy Construction Operations

Construction Phase	Dust-generating Activities
I. Demolition and debris removal	1. Demolition of buildings or other obstacles such as trees, boulders, etc. a. Mechanical dismemberment ("headache ball") of existing structures b. Implosion of existing structures c. Drilling and blasting of soil d. General land clearing 2. Loading of debris into trucks 3. Truck transport of debris 4. Truck unloading of debris
II. Site Preparation (earth moving)	1. Bulldozing 2. Scrapers unloading topsoil 3. Scrapers in travel 4. Scrapers removing topsoil 5. Loading of excavated material into trucks 6. Truck dumping of fill material, road base, or other materials 7. Compacting 8. Motor grading

16.2 Emission Calculations: The quantity of dust emissions from construction operations is proportional to the area of land being worked and to the level of construction activity. According to AP-42, there is currently only one emission factor associated with heavy construction operations as a whole. This emission factor is 1.2 tons/acre/month of activity and is based on field measurements of total suspended particulate (TSP) concentrations surrounding apartment and shopping center construction projects. Since derivation of this TSP emission factor is based on construction activity occurring 30 days per month, it can be converted into the following: 80 pounds/acre/day of activity.

Emissions from heavy construction operations can be estimated by multiplying the emission factor above times the approximate number of full (i.e., 8-hour equivalent) working days in which construction operations are conducted during the year and then by the estimated area (acres) of property in which construction operations are performed on during a typical day. It's important to note that the working days are 8-hour equivalent working days. For example, if construction operations were performed on base during 100 calendar days during the year but for only 4 hours each day, the number of days used in calculating emissions would be 50. When referring to construction operations, only demolition and debris removal and site preparation (earth moving) related activities should be considered.

$$E_{TSP} = 80 * D * A$$

Where,

E_{TSP} = Emissions of Total Suspended Particulate (lb/yr)
80 = Emission factor (lb/acre/day)
D = Estimated number of full (8-hour equivalent) working days during the year in which construction activities (i.e., demolition, debris removal, and/or site preparation) are performed on (days/yr)
A = Average area of property in which daily construction projects are typically performed on (acres)

Section 13.2.3 of AP-42 ("Heavy Construction Operations") does not address what percentage of the TSP emissions could reasonably be assumed to be PM_{10}. Since much of the emissions from construction operations comes from soil emitted during site preparation activities, a review of AP-42 was performed to determine if there was a typical PM_{10} to TSP ratio for fugitive soil emissions. A PM_{10} to PM_{30} ratio was found in Section 13.2.2 for dust emissions from unpaved roads. This ratio equates to 0.45 (e.g., 45%). Assuming the TSP from fugitive dust emissions has an aerodynamic diameter less than or equal to 30 microns, the 0.45 ratio can be used to estimate the PM_{10} emissions from construction operations (Note - Section 11.9 of AP-42 does consider TSP from fugitive dust emissions to be the same as $\leq PM_{30}$).

$$E_{PM10} = E_{TSP} * 0.45$$

Where,

E_{PM10} = Emissions of PM_{10} (lb/yr)
E_{TSP} = Emissions of Total Suspended Particulate (lb/yr)
0.45 = Estimated ratio of PM_{10} to TSP

Note: the procedures above for calculating emissions from heavy construction operations are based on the general emission factor of 1.2 tons/acre/month of activity. Section 13.2.3 of AP-42 states that a more accurate way of estimating the emissions is to calculate the emissions for each specific type of

activity associated with heavy construction operations and then sum them up to get the total emissions. However, this method is much more comprehensive and requires knowledge of a variety of data elements, some of which will probably not be known.

16.3 Information Resources: Heavy construction operations on base are performed either by civil engineering or by contractor. However, base civil engineering should be able to provide the information necessary to calculate emissions from heavy construction operations. This includes estimating the approximate time (i.e., 8-hour equivalent working days) during the year in which heavy construction operations (i.e., demolition, debris removal, and site preparation) were performed on base as well as the average area (acres) of property in which typical daily construction operations were performed on.

16.4 Example Problem: Base civil engineering estimates the total cumulative time in which construction operations (i.e., demolition, debris removal, and site preparation) were performed on base during the year was approximately 35 full working days. They also estimate that on a typical workday, construction operations were performed on an area of approximately ½ acre. Calculate the estimated TSP (i.e., PM) and PM_{10} emissions.

$E_{TSP} = 80 * D * A$
$E_{TSP} = 80 * 35 * 0.5 =$ **<u>1,400 lb/yr</u>**

$E_{PM10} = E_{TSP} * 0.45$
$E_{PM10} = 1{,}400 \text{ lb/yr} * 0.45 =$ **<u>630 lb/yr</u>**

16.5 References

1. U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources* (AP-42), Section 13.2.3, September 1995.

SECTION 17

INCINERATORS

17.1 Background: There are two types of incinerators typically found on Air Force installations; medical (hospital) waste incinerators and classified waste incinerators. Municipal solid waste incinerators (used to burn garbage and other household waste) are usually not found at Air Force installations, and therefore, are not addressed in this document. However, if needed, emission factors and other information applicable to municipal solid waste incinerators can be found in section 2.1 of AP-42.

a. Medical Waste Incinerators

These incinerators are used to burn wastes produced by hospitals/clinics, veterinary facilities, and medical research facilities. The wastes burned in medical wastes incinerators may include both infectious (i.e., red bag) wastes as well as non-infectious (e.g., general housekeeping) wastes. In general, there are three major types of medical waste incinerators: controlled-air incinerators, excess-air incinerators, and rotary kiln incinerators. According to a study performed by the EPA, a vast majority (> 95%) of medical waste incinerators currently in operation are of the controlled-air type, a small percentage (< 2%) are of the excess-air type, and very few (< 1%) are of the rotary kiln type. It is very unlikely that any rotary kiln medical waste incinerators are currently being used in the Air Force. The following is a brief description of each of the three types of medical waste incinerators:

(1) *Controlled-Air Medical Waste Incinerators*: The principle of controlled-air incineration involves sequential combustion operations carried out in two separate chambers. The primary chamber (sometimes referred to as the ignition chamber) accepts the waste, and the combustion process is begun in a below stoichiometric oxygen (starved-air) atmosphere. The amount of combustion air to the primary chamber is strictly regulated (controlled). The combustion air usually is fed to the system as underfire air. Three processes occur in the primary chamber. First, the moisture in the waste is volatilized. Second, the volatile fraction of the waste is vaporized, and the volatile gases are directed to the secondary chamber. Third, the fixed carbon remaining in the waste is combusted. The combustion gases containing the volatile combustible materials from the primary chamber are then directed to the secondary chamber (sometimes referred to as the "combustion chamber"). There, the combustion air is regulated to provide an excess-air combustion condition and is introduced to the chamber in such a manner as to produce turbulence and promote good mixing of the combustion gases and combustion air. The burning of the combustion gases under conditions of high temperature, excess oxygen, and turbulence promotes complete combustion.

Combustion control for a controlled-air incinerator is usually based on the temperature of the primary (ignition) and secondary (combustion) chambers. Thermocouples within each chamber are used to monitor temperatures continuously. Burner operation and combustion air rate in each chamber are adjusted to maintain the desired temperatures. The typical temperature range for the primary chamber is 1000° to 1800° F (1400° - 1800° F if the incinerator is operated in continuous mode) while the typical temperature range for the secondary chamber is 1800° to 2200° F.

Limiting air in the primary chamber to below stoichiometric conditions prevents rapid combustion and allows a quiescent condition to exist within the chamber. This quiescent condition minimizes the entrainment of particulate matter in the combustion gases, which ultimately are emitted to the atmosphere.

Controlled-air incinerators are designed to operate in one of three modes: single batch, intermittent-duty (multiple batch), or continuous operation. For the single batch mode, the incinerator is loaded with one batch of waste per day. After the waste is burned down, the incinerator is allowed to cool down and then the ash is removed before the incinerator is re-charged with another batch of waste. When operating in the intermittent-duty mode, the incinerator is re-charged with one or more additional batches of waste after the initial batch is burned down. After two or more batches of waste are burned, the incinerator is allowed to cool down and the ash removed before the incinerator is used again. As the name implies, continuous-duty incinerators can be operated continuously for an indefinite period of time. Continuous-duty incinerators must be equipped with a mechanism for automatically removing ash from the incinerator hearth. The ash must be moved across the hearth, collected, and removed while the incinerator is still in operation.

Loading of waste into a controlled-air incinerator can be done manually or mechanically. Manual loading involves having the operator load the waste directly to the primary chamber without any mechanical assistance. Mechanical loading requires the use of a hopper/ram feeding system. Although single batch and intermittent-duty incinerators may be designed to be loaded either manually or mechanically, continuous-duty units are typically designed to be loaded mechanically.

(2) *Excess-Air Medical Waste Incinerators*: Combustion in an excess-air incinerator occurs in two (or more) combustion chambers. All chambers are operated with excess air. Ignition of the waste, volatilization of moisture, vaporization of volatile matter, and combustion of the fixed carbon (solid-phase combustion) occur in the primary chamber. The combustion gases containing the volatiles exit the primary chamber through a flame port into a mixing chamber and then pass into the secondary combustion chamber. Secondary air is added into the flame port and is mixed with the combustion gas in the mixing chamber. A secondary burner is provided in the mixing chamber to maintain adequate temperatures for complete combustion as the gases pass into and through the secondary combustion chamber. An excess-air incinerator is designed for surface combustion of the waste which is achieved by predominant use of overfire combustion air and limiting the amount of underfire air in the primary chamber. Excess-air incinerators typically operate with an overall excess air range of 300 to 600 percent.

Excess-air incinerators frequently are designed and used specifically for incinerating pathological ("Type 4" anatomical) wastes. The use of multiple-chamber, excess-air incinerators for incineration of redbag wastes has several drawbacks. First, operating in the surface-combustion excess-air mode in the primary chamber results in entrainment of flyash which can cause excessive particulate matter emissions. Second, since the incinerator is designed to operate with the primary chamber in an excess-air mode, the combustion air levels and the combustion rate within the primary chamber are not easily controlled. Third, operating with high levels of excess air is less energy efficient because it requires auxiliary fuel usage to maintain secondary combustion chamber temperatures. Excess-air incinerators are better suited for incineration of pathological wastes than red bag wastes because the consequences of the above-mentioned drawbacks are not as severe for pathological wastes

Excess-air incinerators are typically designed for single batch or intermittent-duty operation. That is, this type of incinerator typically does not have an automatic, continuous ash removal system which would make continuous operation possible. Consequently, the incinerator must be shut down at routine intervals (e.g., daily) for ash removal.

In regards to waste loading, excess-air incinerators can be charged either manually or mechanically, although manually is the typical method use.

Note: Excess-air incinerators are also often referred to as "multiple-chamber" incinerators. However, this name can be misleading since most controlled-air and rotary kiln incinerators are also equipped with more than one chamber.

(3) *Rotary Kiln Medical Waste Incinerators*: A rotary kiln also utilizes two-stage combustion and has two combustion chambers. The primary combustion chamber is a rotating cylindrical chamber which is slightly inclined from the horizontal plane; hence, the name "rotary kiln." The secondary chamber is often cylindrical in shape and oriented horizontally (much like the secondary chambers used for controlled-air incinerators), or it may be box-like in shape.

The rotating kiln is inclined at an angle determined during the design of the system. Waste is fed to the higher end of the kiln by a mechanical feed system. Inside the kiln, moisture and volatiles are vaporized from the waste, and the waste is ignited. An auxiliary burner provided in the kiln maintains the desired combustion temperature if sufficient heat input is not available from the waste. As the kiln rotates, the solids are tumbled within the kiln and slowly move down the incline toward the discharge end. The turbulence of the waste within the kiln provides exposure of the solid waste to the combustion air. Combustion of the solids occurs within the kiln, and the residue ash is discharged from the end of the kiln into an ash removal system. The volatile gases pass into the secondary chamber where combustion of the gases is completed. A secondary burner is used to maintain the secondary chamber temperature, and secondary combustion air is added to the chamber as necessary to maintain the desired excess air level.

Since the solid waste continuously moves down the length of the rotating kiln, the incineration system is designed to operate in a continuous mode with a semicontinuous or continuous waste feed input. Consequently, a rotary kiln typically has a mechanical waste feed system and a system for continuous ash removal.

b. Classified Waste Incinerators

Many Air Force installations use a classified waste incinerator as a means of disposing of classified information. This information is usually in the form of paper documents, plastic (microfiche) sheets, or computer tapes/discs. Since the EPA does not have any published emission factors specifically for classified incinerators, these incinerators should be considered as a type of "Industrial/Commercial Incinerator."

17.2 Emission Calculations: The emissions from both medical and classified waste incinerators can be calculated by simply multiplying the amount of waste combusted times the appropriate emission factor.

$$E_{pol} = WC * EF$$

Where,

E_{pol} = Emissions of a particular pollutant (lb/yr)
WC = Quantity of waste combusted (tons/yr)
EF = Emission factor (lb/ton)

Emission factors for controlled-air medical waste incinerators are provided in Table 17-1 below. The EPA does not have published emission factors for excess-air incinerators, therefore, the emission factors for controlled-air incinerators should also be used for excess-air incinerators if necessary. Due to the unlikelihood that there are any rotary-kiln medical waste incinerators in the Air Force, emission

factors for rotary-kiln medical waste incinerators are not provided in this document. However, if needed, emission factors for rotary-kiln medical waste incinerators can be found in section 2.3 of AP-42.

The EPA does not have any emission factors specifically for classified waste incineration. However, a review of section 2.1 of AP-42 reveals that the closest incinerator (combustor) category which would be applicable to classified waste incinerators is the category called "Industrial/Commercial Combustors." Emissions factors for uncontrolled Industrial/Commercial Combustors are found in Table 17-2 below.

17.3 Information Resources: Medical waste incinerators are typically operated by the base hospital/clinic. The hospital (or clinic) facility manager should be contacted for specific information (e.g., type of incinerator, quantity of waste combusted, etc.). As for classified waste incinerators, these are usually operated by the base Information Systems office.

17.4 Example Problem: A base has a controlled-air medical waste incinerator located at the hospital. The incinerator is not equipped with any kind of control device. According to records maintained by the hospital facility manager, approximately 36,500 pounds of medical waste were combusted in the incinerator during the year. Calculate the annual PM_{10} emissions.

a. The first step is to convert the 36,500 pounds of waste into tons of waste.

36,500 lb * 1 ton/2000 lb = <u>18.25 tons</u>

b. Next, the PM_{10} emissions are calculated by multiplying the tons of waste combusted times the PM_{10} emission factor listed in Table 17-1 for uncontrolled incinerators.

E_{pol} = WC * EF
E_{PM10} = 18.25 tons/yr * 3.04 lb/ton = **<u>55.5 lb/yr</u>**

Table17-1. Emission Factors for Controlled-Air Medical Waste Incinerators

Pollutant	Control Levels and Emission Factors (lb/ton)[a,b]									
	Uncontrolled	Low Energy Wet Scrubber with FF	Medium Energy Wet Scrubber with FF	FF	Low Energy Wet Scrubber	High Energy Wet Scrubber	DSI with FF	DSI with Carbon Injection and FF	DSI with FF and Scrubber	DSI with ESP
Criteria Pollutants										
NO_X	3.56	ND	ND	ND	ND	ND	ND	ND	ND	ND
CO	2.95	ND	ND	ND	ND	ND	ND	ND	ND	ND
SO_X	2.17	ND	0.375	0.845	2.09	0.0257	0.383	0.714	0.0151	ND
Total PM	4.67	0.909	0.161	0.175	2.90	1.48	0.337	0.0723	2.68	0.734
PM_{10}	3.04	ND	0.116	ND	2.09	ND	ND	ND	ND	ND
$PM_{2.5}$	2.02	ND	0.0043	ND	0.078	ND	ND	ND	ND	ND
VOC[c]	0.299	ND	ND	0.0686	0.140	0.140	0.0471	ND	ND	ND
HAPs										
Antimony	0.0128	ND	3.09×10^{-4}	ND	ND	4.08×10^{-4}	2.10×10^{-4}	1.51×10^{-4}	ND	ND
Arsenic	2.42×10^{-4}	ND	3.27×10^{-5}	3.95×10^{-8}	1.42×10^{-4}	3.27×10^{-5}	1.19×10^{-5}	1.46×10^{-5}	ND	5.01×10^{-5}
Beryllium	6.25×10^{-6}	ND	ND	ND	ND	ND	ND	3.84×10^{-6}	ND	ND
Cadmium	0.00548	ND	1.78×10^{-4}	ND	0.00697	0.0743	2.46×10^{-5}	9.99×10^{-5}	1.30×10^{-5}	5.93×10^{-4}
Chlorine	0.105	ND	ND	ND	ND	ND	ND	ND	ND	ND
Chromium	7.75×10^{-4}	ND	2.58×10^{-4}	2.15×10^{-6}	4.13×10^{-4}	0.00103	3.06×10^{-4}	1.92×10^{-4}	3.96×10^{-5}	6.58×10^{-4}
Dibenzo-furans	7.15×10^{-5}	ND	ND	8.50×10^{-6}	4.92×10^{-6} [d]	4.92×10^{-6} [d]	1.47×10^{-6}	9.47×10^{-8}	ND	1.73×10^{-9}
HCl	33.5	1.90	2.82	5.65	1.00	0.139	12.7	0.901	0.0943	0.498
Hydrogen Fluoride	0.149	ND	ND	ND	ND	ND	ND	0.0133	ND	ND
Lead	0.0728	ND	0.00160	9.92×10^{-5}	0.0794	0.0698	6.25×10^{-5}	9.27×10^{-5}	5.17×10^{-5}	0.00470
Manganese	5.67×10^{-4}	ND	ND	ND	4.66×10^{-4}	6.12×10^{-4}	ND	ND	ND	ND
Mercury	0.107	ND	0.0307	ND	0.0155	0.0173	0.111	0.00974	3.56×10^{-4}	0.0181
Nickel	5.90×10^{-4}	ND	5.30×10^{-4}	ND	3.28×10^{-4}	0.00254	4.54×10^{-4}	2.84×10^{-4}	ND	4.84×10^{-4}
PCBs	4.65×10^{-5}	ND	ND	ND	ND	ND	ND	ND	ND	ND

Table17-1. Emission Factors for Controlled-Air Medical Waste Incinerators (Cont'd)

Pollutant	Control Levels and Emission Factors (lb/ton)[a,b]									
	Uncontrolled	Low Energy Wet Scrubber with FF	Medium Energy Wet Scrubber with FF	FF	Low Energy Wet Scrubber	High Energy Wet Scrubber	DSI with FF	DSI with Carbon Injection and FF	DSI with FF and Scrubber	DSI with ESP
POM[e]	9.28×10^{-5}	ND	ND	1.12×10^{-5}	6.76×10^{-6} [d]	6.76×10^{-6} [d]	1.81×10^{-6}	1.49×10^{-7}	ND	1.90×10^{-9}
2,3,7,8-TCDD[f]	5.47×10^{-8}	ND	ND	6.72×10^{-9}	1.29×10^{-10} [e]	1.29×10^{-10} [e]	5.61×10^{-10}	8.23×10^{-10}	ND	1.73×10^{-10}

[a] Abbreviated control levels are defined as follows: FF = Fabric Filter; DSI = Dry Sorbent Injection; ESP = Electrostatic Precipitator
[b] Emission factors are in units of pounds pollutant emitted per ton of waste burned. ND = No Data
[c] Based on emission factors for Total Organic Compounds (TOC).
[d] Emission factors are based on incinerator controlled by a wet scrubber. However, the exact type of wet scrubber (low energy, medium energy, high energy) is not specified
[e] POM = Polycyclic Organic Matter. Each POM emission factor was estimated by adding together the emission factors for Total Chlorodibenzodioxins (Total CDD) and Total Chlorodibenzofurans (Total CDF).
[f] TCDD = Tetrachlorodibenzo-p-dioxin

Table 17-2. Emission Factors for Uncontrolled Industrial/Commercial Combustors

	Emission Factor (lb/ton)[a]			
	Multiple Chamber		Single Chamber	
Pollutant	**[SCC 5-02-001-01][b]**	**[SCC 5-03-001-01][c]**	**[SCC 5-02-001-02][b]**	**[SCC 5-03-001-02][c]**
Criteria Pollutants				
CO	10.0	10.0	20.0	20.0
NO_X	3.0	3.0	2.0	2.0
Total PM	7.0	7.0	15.0	15.0
PM_{10}	4.7	4.7	5.7	5.7
SO_X	2.5	2.5	2.5	2.5
VOC	3.0	3.0	15.0	15.0
HAPs				
Cadmium	ND	ND	ND	0.0069
Chromium (VI)	ND	ND	ND	2.12×10^{-6}
Hydrogen Chloride	10.0	ND	ND	ND
Lead	ND	ND	ND	0.0018
Mercury	ND	ND	ND	1.66×10^{-4}

[a] Emission factors are in units of pounds pollutant emitted per ton of waste burned. ND = No Data
[b] "Commercial/Institutional" type
[c] "Industrial" type

17.5 References

1. U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources* (AP-42), Section 2.1, October 1996.

2. U.S. Environmental Protection Agency, *Factor Information Retrieval System* (FIRE), Version 6.01, May 1998.

SECTION 18

LABORATORY CHEMICALS

18.1 Background: Chemical laboratories are commonly found at Air Force installations and are typically used for analytical, medical, and/or research purposes. A large variety of chemicals are used in these laboratories; including solvents, acids/bases, and other reagents.

The laboratory chemicals of concern for air emission inventory purposes are primarily liquid reagents which contain VOC and/or volatile HAP ingredients. Most emissions from laboratory chemicals occur during preparation/mixing in laboratory hoods. After preparation/mixing, the laboratory reagents to be used are usually kept in a closed container (e.g., flask). The reagent is subsequently used for a particular process and any excess/waste reagent is usually disposed off. Disposal methods vary according to the type of chemicals used, and can range from pouring into the sanitary sewer to shipping off-site as a hazardous waste.

18.2 Emission Calculations: The manner in which laboratory chemicals are used makes quantifying emissions difficult. However, work performed by Purdue University indicated that on average the emissions from laboratory chemicals are approximately 13% (by weight) of the total quantity of chemicals used. This 13% factor was also adopted by the University of Michigan. Based on this methodology, VOC and/or volatile HAP emissions from laboratory chemicals can be estimated using the following equation:

$$E_{pol} = QC * D * 0.13 * (WP/100)$$

Where,

E_{pol} = Emissions of a particular pollutant (lb/yr)
QC_{pol} = Quantity of a particular chemical/reagent used (gal/yr)
D = Density of the chemical/reagent (lb/gal) [note - density equals specific gravity times 8.33]
0.13 = Emission factor (unitless)
WP = Weight percent of the regulated pollutant found in the chemical/reagent (%)
100 = Factor for converting weight percent to weight fraction

18.3 Information Resources: Information regarding the types and quantities of laboratory chemicals/reagents used can usually be obtained from the laboratories which use the chemicals. This information may also be available from the HAZMAT Pharmacy or from the applicable supply office. Information pertaining to the composition (VOC and HAP content) and density of laboratory chemicals/reagents can be obtained from Material Safety Data Sheets, other product literature, or from the manufacturer.

18.4 Example Problem: A small laboratory on base uses three chemical reagents, hereby referred to as reagents A, B, and C. According to the laboratory supervisor, approximately 20 gallons of Reagent A, 10 gallons of Reagent B, and 25 gallons of Reagent C were used during the year. A review of product literature revealed the following composition and density for each reagent:

Reagent A: 100% 1-butanol (*n*-butyl alcohol); density equals 6.75 lb/gal
Reagent B: 100% methylene chloride; density equals 11.08 lb/gal

Reagent C: Formaldehyde solution containing 37% formaldehyde, 12% methanol, and 51% water; density equals 9.0 lb/gal

Calculate the VOC and HAP emissions from these reagents.

a. The first step is to identify the VOC and HAP ingredients in each reagent:

Reagent A: 1-butanol is a VOC but is not a HAP
Reagent B: methylene chloride is a HAP but is not a VOC
Reagent C: formaldehyde is both a VOC and a HAP; methanol is both a VOC and HAP

b. The second step is to calculate the VOC emissions from Reagent A:

E_{pol} = QC * D * 0.13 * (WP/100)
E_{VOC} = 20 gal/yr * 6.75 lb/gal * 0.13 * (100% / 100) = **17.6 lb/yr**

c. The next step is to calculate the HAP emissions from Reagent B:

E_{pol} = QC * D * 0.13 * (WP/100)
$E_{methylene\ chloride}$ = 10 gal/yr * 11.08 lb/gal * 0.13 * (100% / 100) = **14.4 lb/yr**

d. The final step is to calculate the VOC and HAP emissions from Reagent C:

E_{pol} = QC * D * 0.13 * (WP/100)
E_{VOC} = 25 gal/yr * 9.0 lb/gal * 0.13 * (49% / 100) = **14.3 lb/yr**
$E_{formaldehyde}$ = 25 gal/yr * 9.0 lb/gal * 0.13 * (37% / 100) = **10.8 lb/yr**
$E_{methanol}$ = 25 gal/yr * 9.0 lb/gal * 0.13 * (12% / 100) = **3.51 lb/yr**

18.5 References

1. University of Michigan, *University of Michigan Campus Emissions Inventory*, paper written for October 1997 conference titled “Emission Inventory: Planning for the Future.”

SECTION 19

LANDFILLS

19.1 Background: Many Air Force installations are known to have either active and/or closed landfills on their property. There are a variety of different types of waste which can be (or may have been) disposed of in landfills. Some of these waste types include municipal solid waste (i.e., typical household waste), commercial and industrial organic wastes, municipal sludge, construction/demolition wastes, agricultural wastes, etc. All landfills containing organic wastes will release gaseous emissions. According to AP-42, landfill gas consists of approximately 55 percent by volume methane, 40 percent carbon dioxide, 5 percent nitrogen (and other gases) and trace amounts of non-methane organic compounds (NMOC). Some landfills are equipped with gas collection systems and control devices. Gas collection systems are either active or passive systems. Active collection systems provide a pressure gradient to extract landfill gas by use of mechanical blowers or compressors. Passive systems allow the natural pressure gradient created by the increase in landfill pressure from landfill gas generation to mobilize the gas for collection. Once collected, the gas is sent to a control device such as flare, turbine, or internal combustion engine. Air Force landfills typically utilize a flare to combust the landfill gas.

In general, a three step process is used when disposing of waste in a landfill. This includes spreading the waste, compacting the waste, and covering the waste with soil. The step of covering the waste with soil is performed using heavy equipment (e.g., bulldozers, graders, etc.) and results in airborne emissions of fugitive dust (particulate matter). Although there may be significant emissions associated with the exhaust from the heavy equipment and other motorized vehicles (e.g., trucks) used at landfill sites, these emissions are considered “mobile source emissions” and are therefore not addressed in this document.

19.2 Emission Calculations

a. <u>Uncontrolled Emissions from Landfills</u>

As mentioned above, although landfill gas is composed mainly of methane and CO_2, it also contains small amounts of NMOC. Therefore, emissions of total NMOC (synonymous with VOC for air emission inventory purposes) and of individual organic HAPs must be calculated. The first step is to calculate the methane generation rate as follows:

$$Q_{CH4} = L_o R (e^{-kc} - e^{-kt})$$

Where,

Q_{CH4} = Methane volume generation rate at time t (m^3/yr)
L_o = Methane volume generation potential (m^3 CH_4/Mg refuse)
R = Average annual refuse acceptance rate during active life (Mg/yr)
[Note: 1 Mg = 1.1 tons]
e = Base log (unitless)
k = Methane volume generation rate constant (yr^{-1})
c = Time since landfill closure (yr) [Note: 0 for active landfills]
t = Time since the initial refuse placement (yr)

Site specific landfill information is generally available for variables R, c, and t. A k value of 0.04/yr should be used for areas receiving 25 inches or more of rainfall per year, while a k value of 0.02/yr should be used for areas receiving less than 25 inches of rainfall per year. An L_o value of 100 m^3/Mg refuse is appropriate for most landfills.

Once the methane volume generation rate is calculated, the volume generation rate of regulated pollutants (i.e., total NMOC and individual HAPs) can be calculated using the following equation:

$$Q_{pol} = [Q_{CH4} * 1.82] * [C_{pol} /(1 \times 10^6)]$$

Where,

Q_{pol} = Volume generation rate of a pollutant (m^3/yr)
Q_{CH4} = Methane volume generation rate (m^3/yr)
1.82 = Multiplication factor (assumes 55% of landfill gas is methane)
C_{pol} = Concentration of the pollutant in landfill gas (ppmv)
1×10^6 = Factor for converting "ppmv" into "volume fraction"

In most cases, the concentrations of pollutants (C_{pol}) in landfill gas emitted from a specific landfill are unknown. If site specific data is not available, average concentrations listed in Table 19-1 below can be used instead.

Table 19-1. Typical Pollutant Concentrations in Uncontrolled Landfill Gas[a]

Compound	Molecular Weight	Typical Concentration (ppmv)
Criteria Pollutants		
Total NMOC (as hexane)	86.17	2,420 or 595[b]
Hazardous Air Pollutants		
Acrylonitrile	53.06	6.33
Benzene	78.11	11.1 or 1.91[b]
Carbon disulfide	76.13	0.58
Carbon tetrachloride	153.84	0.004
Carbonyl sulfide	60.07	0.49
Chlorobenzene	112.56	0.25
Chloroethane (ethyl chloride)	64.52	1.25
Chloroform	119.39	0.03
Dichlorobenzene	147	0.21
1,1-Dichloroethane (ethylidene dichloride)	98.95	2.35
1,1-Dichloroethene (vinylidene chloride)	96.94	0.20
1,2-Dichloroethane (ethylene dichloride)	98.96	0.41
Dichloromethane (methylene chloride)	84.94	14.3
1,2-Dichloropropane (propylene dichloride)	112.98	0.18
Ethylbenzene	106.16	4.61
Hexane	86.18	6.57
Mercury (total)	200.61	2.92×10^{-4}
Methyl ethyl ketone	72.11	7.09
Methyl isobutyl ketone	100.16	1.87
Perchloroethylene (tetrachloroethylene)	165.83	3.73
1,1,2,2-Tetrachloroethane	167.85	1.11
Toluene	92.13	165 or 39.3[b]
1,1,1-Trichloroethane (methyl chloroform)	133.42	0.48
Trichloroethylene (trichloroethene)	131.38	2.82
Vinyl chloride	62.50	7.34
Xylenes	106.16	12.1

[a] Information obtained from AP-42. SCC 5-02-006-02

[b] The first value is suggested for landfills known to have co-disposal of municipal solid waste and non-residential waste (e.g., organic commercial/industrial wastes) while the second value should be used for landfills known to contain only municipal solid waste or have very little organic commercial/industrial wastes.

If the landfill is not equipped with a gas collection system/control device, then the volume generation rate of a pollutant (Q_{pol}) will equal to the uncontrolled volume emission rate of that pollutant (UQ_{pol}). However, as mentioned above, some landfills are equipped with a gas collection system and control device. According to AP-42, reported efficiencies for gas collection systems typically range from 60 to 85 percent, with an average of 75 percent most commonly assumed. This means that even if a landfill is equipped with a gas collection system/control device, approximately 25% of the gas emitted

from the landfill will be uncontrolled. Therefore, the following equation is used to calculate the uncontrolled volume emission rate of a pollutant (UQ_{pol}):

$$UQ_{pol} = Q_{pol} * [1-(CE/100)]$$

Where,

UQ_{pol} = Uncontrolled volume emission rate of a pollutant (m^3/yr)
Q_{pol} = Volume generation rate of the pollutant (m^3/yr)
CE = Capture efficiency of the gas collection system (%) [note - if unknown, assume 75%]

Once the uncontrolled volume emission rate of a pollutant is calculated, the uncontrolled mass emission rate of the pollutant (UM_{pol}) can be calculated using the following equation:

$$UM_{pol} = UQ_{pol} * (2.205) * MW_{pol} * (1 \text{ atm}) / [(8.205 \times 10^{-5}) (1000) (T)]$$

Where,

UM_{pol} = Uncontrolled mass emission rate of a pollutant (lb/yr)
UQ_{pol} = Uncontrolled volume emission rate of the pollutant (m^3/yr)
2.205 = Conversion factor (lb/kg)
MW_{pol} = Molecular weight of the pollutant (g/g-mole) [Note: see Table 19-1 above]
8.205×10^{-5} = Gas constant (m^3-atm/gmol-°K)
1000 = Conversion factor (g/kg)
T = Average temperature of landfill gas (°K) [Note: °K = 273 + °C]

Note: The EPA has a software program called the "Landfill Air Emissions Estimation Model" which calculates the uncontrolled volume emission rate and the uncontrolled mass emission rate of pollutants emitted from landfills which are not equipped with a gas collection system/control device . The program (file name "LAND_WIN.EXE") and the manual (file name "LAND_MAN.EXE or LAND_MAN.PDF") can be downloaded from the following website: http://134.67.104.12/html/ctc/ctcsft/htm

b. <u>Controlled Emissions from Landfills</u>

When a landfill is equipped with a gas collection system and control device, then the emissions from the control device must be added to the uncontrolled emissions (e.g., the emissions not captured by the collection system). In regards to the control device, Air Force facilities typically utilize a flare to combust the landfill gas collected by the collection device. Emissions from flares are calculated as follows:

$$FE_{pol} = (Q_{CH4} / 0.55) * (35.31) * (10^{-6}) * (CE/100) * EF$$

Where,

FE_{pol} = Flare emissions of a particular pollutant (lb/yr)
Q_{CH4} = Landfill methane generation rate (m^3/yr)
0.55 = Fraction of landfill gas which is methane (55% / 100)
35.31 = Unit conversion factor (ft^3/m^3)
10^{-6} = Factor for converting "ft^3" to "million ft^3"

CE = Capture efficiency of the gas collection system (%) [note - if unknown, assume 75%]
EF = Emission Factor (lb/million ft^3)

Emission factors for landfill flares are provided in Table 19-2 below.

Table 19-2. Emission Factors for Landfill Gas Flares[a]

Pollutant	Emission Factor (lb/million ft^3 gas burned)
Criteria Pollutants	
CO	3.47
NO_X	28.3
PM	53.0
SO_2	5.75
VOC	5.6
Hazardous Air Pollutants	
Pollutant	**Emission Factor (lb/million ft^3 gas burned)[b]**
Benzene	3.97×10^{-3}
Carbon Tetrachloride	4.03×10^{-4}
Chlorobenzene	1.53×10^{-3}
Chloroform	1.43×10^{-3}
Dibenzofurans	1.36×10^{-6}
Methylene Chloride	1.19×10^{-1}
Naphthalene	5.55×10^{-3}
PCB's	3.39×10^{-5}
Polycyclic Aromatic Hydrocarbons (Polycyclic Organic Matter)	5.44×10^{-1}
Tetrachloroethylene	1.93×10^{-3}
Toluene	6.83×10^{-2}
1,1,1 Trichloroethane	5.66×10^{-3}
Trichloroethylene	6.99×10^{-4}
Vinyl Chloride	2.31×10^{-3}
o-Xylene	7.27×10^{-3}
Xylene (mixed isomers)	1.24×10^{-2}

[a] Emission factors obtained from the EPA's FIRE program (version 6.01). SCC 5-02-006-01 and 5-03-006-01
[b] With the exception of the emission factor for polycyclic aromatic hydrocarbons, the HAP emission factors listed in the EPA FIRE program were in units of "lb/MMBtu Heat Input." These emission factors were converted to "lb/million ft^3 gas burned" by multiplying them times an estimated heating value for landfill gas of 555 MMBtu/million ft^3. The landfill gas heating value of 555 MMBtu/million ft^3 was calculated based on the fact that the heating value of methane is approximately 1,009 Btu/scf (Reference Hawley's Chemical Dictionary) and landfill gas is approximately 55% methane by volume (1,009 * 0.55 = 555).

c. Fugitive Particulate Matter Emissions from Landfills

As mentioned in the Background section above, fugitive dust (particulate matter) is emitted during the process of covering up the landfill waste with soil. Assuming that bulldozers and graders are the two main types of heavy equipment used to cover up the waste with soil, a review of AP-42 was performed to determine if fugitive dust emission factors exist for bulldozing and grading operations. Emission factors were subsequently found in section 11.9 of AP-42, "Western Surface Coal Mining." Table 19-3 below provides the emission factors extracted from this section which can be used with the following equation to estimate fugitive dust emissions from soil covering operations in landfills:

$$E_{pol} = [BEF * 2.205 * BOT] + [GEF * 2.205 * 1.609 * MT]$$

E_{pol} = Emissions of a particular pollutant (lb/yr) [note - the pollutant will be either Total Suspended Particulate (TSP) or PM_{10}]
BEF = Bulldozing Emission Factor (kg/hr)
2.2 = Unit conversion factor (lb/kg)
BOT = Estimated bulldozer operating time during the year (hr/yr)
GEF = Grader emission factor (kg/VKT) [Note: VKT = vehicle kilometers traveled]
1.609 = Unit conversion factor (km/mi)
MT = Estimated grader miles traveled during the year (VMT/yr) [Note: VMT = vehicle miles traveled]

Table 19-3. Fugitive Dust Emission Factors from Bulldozing and Grading Operations[a]

Operation	Emission Factor Values[b]		Emission Factor Units[c]
	Total Suspended Particulates (TSP)	PM_{10}	
Bulldozing (Overburden material)	$2.6\ (s)^{1.2}/(M)^{1.3}$	0.75	kg/hr
Grading	$0.0034(S)^{2.5}$	0.60	kg/VKT

[a] Emission factors were extracted from Table 11.9-1 of AP-42, "Emission Factor Equations for Uncontrolled Open Dust Sources at Western Surface Coal Mines"
[b] Symbols stand for the following: s = material silt content (%); M = material moisture content (%); and S = average vehicle speed (kilometers per hour). If s and M are unknown, assume 6.9% for s and 7.9% for M.
[c] VKT = Vehicle kilometers traveled

19.3 Information Resources: Base civil engineering is typically responsible for operating/maintaining on-base landfills and they should be contacted for specific landfill information. Base weather should be contacted to determine the annual average amount of rainfall received by the base. The average rainfall is required to determine the proper k value (methane generation rate constant) to use when calculating uncontrolled emissions.

19.4 Example Problem: An Air Force facility has an inactive landfill that has been closed for six years. The landfill originally opened 18 years ago and was used to dispose of residential (household) wastes only. Base civil engineering estimates the landfill received an average of 50,000 tons (45,455 Mg) of wastes per year. The landfill is equipped with a gas collection device (efficiency unknown) and a flare. The base is located in an area which receives an average of 36 inches of rain per year. The average temperature of the landfill gas is estimated to be 50 °F (10 °C). Calculate the current annual emission rate of total NMOC (considered the same as VOC) and of methylene chloride (dichloromethane).

a. The first step is to calculate the methane volume generation rate:

Q_{CH4} = L_o R (e^{-kc} - e^{-kt})
Q_{CH4} = 100 m^3/Mg * 45,455 Mg/yr * ($e^{-0.04 * 6}$ - $e^{-0.04 * 18}$) = <u>1.36 x 10^6 m^3/yr</u>

b. The second step is to calculate the volume generate rate for both total NMOC and for methylene chloride:

Q_{pol} = [Q_{CH4} * 1.82] * [C_p /(1 x 10^6)]
Q_{NMOC} = [(1.36 x 10^6 m^3/yr) * 1.82] * [595 ppmv/(1 x 10^6)] = <u>1,472 m^3/yr</u>
$Q_{methylene\ chloride}$ = [(1.36 x 10^6 m^3/yr) * 1.82] * [14.3 ppmv/(1 x 10^6)] = <u>35.4 m^3/yr</u>

c. The third step is to calculate the uncontrolled volume emission rate for both total NMOC and for methylene chloride:

UQ_{pol} = Q_{pol} * [1-(CE/100)]
UQ_{NMOC} = 1,472 m^3/yr * [1-(75%/100)] = <u>368 m^3/yr</u>
$UQ_{methylene\ chloride}$ = 35.4 m^3/yr * [1-(75%/100)] = <u>8.85 m^3/yr</u>

d. The fourth step is to calculate the uncontrolled mass emission rate for both total NMOC and for methylene chloride:

UM_{pol} = Q_p * (2.205) * MW_p * (1 atm)/ [(8.205 x 10^{-5}) (1000) (T)]
UM_{NMOC} = 386 m^3/yr * 2.205 lb/kg * 86.17 g/g-mol * 1 atm
/[(8.205 x 10^{-5} m^3-atm/gmol-°K) * (1000 g/kg) (283 °K)] = <u>3011 lb/yr</u>
$UM_{methylene\ chloride}$= 8.85 m^3/yr * 2.205 lb/kg * 84.94 g/g-mol * 1 atm
/[(8.205 x 10^{-5} m^3-atm/gmol-°K) * (1000 g/kg) (283 °K)] = <u>71.5 lb/yr</u>

e. The fifth step is to calculate the flare emissions of both total NMOC and for methylene chloride:

FE_{pol} = (Q_{CH4} / 0.55) * (35.31) * (10^{-6}) * (CE/100) * EF
FE_{NMOC} = [(1.36 x 10^6 m^3/yr) / 0.55] * (35.31) * (10^{-6}) * (75% / 100) * 5.6 lb/million ft^3
= <u>367 lb/yr</u>
$FE_{methlene\ chloride}$ = [(1.36 x 10^6 m^3/yr) / 0.55] * (35.31) * (10^{-6}) * (75% / 100) * 0.119 lb/million ft^3
= <u>7.8 lb/yr</u>

f. The final step is to calculate the total pollutant mass emissions by adding together the uncontrolled mass emissions and the flare mass emissions:

Total Emissions = UM_{pol} + FE_{pol}
Total Emissions (VOC) = 3,011 lb/yr + 367 lb/yr = **<u>3,378 lb/yr</u>**
Total Emissions (methylene chloride) = 71.5 lb/yr + 7.8 lb/yr = **<u>79.3 lb/yr</u>**

19.5 References

1. U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources* (AP-42), Section 2.4, September 1997.

2. U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources* (AP-42), Section 11.9, September 1988.

3. U.S. Environmental Protection Agency, *Factor Information Retrieval System* (FIRE), Version 6.01, May 1998.

4. U.S. Environmental Protection Agency, *Landfill Air Emissions Estimations Model*, Version 2.0, February 1998.

5. Hawley's Condensed Chemical Dictionary, Twelfth Edition, 1993.

6. Emissions Inventory Improvement Program (EIIP), *Volume III: Chapter 15, "Landfills,"* September 1997.

SECTION 20

MISCELLANEOUS CHEMICAL USE

20.1 Background: Miscellaneous chemicals include various products (e.g., cleaners, solvents, light lubricants/oils, adhesives, sealants, etc.) which are not covered under any of the other source types already addressed in this document. In general, these are chemicals which are used up in process (i.e., no waste is collected) and are uncontrolled.

The primary pollutants of concern associated with miscellaneous chemical use are VOC and organic HAPs. Emissions of these pollutants are a result of product evaporation. However, inorganic HAPs are also a concern when found in products which are spray applied.

Since the emissions from organic chemicals are a result of product evaporation, those organic chemical products which have an extremely low vapor pressure (e.g., < 0.1 mm Hg) are usually not addressed in an air emission inventory. Examples include heavy lubricants/oils, greases, hydraulic fluids, glycol deicers, non-solvent (aqueous) cleaners, etc.

20.2 Emission Calculations: Emissions from miscellaneous chemical use are calculated based on material balance. The emissions of a regulated pollutant are calculated by multiplying the volume quantity of chemical product used times the density of the chemical product and then times the weight fraction (weight percent divided by 100) of the pollutant in the chemical product.

$$E_{pol} = QC * D * (WP/100)$$

Where,

E_{pol} = Emissions of a particular pollutant (lb/yr)
QC = Quantity of chemical product used (gal/yr)
D = Density of the chemical product (lb/gal)
WP = Weight percent of the pollutant in the chemical product (%)
100 = Factor for converting weight percent to weight fraction

20.3 Information Resources: Most of the usage information required to calculate emissions from miscellaneous chemicals (e.g., name, stock number, and manufacturer of applicable chemicals; identity of shops using the chemicals; quantity used by each shop; etc.) can be obtained from the HAZMAT Pharmacy or from Bioenvironmental Engineering. In some cases, it may be necessary to contact the shops using the chemicals to obtain more specific information.

Information pertaining to the composition (VOC and HAP content) and density of miscellaneous chemicals can be obtained from Material Safety Data Sheets, other product literature, or from the manufacturer.

20.4 Example Problem: A shop on base uses the following chemical products to clean and repair equipment parts:

Chemical Product	Quantity Used (gal/yr)	Density (lb/gal)	VOC Content (% by weight)	HAP Constituents and their Weight Percent
Isopropyl Alcohol	12	6.5	100%	None
General Purpose Cleaner	9	8.4	30%	None
Dry Film Lubricant (Aerosol)	6	9.3	85%	Toluene (35%) Methylene Chloride (20%) Antimony Trioxide (2%) Lead Phosphite (1%)
General Adhesive	1.5	6.2	76%	Methyl ethyl ketone (40%) Toluene (15%)

Calculate the VOC and HAP emissions from these chemicals.

a. First calculate the VOC emissions from the isopropyl alcohol.

E_{pol} = QC * D * (WP/100)
E_{VOC} = 12 gal/yr * 6.5 lb/gal * (100% / 100) = **78 lb/yr**

b. Second, calculate the VOC emissions from the general purpose cleaner.

E_{pol} = QC * D * (WP/100)
E_{VOC} = 9 gal/yr * 8.4 lb/gal * (30% / 100) = **23 lb/yr**

c. Next, calculate the VOC and HAP emissions from the dry film lubricant (note - since this lubricant is an aerosol spray, emissions of the inorganic HAP constituents must be calculated).

E_{pol} = QC * D * (WP/100)
E_{VOC} = 6 gal/yr * 9.3 * (85% / 100) = **47 lb/yr**
$E_{toluene}$ = 6 gal/yr * 9.3 * (35% / 100) = **20 lb/yr**
$E_{methylene\ chloride}$ = 6 gal/yr * 9.3 * (20% / 100) = **11 lb/yr**
$E_{antimony}$ = 6 gal/yr * 9.3 * (2% / 100) = **1.1 lb/yr**
E_{lead} = 6 gal/yr * 9.3 * (1% / 100) = **0.6 lb/yr**

d. Finally, calculate the VOC and HAP emissions from the general adhesive.

E_{pol} = QC * D * (WP/100)
E_{VOC} = 1.5 gal/yr * 6.2 lb/gal * (76% / 100) = **7.1 lb/yr**
E_{MEK} = 1.5 gal/yr * 6.2 lb/gal * (40% / 100) = **3.7 lb/yr**
$E_{toluene}$ = 1.5 gal/yr * 6.2 lb/gal * (15% / 100) = **1.4 lb/yr**

SECTION 21

NON-DESTRUCTIVE INSPECTION

21.1 Background: Air Force installations with aircraft maintenance operations typically have a Non-Destructive Inspection (NDI) shop where metal parts are inspected for cracks, fractures, and other flaws. NDI shops use a variety of chemicals to inspect and clean metal parts. Some of these chemicals include inspection penetrants, penetrant removers, penetrant developers, alcohol cleaners (e.g., isopropyl, denatured, methanol), other cleaning compounds (e.g., Electron), etc. The primary emissions of concern from the use of these chemicals are VOC and organic HAPs. ODSs may also be of concern since some inspection chemicals contain methyl chloroform.

There are two general techniques used at NDI to inspect and clean parts. The first technique involves placing chemicals into a tank and then submerging/soaking parts in the chemical. The chemical(s) in a tank bath are periodically replaced when they become too dirty or no longer meet specifications. The removed waste chemicals are collected and sent off-site for disposal. The primary sources of emissions from this technique include direct evaporation (e.g., during storage/use in the tank, during transfer in and out of the tank, etc.) and carryout (i.e., evaporation from wet parts after removal from the tank). The second technique simply involves spraying chemicals on the parts using a spray can or bottle. These chemicals typically include items such as cleaning compounds (e.g., isopropyl alcohol, Electron, etc.) and spotcheck inspection penetrants. With this technique, the entire amount of chemical used is assumed to be emitted into the atmosphere.

21.2 Emission Calculations: Calculating emissions associated with NDI chemicals is accomplished using a mass balance approach. The specific method in which emissions are calculated is dependent on how the chemical is used. The following are the calculation methods for the two chemical use techniques described above:

a. Tank Baths

Emissions from chemicals used in a tank bath are calculated using the following equation:

$$E_{pol} = [(VA - VR) * D] * [WP/100]$$

Where,

E_{pol} = Emissions of a particular pollutant (lb/yr)
VA = Volume of chemical added to the tank during the year (gal/yr)
VR = Volume of chemical removed from the tank for disposal (gal/yr)
D = Density of the chemical (lb/gal) [note - density equals specific gravity times 8.33]
WP = Weight percent of the pollutant in the chemical (%)

b. Spray Applications

As mentioned above, for chemicals which are sprayed on, it is assumed that the entire quantity of used is emitted into the atmosphere. Therefore, emissions associated with sprayed on chemicals can be calculated using the following equation.

E_{pol} = VU * D * [WP/100]

Where,

E_{pol} = Emissions of a particular pollutant (lb/yr)
VU = Volume of chemical used (gal/yr)
D = Density of the chemical (lb/gal) [note - density equals specific gravity times 8.33]
WP = Weight percent of the pollutant in the chemical (%)

21.3 Information Resources: Information regarding chemical usage can be obtained from the NDI shop. Information pertaining to the composition (VOC, HAP, ODS content) and density of the chemicals used can be obtained from Material Safety Data Sheets, other product literature, or from the manufacturer.

21.4 Example Problem: The NDI shop on base uses three chemicals to inspect and clean metal parts. Specific information on each of these chemicals is found in the table below. Calculate the VOC, HAP, and ODS emissions.

Chemical	**Density (lb/gal)**	**Ingredients**	**Use Technique**	**Fresh Solvent Added/Used (gal/yr)**	**Waste Solvent Removed (gal/yr)**
Inspection Penetrant	7.2	• 100% Petroleum Hydrocarbons	Tank Bath	100	95
Penetrant Remover	10.8	• 99% Methyl Chloroform • 1% 1,4-Dioxane	Tank Bath	90	80
Isopropyl Alcohol	6.6	• 100% Isopropyl Alcohol	Sprayed On	8	Not Applicable

a. The first step is to calculate the emissions associated with the inspection penetrant. Since the penetrant is 100% petroleum hydrocarbons, the emissions of concern are VOCs.

E_{pol} = [(VA - VR) * D] * [WP/100]
$E_{VOC(penetrant)}$ = [(100 gal/yr - 95 gal/yr) * 7.2 lb/gal] * [100% / 100] = **36 lb/yr**

b. The second step is to calculate the emissions associated with the penetrant remover. The methyl chloroform ingredient is a HAP and an ODS (note - it is not a VOC since it is specifically listed in 40 CFR 51.100 as having negligible photochemical reactivity). The 1,4-Dioxane ingredient is a HAP and a VOC.

E_{pol} = [(VA - VR) * D] * [WP/100]
$E_{methyl\ chloroform}$ = [(90 gal/yr - 80 gal/yr) * 10.8 lb/gal] * [99% / 100] = **107 lb/yr**
$E_{1,4\text{-}Dioxane}$ = [(90 gal/yr - 80 gal/yr) * 10.8 lb/gal] * [1% /100] = **1 lb/yr**
$E_{VOC(remover)}$ = **1 lb/yr**

c. The third step is to calculate the emissions associated with the isopropyl alcohol. Isopropyl alcohol is a VOC.

E_{pol} = VU * D * [WP/100]
$E_{VOC(alcohol)}$ = 8 gal/yr * 6.6 lb/gal * [100% / 100] = **53 lb/yr**

4. The final step is to sum up the total VOC, total HAP, and total ODS emissions.

$E_{VOC(total)}$ = 36 lb/yr + 1.1 lb/yr + 53 lb/yr = **90 lb/yr**
$E_{HAP(total)}$ = 107 lb/yr + 1 lb/yr = **108 lb/yr**
$E_{ODS(total)}$ = **107 lb/yr**

SECTION 22

OPEN BURNING/OPEN DETONATION OF ENERGETIC MATERIALS

22.1 Background: Open Burning/Open Detonation (OB/OD) is one of the primary methods used to dispose of bulk and assembled (encapsulated) energetic materials in the Air Force. Although incineration and demanufacturing are the environmentally-preferred methods of disposal, they are not used on many types of energetic materials due to safety and financial reasons.

Bulk energetic materials include bulk explosives (e.g., TNT, Composition B, Amatol, C-4, smokeless powder, etc.) and bulk propellants (e.g., M1, M6, M9, M30, MK-6, etc.). Assembled energetic materials are items in which the explosive material is contained in a metal casing. Examples of assembled energetic materials include small arms ammunition, high explosive incinerary (HEI) cartridges, bomb fuzes, mines, flares/signals, and other munitions.

The emissions of concern from OB/OD operations include the criteria pollutants and a variety of HAPs (both organic and inorganic). Emissions are dependent on the type and quantity of energetic material which is burned or detonated. The energetic composition of some common propellants and explosives are listed in Table 22-1 below.

During the 1980's the DOD began conducting tests in an effort to quantify emissions from OB/OD operations. Much of this testing was coordinated with the U.S. EPA. The EPA is currently in the process of developing a report and database which incorporates the results of testing performed thus far. Data from a draft version of EPA's report/database are provided in Appendix F of this document [note - the final report/database is expected to be completed by fall 1998. The EPA point of contact for the report/database is Dr. William Mitchell (919-541-2769)]. The emission factors are in units of mass of pollutant emitted per mass of energetic material (MEM) burned or detonated (e.g., gram pollutant per gram energetic material, or pound pollutant per pound energetic material). To facilitate the detonation of assembled energetic materials (i.e., munitions), a donor charge (e.g., C-4 explosive, detonation cord, smokeless powder, etc.) is usually attached. When a donor charge is used, the MEM used to calculate emissions includes the MEM contained in the munitions <u>and</u> the MEM of the donor charge used to help initiate the detonation.

The MEM contained in the munitions addressed in the EPA's database are listed in Table 22-2 below. This table also lists the names and weight percentages of the primary energetic compounds found in these munitions. Unfortunately, there are many types of munitions used in the Air Force which are currently not listed in EPA's database. However, until additional data (e.g., emission factors) become available, emissions from a particular non-listed munition can be estimated by using the emission factors for a listed munition which most closely resembles the non-listed munition of interest, or by using the alternative calculation techniques described in subsection 22.2b below. The composition and MEM for most munitions used in the military can be obtained from the Army's Munitions Items Disposition Action System (MIDAS). The Internet address for MIDAS is: http://206.39.34.252/midas/index.html. In order to use MIDAS, you must first register and obtain a password from the Army's Defense Ammunition Center (DAC). Registration can be accomplished via the Internet. The MEM is determined by adding up all the energetic components/parts in the munition. In most cases, MIDAS uses one of the following terms to identify the energetic components/parts in a munition: PEP, PROP, PYRO, or PELLET BOOSTER. It's important to note that in many cases MIDAS will also lists "alternative" energetic components/parts for a munition and that the mass of these alternative components/parts <u>should not</u> be included when determining the MEM for the munition (note - alternative components/parts are identified by the abbreviation "ALT").

In addition to developing a database, the EPA is assisting the Army in evaluating several computer models which can be used to predict emissions from OB/OD operations. The following are the names of the four primary programs being evaluated along with the organizations responsible for developing them: POLU13 (Navy), MERLIN (Army), PCAD (El Dorado, Inc.), and ADORA (Blaze Tech, Inc.). According to the EPA, they are also evaluating a fifth model which was developed by the Naval Research Laboratory. IERA/RSEQ will keep track of EPA's evaluation progress and will provide updated information on our Internet site (http://sg-www.satx.disa.mil/iera/rse/air.htm).

Table 22-1. Energetic Composition of Common Explosives and Propellants

Explosive or Propellant	Main Energetic Ingredients and their Weight Percentages
M1 Propellant	85% nitrocellulose, 10% dinitrotoluene, 5% dibutylphthalate, 1% diphenylamine, 1% potassium sulfate
M2 Propellant	77.45% nitrocellulose, 19.5% nitroglycerin, 1.4% barium nitrate
M6 Propellant	87.7% nitrocellulose, 9.7% dinitrotoluene, 2.5% dibutylphthalate, 0.86% diphenylamine, 0.74% potassium sulfate
M9 Propellant	57.75% nitrocellulose, 40% nitroglycerin, 1.5% potassium nitrate, 0.75% ethyl centralite
NOSIH-AA2 Double-base Propellant	51% nitrocellulose, 38.6% nitroglycerin, 5.9% ethyl cellulose, 2.7% triacetin, 2.0% di-n-propyl adipate, 2.0% copper salicylate, 1.5% lead salicylate
NOSIH-AA6 Propellant	49% nitrocellulose, 38.8% nitroglycerin, 3.25% triacetin, 2.0% di-n-propyl adipate, 2.0% 2-nitrodiphenylamine, 1.7% lead salicylate, 1.6% copper salicylate, 1.5% aluminum
MK-6 Composite Propellant	85% ammonium perchlorate, 8.0% hydroxy-terminated polybutadiene, 4.5% dioctyl sebacate, 1.0% aluminum oxide
MK-23 CTBN Propellant	80% ammonium perchlorate, 14.2% carboxyl-terminated polybutadiene, 2.0% aluminum powder
MK-43 LOVA Propellant	76% RDX, 12% cellulose acetate butyrate, 4.0% nitrocellulose, 7.6% of a mix of bis (2,2-dinitropropyl) acetal and bis (2,2-dinitropropyl) formal
PBXN-110 Propellant	88% HMX, 5.0% hydroxyl-terminated polybutadiene, 5.0% isodecyl pelargonate
M30 Triple-base Propellant	47.7% nitroguanidine, 28% nitrocellulose, 22.5% nitroglycerin, 1.5% ethyl centralite
M31A1E1 Triple-base Propellant	55% nitroguanidine, 22% nitrocellulose, 18% nitroglycerin, 1.5% ethyl centralite
WC872 Propellant	86.5% nitrocellulose, 8.5% nitroglycerin
Composition B Explosive	59.5% RDX, 39.5% TNT
HBX (aluminized form of Composition B)	83% Composition B, 17% aluminum powder
Explosive D	99.9% ammonium picrate
C-4 Explosive	91% RDX, 9% polyisobutylene binder
Smokeless Powder (Hercules Unique)	95% nitrocellulose, 5% nitroglycerin
Black Powder	74% potassium nitrate, 15.6% charcoal, 10.4% sulfur
Amatol Explosive	50% TNT, 50% aluminum powder
Tritonal Explosive	80% TNT, 20% aluminum powder
Composition A5 Explosive	98.5% RDX, 1.5% stearic acid

Table 22-2. Mass Energetic Material (MEM) and Energetic Composition of the Munitions Addressed in EPA's Database

Munition Type	Mass Energetic Material (grams/munition)	Energetic Composition (Major Ingredients only)
20 mm HEI Cartridge, M56A4	48.6	69.2% nitrocellulose, 17.9% RDX, 6.8% nitroglycerin
40 mm HEI Cartridge, M384	59	90.3% RDX, 5.9% nitrocellulose, 1.9% stearic acid, 1.5% nitroglycerin
Cartridge, Impulse, M187, ARD446-1	14.8	37.8% nitrocellulose, 33.8% potassium nitrate, 10.8% nitroglycerin, 6.1% charcoal, 6.1% sulfur, 5.4% ethyl centralite
Cartridge, Impulse, BBU-36/B	0.875	71.1% nitrocellulose, 13.7% potassium nitrate, 4.2% potassium perchlorate, 3.7% nitroglycerin, 3.4% barium amorphous powder
Cartridge, Impulse, MK107	24.6	70.7% nitrocellulose, 20.3% nitroglycerin, 4.9% potassium nitrate, 4.1% barium nitrate
Flare, IR Countermeasure, M206	138.6	magnesium powder (> 65%, exact content is classified), 0.9% potassium perchlorate, 0.9% barium amorphous powder, 0.9% barium chromate
Fuze, Tail Bomb, FMU-139A/B	126	100% tetryl
Fuze, Tail Bomb, FMU-54A/B	163.9	99.9% tetryl,
Gas Generator, GGU-2/A	95.3	Composition is classified
Mine, Claymore, M18A1	681	100% C-4
Signal, Illumination, Red Star AN-M43A2	55.8	43.9% strontium nitrate, 23.6% potassium perchlorate, 17.7% magnesium powder, 6.9% asphaltum, 5.9% hexachlorbenzene, 0.75 % potassium nitrate
Signal, Illumination, Red Star M158	36.8	Complete composition is unknown. The known contents include: 29.9% potassium nitrate, 14.1% strontium nitrate, 6.8% black powder, 6.8% magnesium, 6.8% charcoal
T45E7 Adapter-booster	73.2	98% tetryl, 2% graphite

22.2 Emission Calculations:

a. EPA Database Method

Emissions from OB/OD disposal of energetic materials can be estimated utilizing the emission factors in the EPA's database. The specific method used to calculate emissions is dependent on whether the energetic material of concern is bulk or assembled, and whether the disposal method is open burning or open detonation. The following equations are used to calculate emissions:

(1) *Open Burning or Open Detonation of Bulk Energetic Materials*

$$E_{pol} = MEM * EF$$

Where,

E_{pol} = Emissions of a particular pollutant (lb/yr)
MEM = Total mass of energetic material which is open burned or open detonated during the year (lb/yr)
EF = Emission factor (lb/lb)

(2) *Open Burning of Assembled Energetic Materials (Munitions)*

$$E_{pol} = MEM * QM * 0.002205 * EF$$

Where,

E_{pol} = Emissions of a particular pollutant (lb/yr)
MEM = Mass of energetic material contained in the munition item (grams/item or grams/round)
QM = Quantity of the munition open burned during the year (items/yr or rounds/yr)
0.002205 = Factor for converting grams to pounds (lb/gram)
EF = Emission factor (lb/lb)

(3) *Open Detonation of Assembled Energetic Materials (Munitions)*

$$E_{pol} = (MEM + MDC) * QM * 0.002205 * EF$$

Where,

E_{pol} = Emissions of a particular pollutant (lb/yr)
MEM = Mass of energetic material contained in the munition item (grams/item or grams/round)
MDC = Estimated mass of donor charge used per munition item (grams/item or grams/round)
QM = Quantity of the munition open detonated during the year (items/yr or rounds/yr)
0.002205 = Factor for converting grams to pounds (lb/gram)
EF = Emission factor (lb/lb)

b. Alternative Methods

In addition to using emission factors from the database, EPA's draft report also cites some alternative methods which can be used to estimate emissions from OB/OD disposal operations.

(1) *Metals* – emissions of metal pollutants (e.g., lead, chromium, cadmium, etc.) from detonation operations can be estimated by assuming all the metal contained in the energetic material(s) is released into the atmosphere. The emissions are calculated by multiplying the MEM detonated by the weight fraction (weight percent divided by 100) of the metal pollutant contained in the energetic materials.

(2) *PM_{10} and Hydrocarbons* – emissions of PM_{10}, total hydrocarbons, and a couple of organic HAPs (benzene and toluene) can be estimated using general emission factors found in Tables 22-3 and 22-4 below.

(3) *CO, NO_X, PM_{10}* – emissions of CO, NO_X, and PM_{10} can be estimated by using general emission factors found in Tables 22-5 and 22-6 below. The CO emission factors are based on the carbon content of the energetic material while the NO_X emission factors are based on the nitrogen content of the energetic material. The percent carbon and percent nitrogen found in some common types of energetic materials are listed in Table 22-7 below. The PM_{10} emission factors found in Tables 22-5 and 22-6 are weighted averages of the category emission factors listed in Tables 22-3 and 22-4.

Table 22-3. Mean Emission Factors for Selected Open Detonation Pollutants

Pollutant	**Category**	**No. of Sample Values[a]**	**Mean Emission Factor (lb/lb)[b]**
PM_{10}	Encapsulated	12	0.30
	Bulk	8	0.13
Total Hydrocarbons	Encapsulated	11	8.6×10^{-4}
	Bulk	8	1.8×10^{-4}
Benzene	Encapsulated	11	6.9×10^{-5}
	Bulk	8	9×10^{-6}
Toluene	Encapsulated	11	2.6×10^{-5}
	Bulk	8	4×10^{-6}

[a] All samples are from Bang Box testing
[b] Pound pollutant emitted per pound of energetic material detonated

Table 22-4. Mean Emission Factors for Selected Open Burning Pollutants

Pollutant	Category	No. of Sample Values[a]	Mean Emission Factor (lb/lb)[b]
PM_{10}	AP-based[c]	4	0.15
	Organic-based	7	0.28
Total Hydrocarbons	AP-based[c]	4	3.7×10^{-5}
	Organic-based	7	2.9×10^{-5}
Benzene	AP-based[c]	4	1.5×10^{-6}
	Organic-based	7	3.0×10^{-6}
Toluene	AP-based[c]	3	0.0
	Organic-based	7	0.8×10^{-6}

[a] All samples are from Bang Box testing
[b] Pound pollutant emitted per pound of energetic material burned
[c] AP = ammonium perchlorate

Table 22-5. Emission Factor Averages Across Categories for Detonations

Pollutant	Mean Emission Factor
CO	0.0394 pounds per pound of carbon in energetic material detonated
NO_X	0.0178 pounds per pound of nitrogen in energetic material detonated
PM_{10}	0.230 pounds per pound of energetic material detonated

Table 22-6. Emission Factor Averages Across Categories for Burns

Pollutant	Mean Emission Factor
CO	0.00285 pounds per pound of carbon in energetic material burned
NO_X	0.0089 pounds per pound of nitrogen in energetic material burned
PM_{10}	0.233 pounds per pound of energetic material burned

Table 22-7. Elemental Composition of Certain Energetic Materials

Energetic Material	Elemental Composition
Ammonium Nitrate	H (5%); N (35%); O (60%)
Ammonium Perchlorate	Cl (30.2%); H (3.4%); N (11.9%); O (54.5%)
Black Powder	C (15.6%); KNO3 (74%); S (10.4%)
Charcoal	C (100.0%)
Diazodinitrophenol	C (34.3%); H (0.9%); O (38.1%); N (26.7%)
Diphenylamine	C (85.1%); N (8.3%); N (6.6%)
Explosive D (Ammonium Picrate)	C (29.3%); H (2.4%); N (22.7%); O (45.6%)
Haleite	C (16.0%); H (4.0%); N (37.3%); O (42.7%)
HMX	C (16.2%); H (2.7%); N (37.9%); O (43.2%)
Lead Azide	N (28.8%); Pb (71.2%)
Lead Styphnate	C (15.4%); H (0.6%); N (9.0%); O (30.8%); Pb (44.2%)
Lead Thiocyanate	C (4.5%); N (5.3%); Pb (78.1%); S (12.1%)
Mercury Fulminate	C (8.4%); Hg (70.6%); N (9.8%); O (11.2%)
Nitrocellulose	C (26.46%); H (2.78%); N (12.6%); O (58.16%)
Nitroglycerine	C (15.9%); H (2.2%); N (18.5%); O (63.4%)
Nitroguanidine	C (11.5%); H (3.9%); N (53.8%); O (30.8%)
PETN	C (19.0%); H (2.5%); N (17.7%); O (60.8%)
Phosphorous	P (100.0%)
Potassium Chlorate	Cl (28.9%); K (31.8%); O (39.3%)
Potassium Sulfate	K (44.8%); O (36.8%); S (18.4%)
RDX	C(16.3%); H (2.7%); N (37.8%); O (43.2%)
Tetryl	C (29.3%); H (1.7%); N (24.4%); O (44.6%)
TNT	C (37.0%); H (2.2%); N (18.5%); O (42.3%)

22.3 Information Resources: Information pertaining to the type and quantity of munitions disposed of via OB/OD can be obtained from the base Explosive Ordnance Disposal (EOD) shop. The EOD shop will also know which method (open burning or open detonation) was used on each munition type as well as the type and quantity of donor charges used to facilitate detonation of encapsulated munitions. Information about specific munitions (e.g., MEM content and composition) can be obtained from the Army's MIDAS program or from the base EOD shop.

22.4 Example Problem: The EOD shop on base disposes of a variety of munitions via open burning and open detonation. Two types of munitions which are open detonated at the base include TNT and 40 mm HEI cartridges. According to EOD records, approximately 45 pounds of TNT were open detonated during the year. EOD records also showed that twenty (20) 40 mm HEI cartridges were detonated during the year. According to EOD personnel, a donor charge of approximately 10 grams C-4 explosive was used per 40 mm cartridge. Calculate the criteria pollutant and HAP emissions associated with the open detonation of the TNT and 40 mm cartridges:

a. The first step is to calculate the emissions associated with the open detonation of TNT (note - the TNT is a bulk energetic material). Emission factors are found in Appendix F. A review of these emission factors reveals that there are three different sets of emission factors for TNT: TNT (ACC1), TNT (ACC2), and TNT (Sandia). In those cases where a pollutant has more than one emission factor, the average value should be used.

E_{pol} = MEM * EF

Pollutant	MEM Detonated (lb/yr)		Emission Factor (lb/lb)		Emissions (lb/yr)
Criteria					
CO	45	x	8.4×10^{-3}	=	0.38
NO_X ($NO + NO_2$; as NO_2)	45	x	1.5×10^{-2}	=	0.68
PM_{10}	45	x	8.3×10^{-2}	=	3.7
SO_X	45	x	1.4×10^{-4}	=	6.3×10^{-3}
VOC (Total Non-methane Hydrocarbons)	45	x	3.4×10^{-5}	=	1.5×10^{-3}
HAPs					
Antimony	45	x	6.7×10^{-7}	=	3.0×10^{-5}
Benzene	45	x	3.7×10^{-6}	=	1.7×10^{-4}
1,3-Butadiene	45	x	1.0×10^{-6}	=	4.5×10^{-5}
Cadmium	45	x	2.1×10^{-5}	=	9.5×10^{-4}
Chromium	45	x	1.3×10^{-5}	=	5.9×10^{-4}
Ethylbenzene	45	x	4.7×10^{-7}	=	2.1×10^{-5}
Lead	45	x	9.0×10^{-6}	=	4.1×10^{-4}
Methylene Chloride	45	x	1.8×10^{-4}	=	8.1×10^{-3}
Styrene	45	x	1.5×10^{-6}	=	6.8×10^{-5}
Toluene	45	x	3.3×10^{-6}	=	1.5×10^{-4}

b. The second step is to calculate the emissions associated with the open detonation of the 40 mm cartridges (note - the 40 mm cartridge is a type of assembled energetic material). Once again, the emission factors are found in Appendix F.

E_{pol} = [MEM + MDC] * QM * 0.002205 * EF

Pollutant	MEM in Cartridge (grams/round)		Donor Charge (grams/round)		Cartridges Detonated (rounds/yr)		Conversion Factor (lb/gram)		Emission Factor (lb/lb)		Emissions (lb/yr)
Criteria Pollutants											
CO	[59	+	10]	*	20	*	0.002205	*	2.1×10^{-2}	=	0.064
PM_{10}	[59	+	10]	*	20	*	0.002205	*	4.7×10^{-1}	=	1.43
VOC (Total Non-methane Hydrocarbons)	[59	+	10]	*	20	*	0.002205	*	3.3×10^{-4}	=	1.0×10^{-3}
HAPs											
Benzene	[59	+	10]	*	20	*	0.002205	*	2.8×10^{-5}	=	8.5×10^{-5}
1,3-Butadiene	[59	+	10]	*	20	*	0.002205	*	1.9×10^{-6}	=	5.8×10^{-6}
Cadmium	[59	+	10]	*	20	*	0.002205	*	3.2×10^{-5}	=	9.7×10^{-5}
Carbon Tetrachloride	[59	+	10]	*	20	*	0.002205	*	4.5×10^{-6}	=	1.4×10^{-5}
Chromium	[59	+	10]	*	20	*	0.002205	*	8.8×10^{-5}	=	2.7×10^{-4}
Ethyl Benzene	[59	+	10]	*	20	*	0.002205	*	2.5×10^{-6}	=	7.6×10^{-6}
n-Hexane	[59	+	10]	*	20	*	0.002205	*	1.9×10^{-5}	=	5.8×10^{-5}
Lead	[59	+	10]	*	20	*	0.002205	*	3.7×10^{-4}	=	1.1×10^{-3}
Methylene Chloride	[59	+	10]	*	20	*	0.002205	*	8.7×10^{-4}	=	2.6×10^{-3}
Styrene	[59	+	10]	*	20	*	0.002205	*	4.2×10^{-5}	=	1.3×10^{-4}
Toluene	[59	+	10]	*	20	*	0.002205	*	2.6×10^{-5}	=	7.9×10^{-5}

22.5 References

1. U.S. Environmental Protection Agency, *Emission Factors for the Disposal of Energetic Materials by Open Burning and Open Detonation (OB/OD)*, Draft Version, 17 July 1998.

2. U.S. Army Defense Ammunition Center, *Munitions Items Disposition Action System (MIDAS)*, Central Library Version 74, 1 May 1998.

3. U.S. Army Armament, Munitions and Chemical Command, *Development of Methodology and Technology for Identifying and Quantifying Emission Products from Open Burning and Open Detonation Thermal Treatment Methods*, Field Test Series A, B, and C, Volume 1 - Test Summary, January 1992.

SECTION 23

OPEN/PRESCRIBED BURNING

23.1 Background:

a. Open Burning

Open burning is performed on some Air Force installation as a means of disposing of a various types of agricultural refuse such as leaves, wood, forest residue, field crops (including grasses and wild hay), weeds, etc. Open burning can be done in open drums or baskets, in fields and yards, and in large open dumps or pits. Emissions from organic agricultural refuse burning are dependent mainly on the moisture content of the refuse and, in the case of the field crops, on whether the refuse is burned in a headfire or a backfire. Headfires are started at the upwind side of a field and allowed to progress in the direction of the wind, whereas backfires are started at the downwind edge and forced to progress in a direction opposing the wind. Other variables such as fuel loading (how much refuse material is burned per unit of land area) and how the refuse is arranged (in piles, rows, or spread out) are also important in certain instances.

b. Prescribed Burning

Prescribed burning is a land treatment method, used under controlled conditions, to accomplish natural resource management objectives. Prescribed burning is a cost-effective and ecologically sound tool for forest, range, and wetland management. Prescribed fires are conducted within the limits of a fire plan and prescription that describes both the acceptable range of weather, moisture, fuel, and fire behavior parameters, and the ignition method to achieve the desired effects. The use of prescribed burning reduces the potential for destructive wildfires, removes logging residues, controls insects and disease, improves wildlife habitat and forage production, increases water yield, maintains natural succession of plant communities, and reduces the need for pesticides and herbicides.

Methods of prescribed burning differ with fire objectives and with fuel and weather conditions. For example, the various ignition techniques used to burn standing trees include: (1) heading fire - a line of fire that runs with the wind; (2) backing fire - a line of fire that moves into the wind; (3) spot fires - a number of fires ignited along a line or in a pattern; and (4) flank fire - a line of fire that is lit into the wind, to spread laterally to the direction of the wind. Methods of igniting the fires depend on forest management objectives and the size of the area.

The combustion process associated with prescribed burning is divided into the following four phases: preheating, flaming, glowing, and smoldering. The different phases of combustion greatly affect the amount of emissions produced. The preheating phase seldom releases significant quantities of material to the atmosphere. Glowing combustion is usually associated with burning of large concentrations of woody fuels such as logging residue piles. The smoldering combustion phase is a very inefficient and incomplete combustion process that emits pollutants at a much higher ratio to the quantity of fuel consumed than does the flaming combustion of similar materials.

23.2 Emission Calculations: Emissions from open/prescribed burning are calculated by first determining the estimated quantity (mass) of each type of agricultural/forest material burned during the year and then multiplying this quantity by the appropriate emission factor.

$$E_{pol} = MB * EF$$

Where,

E_{pol} = Emissions of pollutant during the year (lb/yr)
MB = Mass of material burned during the year (ton/yr)
EF = Emission Factor (lb/ton)

For open/prescribed burning of certain types of growing vegetation, the mass of material burned (MB) can be estimated by multiplying the area of material burned (acres/yr) by the fuel loading factor (e.g., tons material/acre).

$$MB = AB * FLF$$

Where,

MB = Mass of material burned during the year (ton/yr)
AB = Area of material burned (acres/yr)
FLF = Fuel Loading Factor (tons/acre)

The emission factors associated with open/prescribed burning are found in Tables 23-1 through 23-4 below.

Table 23-1. Criteria Pollutant Emission Factors for Open Burning of Agricultural Materials[a,b,c]

Refuse Category	PM[d] (lb/ton)	CO (lb/ton)	Nonmethane VOC (lb/ton)	NO_X (lb/ton)	Fuel Loading Factors [waste production] (ton/acre)
Wood (SCC 5-02-002-01)	17	140	19	4	ND
Field Crops (SCC 5-02-002-03)					
Unspecified	21	117	18	[e]	2
Grasses	16	101	15	[e]	ND
Wild Hay (Headfire Burning)	32	139	17	[e]	1.0
Wild Hay (Backfire Burning)	17	150	13	[e]	1.0
Weeds (SCC 5-02-002-05)					
Unspecified	15	85	9	[e]	3.2
Russian thistle (tumbleweed)	22	309	1.5	[e]	0.1
Tales (wild reeds)	5	34	21	[e]	ND
Forest Residues (SCC 5-02-002-07)					
Unspecified	17	140	19	4	70
Hemlock, Douglas fir, cedar	4	90	4	4	ND
Ponderosa pine	12	195	11	4	ND

[a] The general SCC for the "Wood/Vegetation/Leaves" category is 5-03-002-01. Other more specific SCCs are listed in the first column of this table.
[b] Emission factors are expressed as weight (pounds) of pollutant emitted per weight (tons) of refuse burned.
[c] ND = No Data
[d] Particulate matter from most agricultural refuse burning has been found to be submicron in size.
[e] No NO_X emission factors are given for these specific emission sources. However, a NO_X emission factor of 4 lb/ton is listed for the general "Wood/Vegetation/Leaves" source category.

Table 23-2. Criteria Pollutant Emission Factors for Leaf Burning[a,b,c]

Leaf Species	PM[d] (lb/ton)	CO (lb/ton)	Nonmethane VOC (lb/ton)
Black Ash	36	127	27
Modesto Ash	32	163	24
White Ash	43	113	32
Catalpa	17	89	13
Horse Chestnut	54	147	40
Cottonwood	38	90	28
American Elm	26	119	19
Eucalyptus	36	90	27
Sweet Gum	33	140	25
Black Locust	70	130	52
Magnolia	13	55	10
Silver Maple	66	102	49
American Sycamore	15	115	11
California Sycamore	10	104	7
Tulip	20	77	15
Red Oak	92	137	69
Sugar Maple	53	108	40
Unspecified	38	112	28

[a] The general SCC for the "Wood/Vegetation/Leaves" category is 5-03-002-01.
[b] Emission factors are expressed as weight (pounds) of pollutant emitted per weight (tons) of refuse burned.
[c] No NO_X emission factors are given for these specific emission sources. However, a NO_X emission factor of 4 lb/ton is listed for the general "Wood/Vegetation/Leaves" source category.
[d] The majority of particulate matter is submicron in size.

Table 23-3. HAP Emission Factors for Open Burning of Agricultural Materials[a]

Refuse Category	Acetaldehyde (lb/ton)	Polycyclic Organic Matter [POM] (lb/ton)
Wood/Vegetation/Leaves (SCC 5-03-002-01)	1.46	0.013

[a] Emission factors are expressed as weight (pounds) of pollutant emitted per weight (tons) of refuse burned.

Table 23-4. Emission Factors for Prescribed Burning[a,b,c]

Fire/Fuel Configuration	Phase[d]	Pollutants (lb/ton)					
		Particulate					
		$PM_{2.5}$	PM_{10}	Total	Carbon Monoxide	Nonmethane VOCs	Fuel Mix (%)
Broadcast Logging slash							
Hardwood	F	12	14	26	88	7.6	33
	S	26	28	40	292	15.4	67
	Fire	22	24	36	224	12.8	
Conifer							
Short needle	F	14	16	24	144	4.2	33
	S	28	30	38	452	8.4	67
	Fire	24	26	34	350	7	
Long needle	F	12	12	18	90	3.4	33
	S	32	34	50	332	10.8	67
	Fire	26	26	40	252	8.4	
Logging slash debris							
Dozer piled conifer							
No mineral soil	F	8	8	10	56	ND	90
	S	12	14	28	232	ND	10
	Fire	8	8	12	74	ND	
10 to 30% Mineral soil	S	ND	ND	50	400	ND	ND
25% Organic soil	S	ND	ND	70	500	ND	ND
Range fire							
Juniper slash	F	14	16	22	82	5.4	ND
	S	24	26	36	250	15.6	ND
	Fire	18	20	28	164	10.4	
Sagebrush	F	30	32	46	156	6.8	ND
	S	26	30	46	212	14.6	ND
	Fire	26	30	46	206	13.8	
Chaparral shrub communities	F	14	16	32	112	16.4	ND
	S	24	26	46	266	31.2	ND
	Fire	20	22	40	202	25	

Table 23-4. Emission Factors for Prescribed Burning[a,b,c] (Cont'd)

Fire/Fuel Configuration	Phase[d]	Pollutants (lb/ton)					Fuel Mix (%)
		Particulate					
		$PM_{2.5}$	PM_{10}	Total	Carbon Monoxide	Nonmethane VOCs	
Line fire							
Conifer							
Long needle (pine)	Heading	ND	80	100	400	ND	
	Backing	ND	40	40	250	ND	
Palmetto/gallberry	Heading	ND	30	34	300	ND	
	Backing	ND	30	30	200	ND	
	Fire	ND	16 - 44	ND	ND	ND	
Chaparral	Heading	16	18	30	124	7	
Grasslands	Fire	ND	20	20	150	0	

[a] When conducting an air emission inventory for prescribed burning, the U.S. Forest Service and/or State forestry agencies can be contacted for additional information such as the estimated amount (tons) of fuel (trees/vegetation) consumed per acre.
[b] No specific NO_X emission factors are given. However, according to AP-42, NO_X from prescribed burning is emitted at rates of 2 to 8 lb/ton, depending on combustion temperatures.
[c] ND = No Data
[d] F = flaming; S = smoldering; Fire = weighted average of F and S

23.3 Information Resources: Open/prescribed burning is usually accomplished by, or under the direction of, the base civil engineering organization. Base civil engineering should be able to provide an estimate of the type(s) and quantities of vegetation burned. If prescribed burning is performed, it may be necessary to contact a government agency (e.g., the U.S. Forest Service, State/local forestry agency, etc.) for additional information, such as the estimated mass (tons) of a specific vegetation per area (acre) of land.

23.4 Example Problem: According to base Civil Engineering, the only open burning performed during the year was on an 18 acre field of wild hay using the "headfire burning" method. Calculate both the criteria and HAP emissions from the open burning of this field.

a. The first step is to calculate the mass of wild hay burned..

$$MB = AB * FLF$$
$$MB = (18 \text{ acres/yr}) * (1.0 \text{ tons/acre}) = 18 \text{ tons/yr}$$

b. The next step is to calculate the pollutant emissions using the appropriate emission factors.

$$E_{pol} = MB * EF$$

Pollutant	Mass Material Burned (tons/yr)		Emission Factor (lb/ton)		Emissions (lb/yr)
Criteria Pollutants					
CO	18	x	139	=	2,502
NO_X	18	x	4	=	72
PM	18	x	32	=	576
VOC	18	x	17	=	306
HAPs					
Acetaldehyde	18	x	1.46	=	26.3
POM	18	x	0.013	=	0.23

23.5 References

1. U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources* (AP-42), Section 2.5, October 1992 (Reformatted January 1995).

2. U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources* (AP-42), Section 13.1, October 1996.

SECTION 24

OZONE DEPLETING SUBSTANCES

24.1 Background: Ozone depleting substances (ODSs) are found in a variety of products used on Air Force installations. Class I and Class II ozone depleting substances regulated under Title VI of the Clean Air Act are listed below in Tables 24-1 and 24-2 respectively. The most common types of ODS-containing products used on Air Force installations are refrigerants (i.e., CFCs and HCFCs), fire extinguishing agents (i.e., Halons), cleaning solvents (e.g., methyl chloroform, carbon tetrachloride, etc.), and sterilants (e.g., CFC-12 and ethylene oxide blend). Other types of ODS-containing products which may be used at Air Force installations include pesticides, foam blowing agents, coatings, adhesives, and aerosols.

Table 24-1. Class I Ozone Depleting Substances

Substance	Chemical Name	ODP[a]	CAS Number
	Group I		
$CFCl_3$ (CFC-11)	Trichlorofluoromethane	1.0	75-69-4
CF_2Cl_2 (CFC-12)	Dichlorodifluoromethane	1.0	75-71-8
$C_2F_3Cl_3$ (CFC-113)	1,1,1-Trichlorotrifluoroethane	0.8	354-58-5
	1,1,2-Trichlorotrifluoroethane	0.8	76-13-1
$C_2F_4Cl_2$ (CFC-114)	Dichlorotetrafluoroethane	1.0	76-14-2
C_2F_5Cl (CFC-115)	Monochloropentafluoroethane	0.6	76-15-3
All isomers of the above chemicals			
	Group II		
CF_2ClBr (Halon 1211)	Bromochlorodifluoromethane	3.0	353-59-3
CF_3Br (Halon 1301)	Bromotrifluoromethane	10.0	75-63-8
$C_2F_4Br_2$ (Halon 2402)	Dibromotetrafluoroethane	6.0	124-73-2
All isomers of the above chemicals			
	Group III		
CF_3Cl (CFC-13)	Chlorotrifluoromethane	1.0	75-72-9
C_2FCl_5 (CFC-111)	Pentachlorofluoroethane	1.0	354-56-3
$C_2F_2Cl_4$ (CFC-112)	Tetrachlorodifluoroethane	1.0	76-12-0
C_3FCl_7 (CFC-211)	Heptachlorofluoropropane	1.0	422-78-6
$C_3F_2Cl_6$ (CFC-212)	Hexachlorodifluoropropane	1.0	3182-26-1
$C_3F_3Cl_5$ (CFC-213)	Pentachlorotrifluoropropane	1.0	2354-06-5
$C_3F_4Cl_4$ (CFC-214)	Tetrachlorotetrafluoropropane	1.0	29255-31-0
$C_3F_5Cl_3$ (CFC-215)	Trichloropentafluoropropane	1.0	1599-41-3
$C_3F_6Cl_2$ (CFC-216)	Dichlorohexafluoropropane	1.0	661-97-2
C_3F_7Cl (CFC-217)	Chloroheptafluoropropane	1.0	422-86-6
All isomers of the above chemicals			
	Group IV		
CCl_4	Carbon tetrachloride	1.1	56-23-5

Table 24-1. Class I Ozone Depleting Substances (Cont'd)

Substance	Chemical Name	ODP[a]	CAS Number
	Group V		
$C_2H_3Cl_3$ All isomers of the above chemical except 1,1,2-trichloroethane	Methyl Chloroform (1,1,1-trichloroethane)	0.1	71-55-6
	Group VI		
CH_3Br	Methyl bromide	0.7	74-83-9
	Group VII		
$CHFBr_2$		1.0	
CHF_2Br (HBFC-2201)		0.74	
CH_2FBr		0.73	
C_2HFBr_4		0.3 - 0.8	
$C_2HF_2Br_3$		0.5 - 1.8	
$C_2HF_3Br_2$		0.4 - 1.6	
C_2HF_4Br		0.7 - 1.2	
$C_2H_2FBr_3$		0.1 - 1.1	
$C_2H_2F_2Br_2$		0.2 - 1.5	
$C_2H_2F_3Br$		0.7 - 1.6	
$C_2H_3FBr_2$		0.1 - 1.7	
$C_2H_3F_2Br$		0.2 - 1.1	
C_2H_4Br		0.07 - 0.1	
C_3HFBr_6		0.3 - 1.5	
$C_3HF_2Br_5$		0.2 - 1.9	
$C_3HF_3Br_4$		0.3 - 1.8	
$C_3HF_4Br_3$		0.5 - 2.2	
$C_3HF_5Br_2$		0.9 - 2.0	
C_3HF_6Br		0.7 - 3.3	
$C_3H_2FBr_5$		0.1 - 1.9	
$C_3H_2F_2Br_4$		0.2 - 2.1	
$C_3H_2F_3Br_3$		0.2 - 5.6	
$C_3H_2F_4Br_2$		0.3 - 7.5	
$C_3H_2F_5Br$		0.9 - 1.4	
$C_3H_3FBr_4$		0.08 - 1.9	
$C_3H_3F_2Br_3$		0.1 - 3.1	
$C_3H_3F_3Br_2$		0.1 - 2.5	
$C_3H_3F_4Br$		0.3 - 4.4	
$C_3H_4FBr_3$		0.03 - 0.3	
$C_3H_4F_2Br_2$		0.1 - 1.0	
$C_3H_4F_3Br$		0.07 - 0.8	
$C_3H_5FBr_2$		0.04 - 0.4	
$C_3H_5F_2Br$		0.07 - 0.8	
C_3H_6FBr		0.02 - 0.7	

[a] Ozone Depletion Potential

Table 24-2. Class II Ozone Depleting Substances

Substance	ODP[a]
$CHFCl_2$-Dichlorofluoromethane (HCFC-21)	[Reserved]
CHF_2Cl-Chlorodifluoromethane (HCFC-22)	0.05
CH_2FCl-Chlorofluoromethane (HCFC-31)	[Reserved]
C_2HFCl_4-(HCFC-121)	[Reserved]
$C_2HF_2Cl_3$-(HCFC-122)	[Reserved]
$C_2HF_3Cl_2$-(HCFC-123)	0.02
C_2HF_4Cl-(HCFC-124)	0.02
$C_2H_2FCl_3$-(HCFC-131)	[Reserved]
$C_2H_2F_2Cl_2$-(HCFC-132b)	[Reserved]
$C_2H_2F_3Cl$-(HCFC-133a)	[Reserved]
$C_2H_3FCl_2$-(HCFC-141b)	0.12
$C_2H_3F_2Cl$-(HCFC-142b)	0.06
C_3HCFCl_6-(HCFC-221)	[Reserved]
$C_3HF_2Cl_5$-(HCFC-222)	[Reserved]
$C_3HF_3Cl_4$-(HCFC-223)	[Reserved]
$C_3HF_4Cl_3$-(HCFC-224)	[Reserved]
$C_3HF_5Cl_2$-(HCFC-225ca)	[Reserved]
C_3HF_5Cl-(HCFC-225cb)	[Reserved]
C_3HF_6Cl-(HCFC-226)	[Reserved]
$C_3H_2FCl_5$-(HCFC-231)	[Reserved]
$C_3H_2F_2Cl_4$-(HCFC-232)	[Reserved]
$C_3H_2F_3Cl_3$-(HCFC-233)	[Reserved]
$C_3H_2F_4Cl_2$-(HCFC-234)	[Reserved]
$C_3H_2F_5Cl$-(HCFC-235)	[Reserved]
$C_3H_3FCl_4$-(HCFC-241)	[Reserved]
$C_3H_3F_2Cl_3$-(HCFC-242)	[Reserved]
$C_3H_3F_3Cl_2$-(HCFC-243)	[Reserved]
$C_3H_3F_4Cl$-(HCFC-244)	[Reserved]
$C_3H_4FCl_3$-(HCFC-251)	[Reserved]
$C_3H_4F_2Cl_2$-(HCFC-252)	[Reserved]
$C_3H_4F_3Cl$-(HCFC-253)	[Reserved]
$C_3H_5FCl_2$-(HCFC-261)	[Reserved]
$C_3H_5F_2Cl$-(HCFC-262)	[Reserved]
C_3H_6FCl-(HCFC-271)	[Reserved]
All isomers of the above chemicals	

[a]Ozone Depletion Potential

24.2 Emission Calculations: The first step in calculating ODS emissions is to identify those products on base which contain an ODS. Once the ODS-containing products have been identified, emissions can be estimated using a mass balance approach. In general, the ODS emissions from an applicable process are considered equal to the amount of ODS used minus the amount removed for purposes of disposal, recycling, or reclamation. In some cases, emissions of certain ODS-containing products (e.g., sterilants, coatings, etc.) may be controlled using devices such as incinerators, carbon adsorbers, or refrigeration

units. In these cases, the efficiency of the control device must be considered when calculating ODS emissions.

$$E_{ODS} = (QP - QR) * (WP/100) * [1- (eff/100)]$$

Where,

E_{ODS} = ODS emissions from a particular process (lb/yr)
QP = Quantity (mass) of ODS-containing product used in the process (lb/yr)
QR = Quantity (mass) of ODS-containing product removed from the process for purposes of disposal, recycling, or reclamation (lb/yr)
WP = Weight percent of ODS in the product (%)
eff = Efficiency of control device, if applicable (%)

24.3 Information Resources: Records/data maintained by the Hazardous Materials Pharmacy should be used to identify which products on base contain ODS and to identify which shops use them. The weight percent of ODS in each applicable product can be determined from Material Safety Data Sheets or other product literature provided by the manufacturer. Information on the quantity of ODS (or ODS-containing products) used and recovered can be obtained from the applicable shops using the products. A listing of organizations/shops on base which may potentially use ODS-containing products is found in the following table:

Product Type	**Possible User Organizations/Shops**
Refrigerants	Civil Engineering, AGSE, Vehicle Maintenance, Auto Hobby
Fire Extinguishing Agents	Fire Department
Sterilants	Hospital/clinic
Cleaning solvents, coatings, adhesives, aerosols	Various organizations/shops including Aircraft Maintenance, Vehicle Maintenance, CE Structural Maintenance, Auto Hobby, Wood Hobby, etc.
Pesticides	Entomology
Foam Blowing Agents	Packing and Crating

If a control device (e.g., incinerator, carbon adsorber, refrigerated condenser, etc.) is used to control emissions of ozone-containing products (typically sterilants and coatings), the manufacturer of the control device should be contacted to determine the estimated control efficiency.

24.4 Example Problem: According to base Civil Engineering, approximately 1,900 pounds of pure HCFC-22 were added to base air conditioning systems during the year while 650 pounds were removed/recovered and turned-in to the Defense Reserve maintained by the Defense Logistics Agency (DLA). Calculate the annual emissions of HCFC-22.

$$E_{ODS} = (QP - QR) * (WP/100) * [1-(eff/100)]$$
$$E_{HCFC\text{-}22} = (1{,}900 \text{ lb/yr} - 650 \text{ lb/yr}) * (100\% / 100) * [1- (0\% / 100)] = \mathbf{1{,}250 \text{ lb/yr}}$$

24.5 References

1. Title 40 Code of Federal Regulations Part 82 (40 CFR 82), "Protection of Stratospheric Ozone."

2. U.S. Environmental Protection Agency's Significant New Alternatives Policy (SNAP) Program [Internet address: http://www.epa.gov/spdpublc/title6/snap/snap.html]

SECTION 25

PESTICIDE APPLICATION

25.1 Background: Pesticides are used at most Air Force installations as a means of controlling plant and animal life. Pesticides include herbicides, insecticides, fungicides, and rodenticides. Pesticides come in a variety of formulations, such as ready to use liquid, emulsifiable concentrate, aqueous concentrate, granule, dust/powder, soluble powder, wettable powder, aerosol spray, etc. Pesticide application methods vary according to the target pest and to the crop or other item to be protected. Some examples include applying directly on the pests, on the host plant, on the soil surface, below the soil surface, in an enclosed air space, etc. The air emissions of concern include the VOCs and organic HAPs emitted during or soon after (e.g., within 30 days) after application.

25.2 Emission Calculations

a. HAP Emissions

Virtually all HAP emissions associated with pesticide application are a result of evaporation of the organic HAP ingredients in the pesticide. The first step in calculating the HAP emissions is to identify the organic HAP ingredients in the pesticide. The next step is to determine the weight percent of each of the organic HAPs. This is done by either reviewing the Material Safety Data Sheet, reviewing the pesticide label (or other product information), or by contacting the manufacturer. Once the weight percent of each organic HAP is known, emissions can be calculated by dividing the weight percent by 100 (to get the weight fraction) and then multiplying this value times the amount (mass) of pesticide applied.

$$E_{HAP} = WP_{HAP}/100 * QP$$

Where,

E_{HAP} = Emissions of a particular HAP (lb/yr)
WP_{HAP} = Weight percent of HAP in the pesticide (%)
QP = Quantity of pesticide applied (lb/yr) [Note - if the mass (pounds) of pesticide applied is not known but the volume (gallons) is, then the mass can be calculated by multiplying the volume times the pesticide density (lb/gal). Also, if the density is not known but the specific gravity is, the density can be calculated by multiplying the specific gravity times the density of water (8.33 lb/gal).

b. VOC Emissions

The method used to calculate the VOC emissions from pesticide application depends on whether the weight percent VOC in the pesticide is known. Unfortunately, in many cases the weight percent VOC is not listed on the MSDS or other product literature (note - either the VOC content is not given or it is listed as a volume percent). If the weight percent can not be found in any product literature, the manufacturer should be contacted to see if they can provide it.

(1) *VOC Emissions (if weight percent VOC is known)*

If the weight percent VOC in the pesticide is known, VOC emissions can be calculated in the same manner in which HAP emissions are calculated. The weight percent VOC is first divided by 100 (to obtain the weight fraction) and this value is then multiplied times the amount (mass) of pesticide applied.

$$E_{VOC} = WP_{VOC}/100 * QP$$

Where,

E_{VOC} = Emissions of VOC (lb/yr)
WP_{VOC} = Weight percent of VOC in the pesticide (%)
QP = Quantity of pesticide applied (lb/yr) [see the Note above for the QP parameter in the HAP Emissions section]

(2) *VOC Emissions (if weight percent VOC is unknown)*

If the weight percent VOC in the pesticide is unknown, the best way to calculate the emissions is to divide the pesticide into its two major component groups, the active ingredient portion and the inert portion. According to AP-42, the EPA is only concerned with the VOC emissions which are expected to occur within 30 days after application of the pesticide (note - this is because after 30 days degradation processes and surface runoff can have major effects on the loss of active ingredients). In general, ingredients which have a vapor pressure above 0.3 mm Hg are assumed to completely volatilize within 30 days of application. Most inert ingredients are typically organic solvents which have a high volatility (i.e., vapor pressure above 0.3 mm Hg). On the other hand, although the active ingredients in pesticides are usually organic compounds, they typically have a low volatility (i.e., vapor pressure below 0.3 mm Hg). Since most active ingredients have a low volatility, only a portion (typically less than 66%) will volatilize within 30 days. The amount which volatilizes depends on the vapor pressure of the active ingredient, the type of formulation (e.g., ready to use liquid solution, emulsifiable concentrate, aqueous concentrate, etc.), and type of application (e.g., surface application, soil incorporation). Estimating the VOC emissions when the weight percent VOC is unknown can be accomplished using the following equation:

$$E_{VOC} = [WP_{active}/100 * QP * 0.0005 * EF] + [WP_{inert}/100 * QP * WP_{VOC\text{-}inert}/100]$$

Where,

E_{VOC} = Emissions of VOC (lb/yr)
WP_{active} = Weight Percent of Active Ingredient portion in pesticide (%)
QP = Quantity of pesticide applied (lb/yr)
0.0005 = Unit conversion factor (ton/lb)
EF = Emission factor (lb/ton) [note - this refers to pounds VOC emitted per ton of active ingredient applied]
WP_{inert} = Weight Percent of Inert portion in pesticide (%)
$WP_{VOC\text{-}inert}$ = Weight Percent VOC in the Inert portion of the pesticide (%)

It's important to note that the weight percent VOC in the inert portion of the pesticide ($WP_{VOC\text{-}inert}$) is not the same as the weight percent VOC in the entire pesticide (WP_{VOC}). In some cases, the $WP_{VOC\text{-}inert}$ can be derived by reviewing the inert ingredients (and their corresponding weight percentages) listed in the MSDS. If the $WP_{VOC\text{-}inert}$ is not known and can not be derived from the MSDS, then the appropriate average value listed in Table 25-1 below can be used. These values are based on the pesticide's formulation type.

Emission factors (EFs) associated with the active ingredient portion of pesticides are listed in Table 25-2 below. These emission factors are dependent on the vapor pressure of the active ingredient and on the type of application (i.e., surface application or soil incorporation). Vapor pressures for some of the common active ingredients found in pesticides are listed in Table 25-3 below.

Table 25-1. Average VOC Contents of the Inert Portion of Various Pesticide Formulations

Formulation Type	Average VOC Content Of Inert Portion (wt. %)
Oils	66
Solution/liquid (ready to use)	20
Emulsifiable concentrate	56
Aqueous concentrate	21
Gel, paste, cream	40
Pressurized gas	29
Flowable (aqueous) concentrate	21
Microencapsulated	23
Pressurized liquid/sprays/foggers	39
Soluble powder	12
Impregnated material	38
Pellet/tablet/cake/briquette	27
Wettable powder	25
Dust/powder	21
Dry flowable	28
Granule/flake	25
Suspension	15
Paint/coatings	64

Table 25-2. Uncontrolled VOC Emission Factors for Pesticide Active Ingredients

Vapor Pressure Range (mm Hg at 20 to 25°C)	Emission Factor (lb/ton)[a]
Surface application (SCC 24-61-800-001)	
1×10^{-4} to 1×10^{-6}	700
$>1 \times 10^{-4}$	1,160
Soil incorporation (SCC 24-61-800-002)	
$<1 \times 10^{-6}$	5.4
1×10^{-4} to 1×10^{-6}	42
$>1 \times 10^{-4}$	104

[a] Emissions Factors are in units of pounds VOC emitted per ton of active ingredient applied.

Table 25-3. Vapor Pressures for Common Pesticide Active Ingredients

Active Ingredient	Vapor Pressure (mm Hg at 20 to 25°C)
1,3-Dichloropropene	29
2,4-D acid	8.0×10^{-6}
Acephate	1.7×10^{-6}
Alachlor	1.4×10^{-5}
Aldicarb	3.0×10^{-5}
Aldoxycarb	9×10^{-5}
Amitraz	2.6×10^{-6}
Amitrole (aminotriazole)	4.4×10^{-7}
Atrazine	2.9×10^{-7}
Azinphos-methyl	2.0×10^{-7}
Benefin (benfluralin)	6.6×10^{-5}
Benomyl	$< 1.0 \times 10^{-10}$
Bifenox	2.4×10^{-6}
Bromacil acid	3.1×10^{-7}
Bromoxynil butyrate ester	1.0×10^{-4}
Butylate	1.3×10^{-2}
Captan	8.0×10^{-8}
Carbaryl	1.2×10^{-6}
Carbofuran	6.0×10^{-7}
Chlorobenzilate	6.8×10^{-6}
Chloroneb	3.0×10^{-3}
Chloropicrin	18
Chlorothalonil	1.0×10^{-3} (estimated)
Chlorpyrifos	1.7×10^{-5}
Clomazone (dimethazone)	1.4×10^{-4}
Cyanazine	1.6×10^{-9}
Cyromazine	3.4×10^{-9}
DCNA (dicloran)	1.3×10^{-6}
DCPA (chlorthal-dimethyl; Dacthal®)	2.5×10^{-6}
Diazinon	6.0×10^{-5}
Dichlobenil	1.0×10^{-3}
Dicofol	4.0×10^{-7}

Table 25-3. Vapor Pressures for Common Pesticide Active Ingredients (Cont'd)

Active Ingredient	Vapor Pressure (mm Hg at 20 to 25°C)
Dicrotofos	1.6×10^{-4}
Dimethoate	2.5×10^{-5}
Dinocap	4.0×10^{-8}
Disulfoton	1.5×10^{-4}
Diuron	6.9×10^{-8}
Endosulfan	1.7×10^{-7}
EPTC	3.4×10^{-2}
Ethalfluralin	8.8×10^{-5}
Ethion	2.4×10^{-6}
Ethoprop (ethoprophos)	3.8×10^{-4}
Fenamiphos	1.0×10^{-6}
Fenthion	2.8×10^{-6}
Fluometuron	9.4×10^{-7}
Fonofos	3.4×10^{-4}
Isofenphos	3.0×10^{-6}
Lindane	3.3×10^{-5}
Linuron	1.7×10^{-5}
Malathion	8.0×10^{-6}
Methamidophos	8.0×10^{-4}
Methazole	1.0×10^{-6}
Methiocarb (mercaptodimethur)	1.2×10^{-4}
Methomyl	5.0×10^{-5}
Methyl parathion	1.5×10^{-5}
Metolachlor	3.1×10^{-5}
Metribuzin	$< 1.0 \times 10^{-5}$
Mevinphos	1.3×10^{-4}
Molinate	5.6×10^{-3}
Naled	2.0×10^{-4}
Norflurazon	2.0×10^{-8}
Oxamyl	2.3×10^{-4}
Oxyfluorfen	2.0×10^{-7}
Parathion (ethyl parathion)	5.0×10^{-6}

Table 25-3. Vapor Pressures for Common Pesticide Active Ingredients (Cont'd)

Active Ingredient	Vapor Pressure (mm Hg at 20 to 25°C)
PCNB	1.1×10^{-4}
Pendimethalin	9.4×10^{-6}
Permethrin	1.3×10^{-8}
Phorate	6.4×10^{-4}
Phosmet	4.9×10^{-7}
Profenofos	9.0×10^{-7}
Prometon	7.7×10^{-6}
Prometryn	1.2×10^{-6}
Propachlor	2.3×10^{-4}
Propanil	4.0×10^{-5}
Propargite	3.0×10^{-3}
Propazine	1.3×10^{-7}
Propoxur	9.7×10^{-6}
Siduron	4.0×10^{-9}
Simazine	2.2×10^{-8}
Tebuthiuron	2.0×10^{-6}
Terbacil	3.1×10^{-7}
Terbufos	3.2×10^{-4}
Thiobencarb	2.2×10^{-5}
Thiodicarb	1.0×10^{-7}
Toxaphene	4.0×10^{-6}
Triallate	1.1×10^{-4}
Tribufos	1.6×10^{-6}
Trichlorfon	2.0×10^{-6}
Trifluralin	1.1×10^{-4}
Triforine	2.0×10^{-7}

25.3 Information Resources: Information about the names, stock numbers, and quantities of each pesticide applied on base should be available from the base entomology shop. Data on the chemical and physical properties/composition of a the pesticides can usually be found on the MSDS, product label (or other product information), or by contacting the product manufacturer. In addition, data on pesticide formulations may also be found in the following publications:

- *Farm Chemicals Handbook* (published annually by Meister Publishing Company, Willoughby, OH)
- *Agricultural Chemical Usage: 1991 Field Crops Summary.* U.S. Department of Agriculture (USDA), Washington, D.C., 1992

25.4 Example Problem: A base applied 25 gallons of a Dursban insecticide (Stock # 6840-00K000019) during the year. All applications were to the ground surface. According to the MSDS, the pesticide is an emulsifiable concentrate with the following composition (note - all percentages are by weight): 22.4% chlorpyrifos (active ingredient), 42.1% light aromatic naphtha, and 35.5% methyl chloroform (1,1,1-trichloroethane). The specific gravity of the pesticide is listed as 0.999. The weight percent VOC in the pesticide is unknown. Calculate the HAP and VOC emissions.

a. The first step is to calculate the mass of the pesticide applied.

Mass = Volume * Density
Density = (Specific Gravity) * (Density of Water)

Density = 0.999 * 8.33 lb/gal = 8.32 lb/gal
Mass = 25 gal/yr * 8.33 lb/gal = <u>208 lb/yr</u>

b. The next step is to calculate the HAP emissions. A look at the listing of ingredients shows that the only HAP is methyl chloroform.

$E_{HAP} = WP_{HAP}/100 * QP$
$E_{methyl\ chloroform}$ = 35.5%/100 * 208 lb/yr = **<u>74 lb/yr</u>**

c. Since the weight percent VOC in the pesticide is unknown, the VOC emissions will have to be calculated by separately calculating the emissions from the active ingredient portion and from the inert portion and then adding them together to obtain the total VOC emissions.

$E_{VOC} = [WP_{active}/100 * QP * 0.0005 * EF] + [WP_{inert}/100 * QP * WP_{VOC\text{-}inert}/100]$

Before this equation can be applied, however, the emission factor (EF) for the active ingredient portion as well as the weight percent VOC in the inert portion ($WP_{VOCinert}$) must first be determined.

d. According to Table 25-3 above, the vapor pressure of the active ingredient (chlorpyrifos) is 1.7 x 10^{-5} mm Hg. Based on this vapor pressure and the fact that the pesticide is applied to the surface, the appropriate emission factor listed in Table 25-2 above is <u>700 lb/ton</u>.

e. Since the MSDS lists the names and weight percentages of the inert ingredients, the weight percent VOC in the inert portion ($WP_{VOC\text{-}inert}$) can be calculated using the MSDS information. Although both inert ingredients (light aromatic naphtha and methyl chloroform) are volatile organic compounds, methyl chloroform is not considered a VOC under the definition found in 40 CFR 51.100 because it is listed as one of the chemicals which has been determined to have negligible photochemical activity. Therefore, the weight percent VOC in the inert portion can be calculated based on the fact that the light aromatic naphtha is the only VOC in the inert portion.

$WP_{VOC\text{-}inert}$ = [42.1%/(42.1% + 35.5%)] * 100 = <u>54.3%</u>

f. The VOC emissions can now be calculated as follows:

$E_{VOC} = [WP_{active}/100 * QP * 0.0005 * EF] + [WP_{inert}/100 * QP * WP_{VOCinert}/100]$
E_{VOC} = [22.4%/100 * 208 lb/yr * (0.0005 ton/lb) * 700 lb/ton] + [(42.1% + 35.5%)/100 * 208 lb/ton * 54.3%/100] = **<u>104 lb/yr</u>**

25.5 References

1. U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources* (AP-42), Section 9.2.2, September 1995.

2. Emissions Inventory Improvement Program (EIIP), *Volume III: Chapter 9, "Pesticides - Agricultural and Nonagricultural,"* December 1997.

SECTION 26

SITE RESTORATION

26.1 Background: Air Force installations sometime have sites which are contaminated with hazardous substances due to leaks, spills, or past disposal practices. In most cases, these substances are organic solvents (e.g., trichloroethylene, perchloroethylene, trichloroethane, etc.) or petroleum products (e.g., jet fuel, diesel fuel, gasoline, etc.). Identification, investigation, and cleanup of these sites falls under the DoD's Installation Restoration Program (IRP). There are a variety of technologies currently being used to remove organic contaminants from soil and groundwater. Some of these technologies work by transferring the pollutants from the soil or groundwater to an air stream. The now contaminated air stream is either exhausted directly to the atmosphere or is vented to a control device (e.g., carbon adsorber, catalytic oxidizer, etc.). This section will focus on estimating air emissions from two common site remediation technologies which may result in air emissions. These two technologies include 1) soil vapor extraction and 2) pump and treat utilizing air stripping. The following is a summary of both technologies:

a. Soil Vapor Extraction - Soil vapor extraction (SVE) is a method used to remove volatile organic contaminants from subsurface soil. This technology involves applying a vacuum to one or more extraction wells to create air flow from inlet air wells through the vadose (unsaturated) zone to the extraction well(s). Volatile contaminants in the soil transfer into the passing air stream, which is sent to an air/liquid separator located a the surface. The residual air stream is then either exhausted directly to the atmosphere or is vented to a control device (e.g., flare, IC engine, turbine, catalytic oxidizer, etc.).

b. Pump and Treat Utilizing Air Stripping - The phrase "pump and treat" refers to the removal of contaminated groundwater via well or trenches and its subsequent treatment above ground. One of the most widely used methods of treating the extracted groundwater is by air stripping. In general, air stripping involves contacting the groundwater flow with an air stream, typically in a countercurrent manner inside a packed tower (i.e., an air stripping tower filled with packing material). The purpose of using a packed tower is to increase the surface area of the contaminated water exposed to air. When the contaminated water (which coats the packing material in a thin film) comes into contact with the clean air, the contaminants tend to volatilize from the water into the air. The contaminated air is then either released into the atmosphere or vented to a control device (e.g., flare, IC engine, turbine, catalytic oxidizer, etc.).

26.2 Emission Calculations: The pollutants of concern from site restoration activities include total VOC and any organic HAP constituents found in the substance being removed from the groundwater or soil. The method used to calculate emissions from site restoration activities depends on the type of restoration technology used.

a. Soil Vapor Extraction: In order to calculate the emissions from soil vapor extraction, the concentration of the pollutants in the residual air stream (the air which is removed from the extraction well) must be measured. Emissions of a particular pollutant can then be calculated for each extraction well by using the following equation:

$$E_{pol} = QA * C * MW * (1.581 \times 10^{-7}) * t * [1 - (CE/100)]$$

Where,

E_{pol} = Emissions of a particular pollutant (lb/yr)
QA = Flow rate of the extracted air (ft^3/min)
C = Concentration of the pollutant in the extracted air (ppmv)
MW = Molecular weight of the pollutant (lb/lb-mole)
1.581×10^{-7} = Constant with units of [(lb-mole min)/(ft^3 ppmv hr)]
t = Time during the year in which the soil vapor extraction process was performed (hr/yr)
CE = Efficiency of any control device in which the extracted air is vented to prior to being exhausted to the atmosphere (%)

Notes

1. Whenever total VOC is measured in an air stream, the concentration will be measured "as" a certain hydrocarbon (usually it's the compound used to calibrate the VOC analyzer, such as methane, propane, or hexane). Therefore, when calculating VOC emissions, the molecular weight of the hydrocarbon in which the VOC concentration was measured as should be used.
2. Calculations must be performed separately for each extraction well and the results added together to get the total emissions.
3. If a combustion source (e.g., flare, IC engine, turbine, etc.) is used to control the extracted air, then the emissions (i.e., combustion by-products) generated from the control device must also be addressed/calculated.

b. Pump and Treat Utilizing Air Stripping: In order to calculate the emissions from air strippers, the concentration of the pollutants in the groundwater entering the air stripper must be measured. Emissions of a particular pollutant can then be calculated using the following equation:

$$E_{pol} = Q * C * RE/100 * (5.042 \times 10^{-4}) * t * [1- (CE/100)]$$

Where,

E_{pol} = Emissions of a particular pollutant (lb/yr)
Q = Groundwater pumping rate (gal/min)
C = Concentration of the pollutant in the groundwater (mg/l)
RE = Removal efficiency of the air stripper (%)
5.042×10^{-4} = Constant with units of [(lb liters min)/(mg gal hr)]
t = Time during the year in which the "Pump and Treat" operation was performed (hr/yr)
CE = Efficiency of any control device in which the contaminated air leaving the air stripper is vented to prior to being exhausted to the atmosphere (%)

Note – If a combustion source (e.g., flare, IC engine, turbine, etc.) is used to control the contaminated air leaving the air stripper, then the emissions (i.e., combustion by-products) generated from the control device must also be addressed/calculated.

26.3 Information Resources: Base civil engineering should have the information, or be able to obtain the information, needed to calculate emissions from site restoration operations involving either soil vapor extraction or groundwater air stripping.

26.4 Example Problems

a. Problem # 1

A base has a site which is contaminated with a 100% perchloroethylene (PCE) solvent. A soil vapor extraction process is being used to remove the PCE from the subsurface soil at the site. According to civil engineering, the process was in operation for approximately 1,200 hours during the year and only one extraction well was used. The air was pulled from the extraction well at an average rate of 120 ft^3/min. A review of monitoring results during the year showed that the average concentration of PCE in the extracted air was 215 ppmv. The extracted air was vented to a catalytic oxidizer prior to being exhausted to the atmosphere. According to the catalytic oxidizer manufacturer, the approximate efficiency of the catalytic oxidizer is 97%. A review of a chemical reference book indicates the molecular weight of PCE is 165.8. Calculate the VOC and HAP emissions.

(1) A review of the definition of VOC in 40 CFR 51.100 shows that perchloroethylene is not considered a VOC because it is a compound which has been determined to have negligible photochemical reactivity. Therefore, it can be assumed that there are no VOC emissions from the soil vapor extraction process.

(2) Since perchloroethylene is a HAP, emissions of perchloroethylene must be calculated.

E_{pol} = QA * C * MW * (1.581 x 10^{-7}) * t * [1 - (CE/100)]
E_{PCE} = 120 ft^3/min * 215 ppmv * 165.8 lb/lb-mole * (1.581 x 10^{-7} lb-mole min/ft^3 ppmv hr) * 1,200 hr/yr * [1 - (97%/100)] = **<u>24 lb/yr</u>**

b. <u>Problem # 2</u>

A base is using a "pump and treat" process to remove JP-4 fuel from groundwater. An air stripper is being used to treat the pumped groundwater. According to civil engineering, the groundwater was pumped at an average rate of 30 gal/min and the air stripper was in operation for approximately 850 hours during the year. A review of analytical results during the year showed that the average pollutant concentrations in the pumped groundwater were as follows:

Pollutant	**Average Concentration in Groundwater (mg/l)**
Benzene	8
Ethylbenzene	5
Hexane	16
Naphthalene	3
Toluene	12
Xylene (mixed isomers)	14
Total Organic Compounds (TOC)	205

According to the manufacturer of the air stripper, the approximate air stripper removal efficiency for this process is 95%. The emissions from the air stripper are exhausted directly to the atmosphere. Calculate the VOC and HAP emissions.

(1) First, the VOC emissions are calculated using the average TOC concentration

E_{pol} = Q * C * RE/100 * (5.042 x 10^{-4}) * t * [1- (CE/100)]

E_{VOC} = 30 gal/min * 205 mg/l * 95%/100 * (5.042 x 10^{-4} lb liters min/mg gal hr) * 850 hr/yr * [1 - (0%/100)] = **<u>2,504 lb/yr</u>**

(2) Since benzene, ethylbenzene, hexane, naphthalene, toluene, and xylene are all HAPs, the emissions of each of these pollutants need to be calculated.

E_{pol} = Q * C * RE/100 * (5.042 x 10^{-4}) * t * [1- (CE/100)]

$E_{benzene}$ = 30 gal/min * 8 mg/l * 95%/100 * (5.042 x 10^{-4} lb liters min/mg gal hr) * 850 hr/yr * [1- (0%/100)] = **98 lb/yr**

$E_{ethylbenzene}$ = 30 gal/min * 5 mg/l * 95%/100 * (5.042 x 10^{-4} lb liters min/mg gal hr) * 850 hr/yr * [1- (0%/100)] = **61 lb/yr**

E_{hexane} = 30 gal/min * 16 mg/l * 95%/100 * (5.042 x 10^{-4} lb liters min/mg gal hr) * 850 hr/yr * [1- (0%/100)] = **195 lb/yr**

$E_{naphthalene}$ = 30 gal/min * 3 mg/l * 95%/100 * (5.042 x 10^{-4} lb liters min/mg gal hr) * 850 hr/yr * [1- (0%/100)] = **37 lb/yr**

$E_{toluene}$ = 30 gal/min * 12 mg/l * 95%/100 * (5.042 x 10^{-4} lb liters min/mg gal hr) * 850 hr/yr * [1- (0%/100)] = **147 lb/yr**

E_{xylene} = 30 gal/min * 14 mg/l * 95%/100 * (5.042 x 10^{-4} lb liters min/mg gal hr) * 850 hr/yr * [1- (0%/100)] = **171lb/yr**

26.5 References

1. U.S. Air Force School of Aerospace Medicine, *Site Restoration Tools, Techniques, and Technologies*, Student Guide for Course Number B3OZY0000E-006, June 1994.

2. U.S. Environmental Protection Agency, *Estimating Air Emissions from Petroleum UST Cleanups*, June 1989.

SECTION 27

SMALL ARMS FIRING

27.1 Background: Most Air Force installations have a firing range used for small arms training. The main pollutants of concern from small arms firing are carbon monoxide and lead. Carbon monoxide is emitted from the detonation of the energetic material inside the ammunition. Lead emissions typically come from the primer (which usually contains lead styphnate) and from the projectile (i.e., the slug). In addition to lead styphnate, some types of ammunition may also contain lead azide as an ingredient in the energetic material.

Firing ranges may either be indoor ranges or outdoor ranges. Emissions from indoor ranges are usually exhausted to the atmosphere through a vent or stack. Some indoor ranges are equipped with filters to control emissions of lead into the atmosphere.

27.2 Emission Calculations:

a. Carbon Monoxide

CO emissions from a particular type of weapon can be calculated by multiplying the number of rounds of ammunition fired times the amount of energetic material per round of ammunition and then times the appropriate emission factor [note - the amount of energetic material in a munition is often referred to as either the Net Explosive Weight (NEW) or the Mass Energetic Material (MEM)].

$$E_{CO} = NR * QP * (1/7000) * (1/2000) * 77$$

Where,

E_{CO} = Emissions of carbon monoxide (lb/yr)
NR = Number of rounds of a particular type of ammunition fired during the year (rounds/yr)
QP = Quantity of energetic material per round of ammunition (grains/round)
1/7000 = Unit conversion factor (1 lb/7000 grains)
1/2000 = Unit conversion factor (1 ton/2000 lb)
77 = CO emission factor (lb/ton) [Note - the emission factor is from AP-42 and is for the detonation of smokeless powder. The units are pounds pollutant emitted per ton of explosive detonated.]

The quantity of energetic material found in some of the common types of ammunition used at Air Force firing ranges are listed in Table 27-1 below. The quantity of energetic material in other types of ammunition can be obtained from the Army's Munitions Items Disposition Action System (MIDAS). More information about MIDAS is provided in the "Open Burning/Open Detonation of Munitions" section of this document. [Note - the total energetic material includes the main propellant charge and the primer (pellet booster)]

Table 27-1. Quantity of Energetic Material found in Specific Types of Small Arms Ammunition[a]

Type of Ammunition	Quantity of Energetic Material (grains/round)
5.56 mm Ball (Model M193)	28.9
5.56 mm Ball (Model M855)	26.5
9 mm Ball	5.5
7.62 mm Ball	46.6
40 mm HE Cartridge (Model M384)	921
40 mm HE Cartridge (Model M406)	377
12 Gauge Shotgun	28.9

[a] Data obtained from the Army's MIDAS database

b. Lead

As mentioned above, lead emissions from small arms firing come from the lead compounds (i.e., lead styphnate and/or lead azide) found in the ammunition's energetic material, and from the projectile. Lead emissions contributed from the energetic material can be estimated by assuming all the lead is released when the ammunition is fired.

$$E_{Pb} = NR * Q_{Pb} * (1/7000) * [1-(CE/100)]$$

Where,

E_{Pb} = Emissions of lead (lb/yr)
NR = Number of rounds of a particular type of ammunition fired during the year (rounds/yr)
Q_{Pb} = Quantity of lead compounds contained in the ammunition (grains/round)
1/7000 = Unit conversion factor (1 lb/7000 grains)
CE = Control efficiency of filters, if applicable (%)

The quantity of lead compounds (i.e., lead styphnate and/or lead azide) found in the energetic material of some common types of ammunition used at Air Force firing ranges are listed in Table 27-2 below. The quantity of lead compounds in other types of ammunition can be obtained from the Army's Munitions Items Disposition Action System (MIDAS). [Note - the lead styphnate is typically listed as an ingredient under "Pellet Booster"]

Table 27-2. Quantity of Lead Compounds found in the Energetic Material of Specific Types of Small Arms Ammunition[a]

Type of Ammunition	Quantity of Lead Compounds[b] (grains/round)
5.56 mm Ball	0.14
9 mm Ball	0.13
7.62 mm Ball	0.22
40 mm HE Cartridge (Model M384)	0.88
40 mm HE Cartridge (Model M406)	1.05
12 Gauge Shotgun	0.36

[a] Data obtained from the Army's MIDAS database
[b] Lead compounds include lead styphnate and lead azide

Unfortunately, no methodology could be found to estimate the lead emissions contributed by the projectile. However, it's important to note that for target practicing purposes many firing ranges are now using ammunition with non-lead (e.g., plastic) projectiles. This ammunition is commonly referred to as "green ammo."

27.3 Information Resources: The Security Police organization is usually responsible for operating the base firing range and they should be contacted for the information needed to calculate emissions from small arms firing (e.g., type of weapons used, number of rounds fired, amount of powder in each round etc.). If the firing range is equipped with a filtration system, base Civil Engineering and/or the filter manufacturer may need to be contacted for assistance in determining the efficiency of the filters for this source type. As mentioned above, information concerning the composition of various munitions (including the quantity of energetic material and quantity of lead compounds contained in the munition) can be obtained from the Army's MIDAS database. Additional information on ammunition (e.g., type of weapon which uses the ammunition, stock number and identification code of the ammunition, etc.) can be found in the Army document titled "Ammunition Book Complete" (also referred to as the "ABC Book"). The ABC Book can be viewed/downloaded from the following internet address: http://www.ioc.army.mil/sm/pubs.htm

27.4 Example Problem: A base has an indoor firing range used for small arms training. The firing range is equipped with a ventilation system which routes the exhaust through dry filters prior to entering the atmosphere. The filter manufacturer's estimated efficiency for controlling lead emissions from this type of source is 90%. According to records maintained by the Security Police, there were 212,715 rounds of 5.56 mm ammunition and 97,275 rounds of 9 mm ammunition fired in the range during the year. No other type of weapon was used. Calculate the carbon monoxide and lead emissions from the range.

a. The first step is to calculate the emissions resulting from the 5.56 mm ammunition:

E_{CO} = NR * QP * (1/7000) * (1/2000) * 77
E_{CO} = 212,715 rounds/yr * 28.9 grains/round * (1 lb/7000 grains) * (1 ton/2000 lb) * 77 lb/ton = <u>33.8 lb/yr</u>

E_{Pb} = NR * Q_{Pb} * (1/7000) * [1-(CE/100)]
E_{Pb} = 212,715 rounds/yr * 0.14 grains/round * (1 lb/7000 grains) * [1-(90%/100)]
= <u>0.43 lb/yr</u>

b. The second step is to calculate the emissions resulting from the 9mm ammunition:

E_{CO} = NR * QP * (1/7000) * (1/2000) * 77
E_{CO} = 97,275 rounds/yr * 5.5 grains/round * (1 lb/7000 grains) * (1 ton/2000 lb) * 77 lb/ton = <u>2.9 lb/yr</u>

E_{Pb} = NR * Q_{Pb} * (1/7000) * [1-(CE/100)]
E_{Pb} = 97,275 rounds/yr * 0.13 grains/round * (1 lb/7000 grains) * [1-(90%/100)]
= <u>0.18 lb/yr</u>

c. The final step is to add together the emissions associated with each weapon

Total CO Emissions = 33.8 lb/yr + 2.9 lb/yr = **<u>36.7 lb/yr</u>**
Total Lead Emissions = 0.43 lb/yr + 0.18 lb/yr = **<u>0.61 lb/yr</u>**

27.5 References

1. U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources* (AP-42), Section 13.3, February 1980 (Reformatted January 1995).

2. U.S. Army Defense Ammunition Center, *Munitions Items Disposition Action System (MIDAS)*, Central Library Version 74, 1 May 1998.

SECTION 28

SOLVENT CLEANING MACHINES

28.1 Background: Solvent machines (including solvent tanks and parts washers) are commonly used by Air Force maintenance organizations to clean (or degrease) parts associated with a variety of vehicles and equipment such as aircraft, automobiles, and Aerospace Ground Support Equipment (AGSE). On a smaller scale, solvent cleaning machines may also be found within the Civil Engineering organization and in those workplaces associated with communication and electronics maintenance. Solvent cleaning machines are used to remove grease, oils, lubricants, soil, waxes, carbon deposits, fluxes, tars, and other contaminants from metal, plastic, glass, and other surfaces.

The emissions of concern from solvent cleaning machines include VOCs and organic HAPs. In an effort to lower emissions and reduce hazardous waste, there is currently a growing trend to replace traditional organic solvents with safer and more environmentally friendly water-based cleaners. However, organic solvents are still used in cleaning operations in which water-based cleaners are not acceptable (e.g., don't clean adequately, cause corrosion, etc.).

Organic solvents may be composed of non-halogenated compounds, halogenated compounds, or a mixture of both. Common <u>non-halogenated</u> solvents include aliphatic petroleum distillates (e.g., mineral spirits, Stoddard solvent, PD-680, petroleum naphthas), alcohols, ketones (e.g., methyl ethyl ketone, methyl isobutyl ketone, acetone), and glycol ethers. Common <u>halogenated</u> solvents include methylene chloride, perchloroethylene, trichloroethylene, 1,1,1-trichloroethane (methyl chloroform), carbon tetrachloride, and chloroform. Many of the compounds found in organic solvents are classified as either a VOC, a HAP, or both. It's important to note that the EPA has identified several organic compounds which are not considered VOCs because they have been determined to have negligible photochemical reactivity. Some of the more common cleaning solvent compounds which are exempt from being classified as a VOC include acetone, methylene chloride, perchloroethylene, and 1,1,1-trichloroethane. The complete list of organic compounds which are not considered VOCs can be found in 40 CFR 51.100 under the definition of "Volatile organic compounds (VOC)."

In general, there are four types of machines used for solvent cleaning. These include batch cold cleaning machines, batch vapor cleaning machines, in-line cold cleaning machines, and in-line vapor cleaning machines. With cold cleaning, the solvent is either used at room temperature or is heated to a temperature which is below the solvent's boiling point. With vapor cleaning, the solvent is heated to a temperature which is at or above the solvent's boiling point. The difference between a "batch" type and an "in-line" type machine is that the batch type allows only one load of parts to be cleaned at a time while the in-line type employs automated loading (e.g., using a conveyer system) to continuously clean parts. Since in-line machines are usually only used for very large cleaning operations, they are typically not found at Air Force installations. The most common type of machine found in the Air Force is the batch cold cleaning machine, although some installations also use open-top vapor cleaning machines.

Batch cold cleaning machines provide the simplest and least expensive method of metal cleaning. These machines typically use non-halogenated solvents (e.g., petroleum distillates) to clean parts. Cleaning operations with these machines include one or more of the following: spraying, flushing, solvent or parts agitation, wipe cleaning, brushing, and immersion. In a typical maintenance cleaner, parts are cleaned manually by spraying and then soaking in the tank. After cleaning, the parts are either suspended over the tank to drain or are placed on an external rack that routes the drained solvent back into the cleaner. The cover is intended to be closed whenever parts are not being handled in the cleaner. Emissions from batch cold cleaning machines may occur from a variety of sources, including: 1) waste

solvent evaporation; 2) solvent carryout (evaporation from wet parts); 3) solvent bath evaporation; 4) spray evaporation; and 5) agitation. Emissions from the latter three sources can be significantly reduced by using a cover regularly. A schematic illustrating a typical batch cold cleaning machine and the possible emission points is shown in Figure 28-1 below.

Batch vapor cleaning machines use halogenated solvents because they are not flammable and their vapors are much heavier than air. The most common type of batch vapor cleaning machine is the open-top vapor cleaner. This cleaner is a tank designed to generate and contain solvent vapor. The tank is equipped with a heater which boils the liquid solvent. As the solvent boils, dense solvent vapors rise and displace the air in the tank. Coolant is circulated in condensing coils at the top of the tank to create a controlled vapor zone within the tank. Parts are lowered into the vapor zone and are cleaned when the solvent vapors condense on the surface of the parts. The condensation and cleaning continues until the parts reach the same temperature as the vapors. Cleaning may then be enhanced by either spraying the parts with the hot liquid or by immersing the parts into the hot liquid solvent. Batch vapor cleaning machines are usually equipped with a lip mounted ventilation system to carry solvent vapors away from operating personnel. The vapors captured by the ventilation system may then be passed through a control device, such as a carbon adsorbtion unit, prior to being exhausted into the atmosphere. As with the batch cold cleaning machines, emissions from batch vapor cleaning machines may occur from a variety of mechanisms. Most emissions are due to diffusion and convection which can be reduced by using an automated cover or by using a manual cover regularly. Additional sources of emissions include ventilation/exhaust systems (as described above), solvent carryout, and waste solvent evaporation. A schematic illustrating a typical batch vapor cleaning machine and the possible emission points is shown in Figure 28-1 below.

28.2 Emission Calculations: Emissions from solvent cleaning tanks can usually be calculated using a mass balance approach. In general, the amount of solvent emitted is approximately equal to the total amount of fresh solvent added to the cleaning machine minus the amount of waste solvent which is removed from the machine and either disposed of, recycled, or reclaimed. For batch vapor cleaning machines which are equipped with an exhaust control device (e.g., carbon adsorption unit), the quantity of solvent captured by the control device must be estimated and subtracted from the total amount of solvent used in the cleaning machine. The volume of solvent emitted can be converted to the mass of solvent emitted by multiplying the volume times the density of the solvent. Once the mass of solvent emitted is determined, emissions of the applicable pollutants (i.e., VOC and individual HAPs) can be calculated by multiplying the mass of solvent emitted times the weight fraction (weight percent divided by 100) of the pollutant in the solvent.

$$E_{pol} = [(VA - VR - VC) * D] * [WP/100]$$

Where,

E_{pol} = Emissions of a particular pollutant (lb/yr)
VA = Volume of fresh solvent added to the machine (gal/yr)
VR = Volume of waste solvent removed from the machine for disposal, recycling, or reclamation (gal/yr)
VC = Volume of solvent captured by carbon adsorber or other exhaust control device, if applicable (gal/yr)
D = Density of the solvent (lb/gal) [note - density equals specific gravity times 8.33]
WP = Weight percent of the pollutant in the solvent (%)

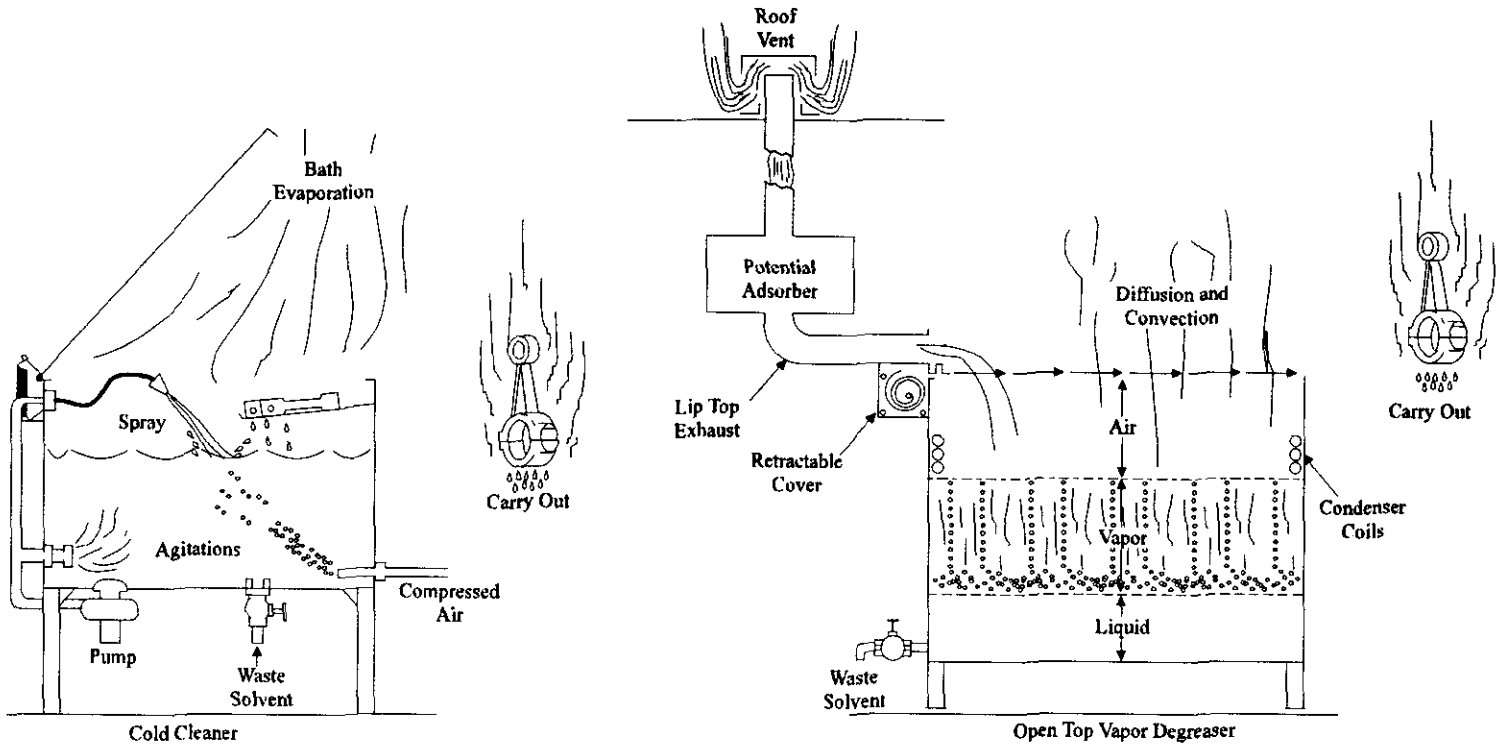

Figure 28-1. Emission Sources from Batch Cleaning Machines

It's important to note that in many cases the weight percent VOC content of a solvent is not available. For example, most Material Safety Data Sheets list the "Percent Volatiles by Volume" but do not provide the "Percent VOC by Weight." The following alternatives are provided for those situations in which the weight percent VOC content is not listed:

a. Alternative # 1 - If the VOC content is available in units of grams per liter (g/L), then VOC emissions can be calculated using the following equation:

$$E_{VOC} = (VA - VR - VC) * (C_{VOC} * 3.785 * 0.002205)$$

Where,

E_{VOC} = Emissions of VOC (lb/yr)
VA = Volume of fresh solvent added to the machine (gal/yr)
VR = Volume of waste solvent removed from the machine for disposal, recycling, or reclamation (gal/yr)
VC = Volume of solvent captured by carbon adsorber or other exhaust control device, if applicable (gal/yr)
C_{VOC} = VOC content in solvent (g/L)
3.785 = Volume conversion factor (L/gal)
0.002205 = Mass conversion factor (lb/g)

b. Alternative # 2 - If the VOC content is available in units of pounds per gallon (lb/gal), then VOC emissions can be calculated using the following equation:

$$E_{VOC} = (VA - VR - VC) * C_{VOC}$$

Where,

E_{VOC} = Emissions of VOC (lb/yr)
VA = Volume of fresh solvent added to the machine (gal/yr)
VR = Volume of waste solvent removed from the machine for disposal, recycling, or reclamation (gal/yr)
VC = Volume of solvent captured by carbon adsorber or other exhaust control device, if applicable (gal/yr)
C_{VOC} = VOC content in solvent (lb/gal)

c. Alternative # 3 - If the VOC content is not available, identify which ingredients in the solvent are considered VOCs under EPA's definition found in 40 CFR 51.100 and add up the weight percents of these ingredients to obtain the total weight percent VOC.

Note – For some solvent cleaning tanks it might not be possible to calculate emissions using a mass balance approach because no new solvent was added to the tank during the year. In these cases, the shop personnel who use the tank should be asked what is the maximum amount of solvent that they believe evaporated from the tank during the year (gallons/yr). If this is not directly known, the shop personnel should be asked what is the maximum amount the level in the tank dropped during the year (inches/yr). Once this drop in solvent level is known, it can be divided by 12 (to convert from inches/yr to feet/yr) and then multiplied by the cross sectional area of the tank (in square feet) to give a volume loss in cubic feet/year. The volume loss in cubic feet/year is then multiplied by 7.48 to produce a volume loss in

gallons/yr. This gallons/yr value can then be substituted for "VA – VR" in the equations above in order to calculate pollutant emissions.

28.3 Information Resources: Most information required to calculate the emissions from a solvent cleaning machine can be obtained from the shop which uses the machine. In many cases, a commercial contract service, such as Safety Kleen, is used for the supply and removal (e.g., disposal, recycling, or reclamation) of cleaning solvents. If a commercial service is used, the contract vendor should have records which indicate the quantity of fresh solvent delivered and the quantity of waste solvent picked up. If a commercial service is not used, information on the quantity of fresh solvent delivered to a shop and the quantity of waste solvent removed from a shop should be available from records/databases maintained by the Hazardous Materials Pharmacy (note - the quantity delivered to a shop should be approximately the same as the amount used by the shop). Information on the VOC content, HAP composition, and density (or specific gravity) of the solvent can usually be obtained from either the product literature (e.g., MSDS, container label, technical specification sheet, etc.), the commercial vendor (if applicable), or solvent manufacturer. For solvents purchased from a government supply center such as the Defense Logistics Agency (DLA) or the General Services Administration (GSA), information on a solvent can usually be obtained from the applicable supply center (DLA or GSA) the solvent was purchased from.

28.4 Example Problem: An aircraft maintenance shop uses "Solvent X" to clean small metal parts in two batch cold cleaning machines. The base has a contract with a commercial vendor to deliver fresh solvent and pick up waste solvent. According to the vendor, 445 gallons of fresh Solvent X were delivered to the maintenance shop during the year while 390 gallons of waste Solvent X were picked up. According to the MSDS, Solvent X is composed of the following ingredients and corresponding weight percents:

Petroleum Naphtha 37%
Ethyl Acetate 25%
Methyl Ethyl Ketone 20%
Acetone 10%
Isopropyl Alcohol 8%

The MSDS lists the specific gravity as 0.86. Unfortunately, the VOC content of Solvent X was not listed on the MSDS or other product literature and was not available from either the solvent vendor or manufacturer. According to the shop supervisor, there are no control devices used with the solvent cleaning machines. Calculate the VOC and HAP emissions associated with these solvent cleaning machines.

a. The first step is to review the listing of ingredients to determine which ones, if any, are HAPs. The only ingredient which is on the HAP listing is methyl ethyl ketone (MEK).

b. Since a listed VOC content in the solvent could not be found, the next step is to calculate the weight percent VOC based on the ingredients. A review of the ingredients reveals that they all meet the definition of VOC except acetone which is specifically listed in 40 CFR 51.100 as being exempt from the definition of VOC due to negligible photochemical reactivity. Since Solvent X contains 10% acetone by weight, the weight percent VOC in Solvent X can be assumed to be 90%.

c. The third step is to calculate the solvent density using the specific gravity

Density = Specific Gravity * 8.33 lb/gal
Density = 0.86 * 8.33 lb/gal = 7.16 lb/gal

d. The final step is to calculate the VOC and MEK emissions

E_{pol} = [(VA - VR - VC) * D] * [WP/100]
E_{VOC} = [(445 gal/yr - 390 gal/yr - 0 gal/yr) * 7.16 lb/gal] * [90% / 100] = **354 lb/yr**
E_{MEK} = [(445 gal/yr - 390 gal/yr - 0 gal/yr) * 7.16 lb/gal] * [20% / 100] = **79 lb/yr**

28.5 References

1. U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources* (AP-42), Section 4.6, April 1981 (Reformatted January 1995).

2. Emissions Inventory Improvement Program (EIIP), *Volume III: Chapter 6, "Solvent Cleaning,"* September 1997.

SECTION 29

STATIONARY INTERNAL COMBUSTION ENGINE EQUIPMENT

29.1 Background: Several types of stationary internal combustion engine equipment are typically found on Air Force installations. Examples include emergency generators, pumps (e.g., fire water system pumps), compressors, and aircraft arresting systems. Although State/local regulators may classify certain types of Aerospace Ground Support Equipment (AGSE) as stationary internal combustion engine equipment, most types of AGSE are considered mobile sources. For this reason, AGSE is not specifically addressed in this report. However, information on AGSE can be obtained from IERA/RSEQ.

Emergency generators are usually the most common type of stationary internal combustion engine found on an Air Force installation. They are located at various locations across an installation to provide emergency backup power to facilities/systems when the primary electrical power is not available (e.g., power outages caused by natural disasters, equipment breakdowns, etc.).

Stationary internal combustion engines are typically fueled with either diesel, gasoline, natural gas, or a dual-fuel (natural gas and diesel). Due to the Air Force wide conversion to JP-8 fuel, it may be possible that stationary internal combustion engines in the Air Force are now, or soon will be, fueled with JP-8. A review of the EPA's FIRE program revealed that with the exception of sulfur oxides (SO_X), jet kerosene emission factors associated with internal combustion engines are the same as the diesel emission factors. In regards to SO_X, the emission factors for jet kerosene are six times lower than the emission factors for diesel.

There are two primary types of internal combustion engines: reciprocating and gas turbine. With reciprocating engines, a combustible mixture is first compressed in a small volume between the head of a piston and its surrounding cylinder. The mixture is then ignited, and the resulting high-pressure products of combustion push the piston through the cylinder. This movement is converted from linear to rotary motion by a crankshaft. The piston returns, pushing out exhaust gases, and the cycle is repeated.

There are two methods used for stationary reciprocating internal combustion engines: compression ignition (CI) and spark ignition (SI). Diesel-fueled engines are compression ignited while natural gas and gasoline-fueled engines are spark ignited. In CI engines, combustion air is first compression heated in the cylinder, and diesel fuel is then injected into the hot air. Ignition is spontaneous because the air temperature is above the autoignition temperature of the fuel. SI engines initiate combustion by the spark of an electrical discharge. Usually the fuel is mixed with the air in a carburetor (for gasoline) or at the intake valve (for natural gas), but occasionally the fuel is injected into the compressed air in the cylinder.

Reciprocating engines are also separated into different design classes: 2-cycle (stroke) lean burn, 2-stroke ultra lean (clean) burn, 4-stroke lean burn, 4-stroke clean burn, and 4-stroke rich burn. Each of these have design differences that affect both uncontrolled emissions as well as the potential for emissions control. Two-stroke engines complete the power cycle in a single crankshaft revolution as compared to the two crankshaft revolutions required for 4-stroke engines.

In a 2-stroke engine, the air/fuel charge is injected with the piston near the bottom of the power stroke. The intake ports are then covered or closed, and the piston moves to the top of the cylinder, thereby compressing the charge. Following ignition and combustion, the power stroke starts with the downward movement of the piston. Exhaust ports or valves are then uncovered to exhaust the combustion products, and a new air/fuel charge is injected.

Four-stroke engines use a separate engine revolution for the intake/compression cycle and the power/exhaust cycle. These engines may be either naturally aspirated, using the suction from the piston to entrain the air charge, or turbocharged, using an exhaust-driven turbine to pressurize the charge. Turbocharged units produce a higher power output for a given engine displacement, whereas naturally aspirated units have lower initial cost and maintenance. Rich burn engines operate near the stoichiometric air/fuel ratio with exhaust excess oxygen levels less than 4 percent. Lean burn engines may operate up to the lean flame extinction limit, with exhaust oxygen levels of 12 percent or greater.

Gas turbines are essentially composed of three major components: compressor, combustor, and power turbine. Ambient air is drawn in and compressed up to 30 times ambient pressure and directed to the combustor section where fuel is introduced, ignited, and burned. The hot expanding exhaust gases are then passed into the power turbine to produce usable shaft energy (note - more than 50 percent of the shaft energy produced is needed to drive the internal compressor. The balance is available to drive an external load, such as an electric generator).

Most stationary internal combustion engine equipment used in the Air Force are powered with reciprocating engines, although a few installations may have large electric generators which are powered with gas turbine engines. Since these gas turbine generators are not commonly found on Air Force installations, they are not addressed in this document. If needed, emission factors for gas turbine engines used for electrical generation can be found in section 3.1 of AP-42 and in the EPA's SPECIATE program (SCC 2-01-001-01 for diesel fueled turbines and SCC 2-01-002-01 for natural gas fueled turbines).

Three generic techniques are used to control NO_X emissions from reciprocating engines and gas turbines. These include parametric controls (timing and operating at a leaner air/fuel ratio for reciprocating engines and water injection for gas turbines); combustion modification, such as advanced engine design for new sources or major modification to existing sources (clean burn reciprocating head designs and dry gas turbine combustor can designs); and post combustion catalytic NO_X reduction (selective catalytic reduction [SCR] for gas turbines and lean burn reciprocating engines and non-selective catalytic reduction [NSCR] for rich burn engines). A brief discussion of each control technique can be found under section 3.2.4 of AP-42.

29.2 Emission Calculations: There are two methods which can be used to calculate the emissions from stationary combustion engines. Additionally, a third alternative method can be used specifically for emergency generators.

a. <u>Method 1</u>

The first (and recommended) method for calculating emissions from stationary combustion engines is to simply multiply the engine fuel consumption times the appropriate emission factor.

$$E_{pol} = FC * EF$$

Where,

E_{pol} = Emissions of a particular pollutant (lb/yr)
FC = Fuel consumption (10^3 gal/yr or 10^6 ft^3/yr)
EF = Emission Factor (lb/10^3 gal or lb/10^6 ft^3)

b. <u>Method 2</u>

The second method for calculating emissions from stationary combustion engines involves using the engine's rated power output (maximum horsepower), a loading factor, the engine's operating time, and the appropriate emission factor. The loading factor mentioned above is defined as the percent of maximum power in which the engine is run at. The following equation is used for Method 2:

$$E_{pol} = [PO * (LF / 100) * OT]/1000 * EF$$

Where,

E_{pol} = Emissions of a particular pollutant (lb/yr)
PO = Rated power output of engine (hp)
LF = Loading Factor (% of Maximum Power)
OT = Operating time of the engine (hr)
1000 = Factor for converting "hp-hr" to "10^3 hp-hr"
EF = Emission Factor (lb/10^3 hp-hr)

Typical loading factors for generators, air compressors, and pumps are listed in Table 29-1 below. **However, actual site specific loading factors should be used whenever possible.**

Table 29-1. Typical Load Factors for Internal Combustion Engine Equipment

Equipment Type	Diesel Load Factor (% of Max. Power)	Gasoline Load Factor (% of Max. Power)
Generator Sets	74	68
Air Compressors	48	56
Gas Compressors	60	60
Pumps	74	69
Aircraft Support	51	56
Aerial Lifts	46	46
Refrigeration/AC	28	46
Welders	45	51

c. Alternative Method for Emergency Generators

Unfortunately, most Air Force installations do not keep track of the quantity of fuel used by electrical generators, nor do they maintain a listing which contains the rated power output of emergency generator engines. However, installations do maintain an inventory (in accordance with Paragraph 1.7 of AFI 32-1063) which contains the electrical power rating (in kilowatts) for each emergency generator, the annual peak electrical demand (also in kilowatts) for each generator, and the number of hours each generator was operated during the year. The electrical power rating is the maximum amount of electrical power a generator is capable of supplying, while the peak electrical demand is the highest amount of electric power which was supplied by a generator during the calendar year. For calculating actual emissions from emergency generators, it is assumed that the generator's peak electrical demand during the year is approximately the same as the power output of the engine. Therefore, actual emissions can be calculated using the following equation:

$$E_{pol} = (PD * 1.341 * OT)/1000 * EF$$

Where,

E_{pol} = Emissions of a particular pollutant (lb/yr)
PD = Peak demand of the generator (kW)
1.341 = Factor for converting 'kW" to "hp"
OT = Operating time of the generator (hr)
1000 = Factor for converting "hp-hr" to "10^3 hp-hr"
EF = Emission Factor (lb/10^3 hp-hr)

Note – When calculating potential emissions from emergency generators using the alternative method, the maximum power rating (kilowatt capacity) of the generator is used instead of the peak demand.

Emission factors for various types of internal combustion engines are listed in Tables 29-2 through 29-10.

Table 29-2. Emission Factors for Uncontrolled Gasoline Internal Combustion Engines (SCC 2-02-003-01, 2-03-003-01)

Pollutant[a]	Emission Factor (lb/10^3 gal)[b]	Emission Factor (lb/10^3 hp-hr)[c]
CO	7,900	439
NO_X	205	11
PM[d]	12.6	0.721
PM_{10}[d]	12.6	0.721
SO_X	10.6	0.591
VOC[e]	382	21.6

[a] No emission factors are currently available for hazardous air pollutants emitted from this source category.
[b] Pounds pollutant emitted per thousand gallons of fuel burned. These emission factors are from the EPA's FIRE Program.
[c] Pounds pollutant emitted per thousand horsepower-hour (power output). These emission factors are from Section 3.3 of AP-42.
[d] All particulate is assumed to be less than 1 μm in size.
[e] Based on the emission factor for Total Organic Compounds (TOC).

Table 29-3. Emission Factors for Uncontrolled Small Diesel Internal Combustion Engines (≤ 600 hp)[a] (SCC 2-02-001-02, 2-03-001-01)

Pollutant	Emission Factor ($lb/10^3$ gal)[b]	Emission Factor ($lb/10^3$ hp-hr)[c]
Criteria Pollutants		
CO	130	6.68
NO_X	604	31
PM[d]	42.5	2.2
PM_{10}[d]	42.5	2.2
SO_X	39.7	2.05
VOC[e]	49.3	2.5
Hazardous Air Pollutants		
Acetaldehyde	0.105	0.0054
Acrolein	0.013	6.48×10^{-4}
Benzene	0.128	0.0065
1,3-Butadiene	0.005	2.74×10^{-4}
Formaldehyde	0.162	0.0083
Naphthalene	0.012	5.94×10^{-4}
Polycyclic Aromatic Hydrocarbons (PAH)[f]	0.023	0.0012
Toluene	0.056	0.0029
Xylenes	0.039	0.0020

[a] Applies to stationary diesel reciprocating internal combustion engines with a rated power up to 600 horsepower (447 kilowatts).
[b] Pounds pollutant emitted per thousand gallons of fuel burned. These emission factors are from the EPA's FIRE program. The "$lb/10^3$ gal" HAP emission factors were calculated by multiplying the "lb/MMBtu" emission factors listed in FIRE times the typical heating value of diesel fuel (137 $MMBtu/10^3$ gal).
[c] Pounds pollutant emitted per thousand horsepower-hour (power output). These emission factors are from Section 3.3 of AP-42. The "$lb/10^3$ hp-hr" HAP emission factors were calculated by multiplying the "lb/MMBtu" emission factors listed in AP-42 times an average brake-specific fuel consumption (BSFC) value of 7 $MMBtu/10^3$ hp-hr.
[d] All particulate is assumed to be less than 1 μm in size.
[e] Based on the emission factor for Total Organic Compounds (TOC).
[f] For inventory purposes, assume PAH is the same as Polycyclic Organic Matter (POM).

Table 29-4. Emission Factors for Uncontrolled Large Diesel Internal Combustion Engines (> 600 hp)[a] (SCC 2-02-004-01)

Pollutant	Emission Factor ($lb/10^3$ gal)[b]	Emission Factor ($lb/10^3$ hp-hr)[c]
Criteria Pollutants		
CO	111	5.5
NO_X	425	24
PM	9.55	0.49
PM_{10}	7.85	0.40
SO_X	138S[d]	8.09S[d]
VOC	13.7	0.64
Hazardous Air Pollutants		
Acetaldehyde	0.003	1.76×10^{-4}
Acrolein	0.001	5.52×10^{-5}
Benzene	0.106	0.0054
Formaldehyde	0.011	5.52×10^{-4}
Naphthalene	0.018	9.1×10^{-4}
Polycyclic Aromatic Hydrocarbons (PAH)[e]	0.029	0.0015
Toluene	0.038	0.0020
Xylenes	0.026	0.0014

[a] Applies to stationary diesel reciprocating internal combustion engines with a rated power greater than 600 horsepower (447 kilowatts).

[b] Pounds pollutant emitted per thousand gallons of fuel burned. These emission factors are from the EPA's FIRE program. The "$lb/10^3$ gal" HAP emission factors were calculated by multiplying the "lb/MMBtu" emission factors listed in FIRE times the typical heating value of diesel fuel (137 $MMBtu/10^3$ gal).

[c] Pounds pollutant emitted per thousand horsepower-hour (power output). These emission factors are from Section 3.3 of AP-42. The "$lb/10^3$ hp-hr" HAP emission factors were calculated by multiplying the "lb/MMBtu" emission factors listed in AP-42 times an average brake-specific fuel consumption (BSFC) value of 7 $MMBtu/10^3$ hp-hr.

[d] S = weight percent sulfur in the fuel. The SO_X emission factor is equal to the numerical value in the table times the weight percent sulfur. A typical sulfur content for diesel fuel used in internal combustion engines is 0.05%, which would yield a SO_X emission factor of 6.9 $lb/10^3$ gal or 0.40 $lb/10^3$ hp-hr.

[e] For inventory purposes, assume PAH is the same as Polycyclic Organic Matter (POM).

Table 29-5. Emission Factors for Uncontrolled Stationary Dual-Fuel Internal Combustion Engines[a] (SCC 2-02-004-02)

Pollutant	Emission Factor (lb/MMBtu)[b]	Emission Factor (lb/10^3 hp-hr)[c]
Criteria Pollutants		
CO	1.16[d]	7.5[d]
NO_X	2.7[d]	18[d]
PM	0.31[e]	2.2[f]
PM_{10}	0.29[e]	2.0[f]
SO_X	0.1[e]	0.7[f]
VOC[g]	0.2[d]	1.32[d]
Hazardous Air Pollutants[f]		
Benzene	0.0045[f]	0.0315[h]
Formaldehyde	0.0054[f]	0.0378[h]
Naphthalene	0.0014[f]	0.0098[h]
Styrene	9.31×10^{-6} [f]	6.52×10^{-5} [h]
Toluene	0.0052[f]	0.0366[h]
Xylene, mixed isomers	0.0013[f]	0.0091[h]

[a] Dual fuel assumes 95% natural gas and 5% diesel fuel.
[b] Pounds pollutant emitted per million Btu heat input. The heat input (MMBtu) can be calculated by multiplying the amount of fuel used (i.e., thousand gallons for diesel fuel and million cubic feet for natural gas) by the heating value of the fuel. The typical heating value for diesel fuel is 137 MMBtu/10^3 gallons while the typical heating value for natural gas is 1,050 MMBtu/10^6 cubic feet.
[c] Pounds pollutant emitted per 1000 horsepower-hour (power output).
[d] Emission factor from Section 3.4 of AP-42.
[e] The "lb/MMBtu" emission factors for SO_X, PM, and PM10 were calculated by dividing the "lb/10^3 horsepower-hour" emission factors found in the EPA's FIRE program by the typical brake-specific fuel consumption (BSFC) value of 7 MMBtu/10^3 horsepower-hour.
[f] Emission factor from the EPA's FIRE Program.
[g] Based on the emission factor for Total Nonmethane Organic Compounds (TNMOC).
[h] The "lb/10^3 hp-hr" HAP emission factors were calculated by multiplying the "lb/MMBtu" emission factors found in FIRE by an average brake-specific fuel consumption (BSFC) value of 7 MMBtu/10^3 horsepower-hour.

Table 29-6. Emission Factors for Uncontrolled Natural Gas Engines[a]

Pollutant	Industrial Gas Turbines (SCC 2-02-002-01)		2-Cycle Lean Burn (SCC 2-02-002-52)		4-Cycle Lean Burn (SCC 2-02-002-54)		4-Cycle Rich Burn (SCC 2-02-002-53)	
	($lb/10^6$ ft^3)[b]	($lb/10^3$ hp-hr)[c]	($lb/10^6$ ft^3)[b]	($lb/10^3$ hp-hr)[c]	($lb/10^6$ ft^3)[b]	($lb/10^3$ hp-hr)[c]	($lb/10^6$ ft^3)[b]	($lb/10^3$ hp-hr)[c]
Criteria Pollutants								
CO	179[d]	1.83[e]	399[d]	3.31[e]	441[d]	3.53[e]	1,680[d]	19[e]
NO_X	357[d]	2.87[e]	2,840[d]	24[e]	3,360[d]	26[e]	2,420[d]	22[e]
PM	44[d]	0.335[f]	10[d]	0.067[g]	ND	ND	ND	ND
PM_{10}	44[d]	0.335[f]	10[d]	0.067[g]	ND	ND	ND	ND
SO_X	0.6[d]	4.57×10^{-3} [f]	0.6[d]	4×10^{-3} [g]	0.6[d]	4×10^{-3} [g]	0.6[d]	4×10^{-3} [g]
VOC	2.1[d]	0.022[e,h]	116[d]	0.948[e,h]	189[d]	1.59[e,h]	31.5[d]	0.309[e,h]
HAPs								
Acetaldehyde	0.0166[i]	1.26×10^{-4} [j]	ND	ND	ND	ND	ND	ND
Benzene	ND	ND	0.54[k]	3.62×10^{-3} [e]	ND	ND	ND	ND
Cadmium	7.3×10^{-3} [i]	5.54×10^{-5} [j]	ND	ND	ND	ND	ND	ND
Chromium	0.0140[i]	1.06×10^{-4} [j]	ND	ND	ND	ND	ND	ND
Ethylbenzene	ND	ND	0.27[k]	1.81×10^{-3} [e]	ND	ND	ND	ND
Formaldehyde	0.342[i]	2.60×10^{-3} [j]	---	[l]	ND	ND	ND	ND
Manganese	0.0842[i]	6.42×10^{-4} [j]	ND	ND	ND	ND	ND	ND
Mercury	6.9×10^{-3} [i]	5.30×10^{-5} [j]	ND	ND	ND	ND	ND	ND
Naphthalene	6.3×10^{-3} [i]	4.82×10^{-5} [j]	ND	ND	ND	ND	ND	ND
Nickel	0.121[i]	9.18×10^{-4} [j]	ND	ND	ND	ND	ND	ND
Phenol	0.0133[i]	1.02×10^{-4} [j]	ND	ND	ND	ND	ND	ND
Toluene	0.519[i]	3.95×10^{-3} [j]	0.54[k]	3.62×10^{-3} [e]	ND	ND	ND	ND
Xylenes	1.154[i]	8.79×10^{-3} [j]	0.81[k]	5.43×10^{-3} [e]	ND	ND	ND	ND

[a] ND = No Data
[b] Pounds pollutant emitted per million cubic feet of fuel burned.
[c] Pounds pollutant emitted per 1000 horsepower-hour (power output).
[d] Emission factor from the EPA's FIRE program.
[e] Emission factor from Section 3.2 of AP-42.
[f] Emission factor was derived by dividing the "$lb/10^6$ ft^3" emission factor by an typical heating value of natural gas (1,050 $MMBtu/10^6$ ft^3) and then multiplying times and average heat rate (for gas turbines) of 8 $MMBtu/10^3$ hp-hr.
[g] Emission factor was derived by dividing the "$lb/10^6$ ft^3" emission factor by the typical heating value of natural gas (1,050 $MMBtu/10^6$ ft^3) and then multiplying times an average brake-specific fuel consumption (BSFC) value of 7 $MMBtu/10^3$ hp-hr.
[h] Based on the value for Total Nonmethane Organic Compounds (TNMOC).
[i] Emission factor was derived by multiplying the "lb/MMBtu" value in FIRE times the typical heating value of natural gas (1,050 $MMBtu/10^6$ ft^3).

[j] Emission factor was derived by multiplying the "lb/MMBtu" value in FIRE times an average heat rate (for gas turbines) of 8 MMBtu/10^3 hp-hr.
[k] Emission factor was derived by dividing the "lb/10^3 hp-hr" emission factor by an average brake-specific fuel consumption value of 7 MMBtu/10^3 hp-hr and then multiplying times the typical heating value of natural gas (1,050 MMBtu/10^6 ft^3).
[l] The emission factor listed in FIRE and in AP-42 (2.93 lb/10^3 hp-hr) appears to be incorrect (excessively high), therefore, it was not included in this Table.

Table 29-7. Controlled Emission Factors for Industrial Turbine Natural Gas Engines[a]

Pollutant	Control Type		
	Selective Catalytic Reduction (SCR) and Ammonia Injection	Afterburner	Catalytic Reduction
Acetaldehyde	4.5×10^{-3} [b] (3.43×10^{-5})[c]	2.24×10^{-2} [b] (1.70×10^{-4})[c]	ND
Cadmium	ND	ND	2.9×10^{-3} [b] (2.18×10^{-5})[c]
Formaldehyde	ND	ND	1.69×10^{-1} [b] (1.29×10^{-3})[c]
Naphthalene	1.08×10^{-2} [b] (8.22×10^{-5})[c]	ND	ND

[a] ND = No Data
[b] Values not in parenthesis are in units of pounds pollutant emitted per million cubic feet of fuel burned (lb/10^6 ft^3). These emission factors were derived by multiplying the "lb/MMBtu" values found in the EPA's FIRE program times the typical heating value of natural gas (1,050 MMBtu/10^6 ft^3).
[c] Values in parenthesis are in units of pounds pollutant emitted per 1000 horsepower-hour (power output). These "lb/10^3 hp-hr" emission factors were derived by multiplying the "lb/MMBtu" values found in the EPA's FIRE program times an average heat rate (for gas turbines) of 8 MMBtu/10^3 hp-hr.

Table 29-8. Controlled Emission Factors for 2-Cycle Lean Burn Natural Gas Engines[a]

Pollutant	Increased Air/Fuel Ratio With Intercooling		Clean Burn		Precombustion Chamber	
	(lb/10^6 ft^3)[b]	(lb/10^3 hp-hr)[c]	(lb/10^6 ft^3)[b]	(lb/10^3 hp-hr)[c]	(lb/10^6 ft^3)[b]	(lb/10^3 hp-hr)[c]
CO	483	3.31	315	2.43	704	5.29
NO_X	1,580	11	872	5.07	893	6.39
PM_{10}	57.8	0.4	ND	ND	ND	ND
VOC[d]	1,890	13	158	0.265	263	1.94

[a] ND = No Data
[b] Pounds pollutant emitted per million cubic feet of fuel burned. These values are from the EPA's FIRE program.
[c] Pounds pollutant emitted per 1000 horsepower-hour (power output). These values are from Section 3.2 of AP-42.
[d] Based on the values for Total Nonmethane Organic Compounds.

Table 29-9. Emission Factors for 4-Cycle Lean Burn Natural Gas Engines Controlled by Selective Catalytic Reduction (SCR)

Pollutant	Emission Factors	
	(lb/10^6 ft^3)[a]	(lb/10^3 hp-hr)[b]
Criteria Pollutants		
CO	389[c]	2.43
NO_X	1,260[c]	7.94
HAPs		
Ammonia	95.6[d]	0.6

[a] Pounds pollutant emitted per million cubic feet of fuel burned.
[b] Pounds pollutant emitted per 1000 horsepower-hour (power output). These values are from Section 3.2 of AP-42.
[c] Emission factor is from the EPA's FIRE program.
[d] Emission factor was derived by multiplying the "lb/MMBtu" value listed in AP-42 times the typical heating value of natural gas (1,050 MMBtu/10^6 ft^3).

Table 29-10. Emission Factors for 4-Cycle Rich Burn Natural Gas Engines Controlled by Non-Selective Catalytic Reduction (NSCR)

Pollutant	Emission Factors	
	(lb/10^6 ft^3)[a]	(lb/10^3 hp-hr)[b]
Criteria Pollutants		
CO	2,520[c]	22[d]
NO_X	609[c]	5.51[d]
PM	0.74[c]	6.6×10^{-3} [d]
VOC[e]	49.4[f]	0.44[d]
HAPs		
Acetaldehyde	5.0×10^{-3} [f]	3.4×10^{-5} [g]
Acrolein	1.0×10^{-2} [f]	6.7×10^{-5} [g]
Ammonia	200[f]	1.81[d]
Benzene	0.116[f]	7.7×10^{-4} [g]
Formaldehyde	7.6×10^{-3} [f]	5.0×10^{-5} [g]
Naphthalene	5.1×10^{-2} [f]	3.4×10^{-4} [g]
Toluene	2.4×10^{-2} [f]	1.6×10^{-4} [g]
Xylenes (mixed isomers)	4.2×10^{-2} [f]	2.8×10^{-4} [g]

[a] Pounds pollutant emitted per million cubic feet of fuel burned. The HAP emission factors were calculated by multiplying "lb/MMBtu" emission factors (found in AP-42 and in the FIRE program) times the typical heating value of natural gas (1,050 MMBtu/10^6 ft^3).
[b] Pounds pollutant emitted per 1000 horsepower-hour (power output).
[c] Emission factor is from the EPA's FIRE program.
[d] Emission factor is from Section 3.2 of AP-42.
[e] Based on values for Total Organic Compounds (TOC).
[f] Emission factor was derived by multiplying the "lb/MMBtu" value listed in AP-42 times the typical heating value of natural gas (1,050 MMBtu/10^6 ft^3).
[g] Emission factor was derived by multiplying the "lb/MMBtu" value listed in AP-42 times an average brake-specific fuel consumption (BSFC) value of 7 MMBtu/10^3 hp-hr.

Table 29-11. Uncontrolled Emission Factors for Natural Gas-Fired Electrical Generating Gas Turbine Engines (SCC 2-01-002-01)

Pollutant	Emission Factor ($lb/10^6\ ft^3$)[a]	Emission Factor ($lb/10^3$ hp-hr)[b]
CO	115	0.86
NO_X	462	3.53
PM[c]	44	0.335[d]
PM_{10}[c]	44	0.335[d]
SO_X	0.6	7.52S[e]
VOC	1.0	7.6×10^{-3} [f]

[a] Pounds pollutant emitted per million cubic feet of fuel burned. These values are from the EPA's FIRE program.
[b] Pounds pollutant emitted per 1000 horsepower-hour (power output). With the exception of the emission factor for VOC, these values are from Section 3.1 of AP-42.
[c] All particulate matter is assumed to be less than 1 μm in size.
[d] This value is the sum of the filterable and condensable particulate matter emission factors.
[e] S = weight percent sulfur in the fuel. The SO_X emission factor is equal to the numerical value in the table times the weight percent sulfur. If the sulfur content is unknown, use an emission factor of 4.6×10^{-3} $lb/10^3$ hp-hr. This emission factor was derived by dividing the 0.6 $lb/10^6\ ft^3$ emission factor by the typical heating value of natural gas (1,050 $MMBtu/10^6\ ft^3$) and then multiplying times an average heat rate of 8 $MMBtu/10^3$ hp-hr.
[f] This value was derived by dividing the 1.0 $lb/10^6\ ft^3$ emission factor by the typical heating value of natural gas (1,050 $MMBtu/10^6\ ft^3$) and then multiplying times an average heat rate of 8 $MMBtu/10^3$ hp-hr.

Table 29-12. Uncontrolled Emission Factors for Diesel-Fired Electrical Generating Gas Turbine Engines (SCC 2-01-001-01)

Pollutant	Emission Factor ($lb/10^3$ gal)[a]	Emission Factor ($lb/10^3$ hp-hr)[b]
Criteria Pollutants		
CO	6.72	0.384
NO_X	97.7	5.60
PM[c]	8.54	0.489[d]
PM_{10}[c]	8.54	0.489[d]
SO_X	140S[e]	8.09S[e]
VOC	2.38[f]	0.137[f]
Hazardous Air Pollutants		
Antimony	3.01×10^{-3} [g]	1.76×10^{-4} [h]
Arsenic	6.71×10^{-4} [g]	3.92×10^{-5} [h]
Benzene	3.94×10^{-3}	2.30×10^{-4} [i]
Beryllium	4.52×10^{-5} [g]	2.64×10^{-6} [h]
Cadmium	5.75×10^{-4} [g]	3.36×10^{-5} [h]
Chromium	6.44×10^{-3} [g]	3.76×10^{-4} [h]
Cobalt	1.25×10^{-3} [g]	7.28×10^{-5} [h]
Formaldehyde	1.31×10^{-2}	7.65×10^{-4} [i]
Lead	8.10×10^{-3}	4.64×10^{-4} [h]
Manganese	4.66×10^{-2} [g]	2.72×10^{-3} [h]
Mercury	1.25×10^{-4} [g]	7.28×10^{-6} [h]
Nickel	1.64×10^{-1} [g]	9.60×10^{-3} [h]
Phosphorus	4.11×10^{-2} [g]	2.40×10^{-3} [h]
Selenium	7.26×10^{-4} [g]	4.24×10^{-5} [h]

[a] Pounds pollutant emitted per thousand pounds of fuel burned. Unless otherwise noted, these values are from the EPA's FIRE program.
[b] Pounds pollutant emitted per 1000 horsepower-hour (power output). Unless otherwise noted, these values are from Section 3.1 of AP-42.
[c] All particulate matter is assumed to be less than 1 μm in size.
[d] This value is the sum of the filterable and condensable particulate matter emission factors.
[e] S = weight percent sulfur in the fuel. The SO_X emission factor is equal to the numerical value in the table times the weight percent sulfur.
[f] Based on the value for Total Organic Compounds (TOC).
[g] These "$lb/10^3$ gal" HAP emission factors were calculated by multiplying the "lb/MMBtu" emission factors (listed in AP-42 and in FIRE) times the typical heating value of diesel fuel (137 $MMBtu/10^3$ gal).
[h] These "$lb/10^3$ hp-hr" HAP emission factors were calculated by multiplying the "lb/MMBtu" emission factors (listed in AP-42 and in FIRE) times an average heat rate of 8 $MMBtu/10^3$ hp-hr.
[i] This "$lb/10^3$ hp-hr" HAP emission factor was calculated by dividing the "$lb/10^3$ gal" emission factor listed in FIRE by the typical heating value of diesel fuel (137 $MMBtu/10^3$ gal) and then multiplying this value times an average heat rate of 8 $MMBtu/10^3$ hp-hr.

Table 29-13. Controlled Emission Factors for Natural Gas-Fired Electrical Generating Gas Turbine Engines[a] (SCC 2-01-002-01)

Pollutant	Water Injection (0.8 water/fuel ratio)		Steam Injection (1.2 water/fuel ratio)		Water Injection with Selective Catalytic Reduction (SCR)		Afterburner	
	Emission Factor ($lb/10^6 ft^3$)[b]	Emission Factor ($lb/10^3$ hp-hr)[c]	Emission Factor ($lb/10^6 ft^3$)[b]	Emission Factor ($lb/10^3$ hp-hr)[c]	Emission Factor ($lb/10^6 ft^3$)[b]	Emission Factor ($lb/10^3$ hp-hr)[c]	Emission Factor ($lb/10^6 ft^3$)[b]	Emission Factor ($lb/10^3$ hp-hr)[c]
Criteria								
CO	294[d]	2.07[e]	168[d]	1.16[e]	8.82[d]	0.070[f]	ND	ND
NO_X	147[d]	1.1[e]	126[d]	0.975[e]	31.5[d]	0.067[f]	ND	ND
VOC	ND	ND	ND	ND	3.36[d]	0.026[f]	ND	ND
HAP								
Formaldehyde	ND	ND	ND	ND	2.84[g]	0.022[f]	0.36[f]	2.75×10^{-3} [g]

[a] ND = No Data
[b] Pounds pollutant emitted per million cubic feet of fuel burned.
[c] Pounds pollutant emitted per 1000 horsepower-hour (power output).
[d] Emission factor from the EPA's FIRE Program.
[e] Emission factor from Section 3.1 of AP-42.
[f] Emission factor was calculated by multiplying the "lb/MMBtu" emission factor listed in Section 3.1 of AP-42 times the typical heating value of natural gas (1,050 MMBtu/10^6 ft^3).
[g] Emission factor was calculated by multiplying the "lb/MMBtu" emission factor listed in Section 3.1 of AP-42 times an average heat rate of 8 MMBtu/10^3 hp-hr.

Table 29-14. Controlled Emission Factors for Diesel-Fired Electrical Generating Gas Turbine Engines[a] (SCC 2-01-001-01)

	Water Injection (0.8 water/fuel ratio)		Direct Flame Afterburner	
Pollutant	**Emission Factor ($lb/10^3$ gal)[b]**	**Emission Factor ($lb/10^3$ hp-hr)[c]**	**Emission Factor ($lb/10^3$ gal)[b]**	**Emission Factor ($lb/10^3$ hp-hr)[c]**
Criteria				
CO	2.69[d]	0.154[e]	ND	ND
NO_X	40.6[d]	2.31[e]	ND	ND
PM[f]	5.21[d]	0.298[e]	ND	ND
PM_{10}[f]	5.21	0.298	ND	ND
SO_X	140S[g]	8.09S[g]	ND	ND
VOC	0.672[h]	0.0384[h]	ND	ND
HAPs				
Benzene	ND	ND	0.0125[i]	7.30×10^{-4} [j]
Formaldehyde	ND	ND	0.139[i]	8.08×10^{-3} [j]

[a] ND = No Data
[b] Pounds pollutant emitted per thousands of fuel burned.
[c] Pounds pollutant emitted per 1000 horsepower-hour (power output).
[d] Emission factor from the EPA's FIRE Program.
[e] Emission factor from Section 3.1 of AP-42.
[f] All particulate matter is assumed to be less than 1 μm in size.
[g] S = weight percent sulfur in the fuel. The SO_X emission factor is equal to the numerical value in the table times the weight percent sulfur. The emission factor is based on the assumption that all sulfur in the fuel is converted to SO_X (i.e., the emission factor is the same as the one used for uncontrolled units).
[h] Based on the value for Total Organic Compounds (TOC).
[i] Emission factor was calculated by multiplying the "lb/MMBtu" emission factor listed in FIRE times the typical heating value of diesel (137 MMBtu/10^3 gal).
[j] Emission factor was calculated by multiplying the "lb/MMBtu" emission factor listed in FIRE times an average heat rate of 8 MMBtu/10^3 hp-hr.

29.3 Information Resources: Civil Engineering is usually responsible for operating/maintaining stationary internal combustion equipment on base (except AGSE) and should be contacted to obtain specific information (e.g., power rating, fuel consumption, operating time, etc.) on each piece of equipment. Additionally, Supply Fuels Maintenance may also be a source of information regarding fuel consumption.

29.4 Example Problems:

a. Problem # 1

Building # 218 on base has a diesel-fired emergency generator. The rated power output of the engine associated with this generator is 420 hp. According to the Civil Engineering Power Production Shop, the total amount of diesel fuel used by this generator during the year was 550 gallons. Calculate the annual NO_X emissions from this generator.

E_{pol} = FC * EF
E_{NOx} = (0.550 x 10^3 gal/yr) * (604 lb/10^3 gal) = 332 lb/yr

b. Problem # 2

Building # 345 on base has diesel-fired emergency generator. According to the Civil Engineering Power Production Shop, the rated power output of the generator's engine, as well as the quantity of fuel consumed by the engine during the year, are unknown. However, the annual generator inventory reveals that the generator was operated for 42 hours during the year and had a peak demand of 250 kW. Calculate the annual NO_X emissions.

E_{pol} = (PD * 1.341 * OT)/1000 * EF
E_{NOx} = (250 kW * 1.341 * 42 hr/yr)/1000 * (31 lb/10^3 hp-hr) = 436 lb/yr

29.5 References

1. U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources* (AP-42), Chapter 3, October 1996.

2. U.S. Environmental Protection Agency, *Factor Information Retrieval System* (FIRE), Version 6.01, May 1998.

3. U.S. Environmental Protection Agency, *Emission Factor Documentation for AP-42 Section 3.3, Gasoline and Diesel Industrial Engines*, April 1993.

4. U.S. Environmental Protection Agency, Office of Mobile Sources, *Average Life, Annual Activity, and Load Factor Value for Nonroad Engine Emissions Modeling*, Report No. NR-005, December 1997.

SECTION 30

SURFACE COATINGS

30.1 Background: Surface coating operations are typically performed by a variety of shops on an Air Force installation including Corrosion Control shops, Civil Engineering structural maintenance shops, munitions maintenance shops, vehicle maintenance shops, woodworking and automobile hobby shops, etc. Surface coating operations involve the application of primers, paints (e.g., enamels, lacquers, polyurethanes), thinners, stains, varnishes, shellacs, glazes, etc., for decorative and protective purposes.

The types of emissions of concern from surface coating include VOCs, organic HAPs, particulate matter, and inorganic HAPs. The type and quantity of emissions are dependent on the composition of the surface coating, the application technique, and whether or not a control device is used.

In general, surface coatings are typically composed of a solvent portion and a solids portion (the one exception is thinners which only contain solvents). VOC emissions result from the evaporation of the solvent portion during drying of the surface coating. It's important to note that some of the solvent ingredients may include organic compounds which are exempt from the definition of VOC found in 40 CFR 51.100 because they have been determined to have negligible photochemical reactivity (e.g., acetone, 1,1,1-trichloroethane). Organic HAP emissions occur if the solvent portion includes HAP ingredients such as toluene, xylenes, and 1,1,1-trichlorothane.

If surface coatings are applied via spraying, only a portion of the coating will be deposited onto the substrate (surface being coated). The portion of coating which is sprayed but fails to deposit on the substrate is known as "coating overspray." The solids contained in the coating overspray are considered particulate emissions. Inorganic HAP emissions will also occur as a result of coating overspray <u>if</u> the solid portion of the coating includes HAP ingredients such as chromium, lead, or cadmium. The ratio of the amount of paint solids deposited on the substrate to the total amount of paint solids sprayed is known as the transfer efficiency. The transfer efficiency is dependent on several variables, including the type of spray application (e.g., spray gun) used and the shape/design of the object being coated.

Surface coatings can be applied using a variety of application techniques. Some of the most common techniques include the following:

a. <u>Conventional Spraying</u> - this technique involves the use of hand-held guns that use air pressure to atomize a coating. The coating material, which is usually thinned prior to use, is atomized by one or more high speed jets of compressed air and emerges from the spray gun nozzle as a mist. A very large volume of air in comparison to the volume of the paint is required at high speed to properly atomize and convey viscous coating materials. The air pressure used for conventional spraying typically ranges from 40 to 80 psig.

b. <u>High Volume/Low Pressure (HVLP) Spraying</u> - With this technique the coating material is atomized by a high volume of low pressure air through a spray gun. The difference between HVLP and conventional spraying is that a much lower pressure (between 0.1 and 10 psig) is used to atomize the coating material while a high volume of air is used to push, not propel, the material into a very soft, low-velocity pattern. This soft spray will generally provide a more consistent coverage and a better overall finish.

c. Electrostatic Spraying - With this technique the substrate to be painted is grounded and a negative electric charge is applied to the coating material. As the coating material is sprayed, an electrostatic field is created which draws the coating to the substrate, thereby minimizing overspray.

d. Airless Spraying - With this technique hydraulic pressure alone (no air) is used to atomize the coating at high pressure (400 to 4,500 psi) through a small orifice in the spray nozzle. Upon exiting the spray nozzle at high pressure, the coating breaks up into fine droplets resulting in a fine atomized spray. The droplets move toward the substrate by their momentum and are significantly slowed down by air resistance, resulting in less particle "bounce" (i.e., coating particles that ricochet off the substrate surface) and less overspray.

e. Air-Assisted Airless Spraying - This method is similar to the airless spraying method except a much lower hydraulic pressure is used to atomize the coating material and low air pressure is directed at the paint mist. When atomizing the coating at low hydraulic pressure through a spray nozzle, proper spray pattern formation can not be achieved. The addition of low pressure air jets on the atomized coating provides even dispersement of the paint in a properly formed pattern. This method offers similar advantages to the airless spraying method, while being safer due to the low hydraulic pressures used.

f. Electrodeposition - With this technique a direct-current voltage is applied between the coating bath (or carbon or stainless-steel electrodes in the bath) and the part to be coated. The part, which can act as either the cathode or the anode, is dipped into the bath. Because the bath and the part are oppositely charged, coating particles are attracted from the bath to the part, yielding an extremely even coat.

g. Brush Coating - This technique involves the use of brushes or hand rollers to apply the coating on the substrate.

h. Roller Coating - With this application a series of mechanical rollers are used to coat flat surfaces. Roller coating machines typically have three or more power-driven rollers. One roller runs partially immersed in the coating and transfers the coating to a second, parallel roller. The strip or sheet to be coated is run between the second and third roller and is coated by transfer of coating from the second roller. If the cylindrical rollers move in the same direction as the surface to be coated, the system is called a direct roll coater. If the rollers move in the opposite direction of the surface to be coated, the system is called a reverse roll coater. The quantity of coating applied to the sheet or strip is established by the distance between the rollers.

i Dip Tanks - With this application objects to be coated are immersed manually or by conveyor into a tank of coating. The objects are then removed from the tank and held over it until the excess coating drips back into the tank. Dip coating operations can be totally enclosed and vented by a roof exhaust system, or may have a ventilation system adjoining the dip tank.

j. Flow Coating - In this application the part to be coated is conveyed over an enclosed sink and a pumped stream of coating gently flows over the surface of the part. The excess coating is drained into the sink, filtered, and pumped to a holding tank for reuse. Flow coating is typically limited to flat sheets and non-critical parts.

With the exception of touch-up painting, coating operations involving spray applications (e.g., conventional spraying, HVLP spraying, electrostatic spraying, airless spraying, etc.) are usually performed in either a spray booth or spray hangar. A typical spray booth/hangar is equipped with a ventilation system which draws air either across or downward onto the object being coated and then through a particulate matter/inorganic HAP control device such as a dry filter system or a waterwash

system. After passing through the particulate matter/inorganic control device, the air is either vented directly to the atmosphere or is vented to a VOC/organic HAP control device such as a carbon adsorption system or an incinerator.

30.2 Emission Calculations:

a. VOC and Organic HAPs - VOC and organic HAP emissions from surface coating applications are calculated using a mass balance approach. In general, the entire VOC and organic HAP portion of a coating is assumed to evaporate after the coating is applied. To calculate emissions of VOC and individual organic HAPs, the volume of coating applied is first multiplied by the coating density to obtain the mass of coating applied. Once the mass of coating applied is determined, uncontrolled emissions of the applicable pollutants (VOC or individual organic HAPs) can be calculated by multiplying the mass of coating applied times the weight fraction (weight percent divided by 100) of the pollutant in the coating. If a VOC/organic HAP control device (e.g., carbon adsorption system, incinerator, etc.) is used, then the efficiency of the control system must be accounted for when calculating the emissions. Emissions are calculated using the following equation:

$$E_{pol} = VC * D * (WP/100) * [1- (CE/100)]$$

Where,

E_{pol} = Emissions of a particular pollutant (lb/yr) [note: pollutant must be VOC or an organic HAP]
VC = Volume of coating applied (gal/yr)
D = Density of the coating (lb/gal) [note: density equals specific gravity times 8.33]
WP = Weight percent of the pollutant in the coating (%)
100 = Factor for converting "percent" into a fraction
CE = Efficiency of the VOC/organic HAP control system (%) [note: CE equals zero if no VOC/organic HAP control device is used]

It's important to note that in many cases the weight percent VOC content of a coating is not available. For example, Material Safety Data Sheets (MSDS) found in the Hazardous Materials Information System (HMIS) will list the "Percent Volatiles by Volume" but do not list the "Percent Volatiles by Weight." The following alternatives are provided for those situations in which the weight percent VOC content is not listed:

(1) *VOC Alternative # 1* - If the VOC content is available in units of grams per liter (g/L), then VOC emissions can be calculated using the following equation:

$$E_{VOC} = VC * (C_{VOC} * 3.785 * 0.002205) * [1- (CE/100)]$$

Where,

E_{VOC} = Emissions of VOC (lb/yr)
VC = Volume of coating applied (gal/yr)
C_{VOC} = VOC content in coating (g/L)
3.785 = Volume conversion factor (L/gal)
0.002205 = Mass conversion factor (lb/g)
CE = Efficiency of the VOC/organic HAP control system (%) [note: CE equals zero if no VOC/organic HAP control device is used]
100 = Factor for converting "percent" into a fraction

(2) *VOC Alternative # 2* - If the VOC content is available in units of pounds per gallon (lb/gal), then VOC emissions can be calculated using the following equation:

$$E_{VOC} = VC * C_{VOC} * [1- (CE/100)]$$

Where,

E_{VOC} = Emissions of VOC (lb/yr)
VC = Volume of coating applied (gal/yr)
C_{VOC} = VOC content in coating (lb/gal)
CE = Efficiency of the VOC/organic HAP control system (%) [note: CE equals zero if no VOC/organic HAP control device is used]
100 = Factor for converting "percent" into a fraction

(3) *VOC Alternative # 3* - If the VOC content is not available, identify which ingredients in the coating are considered VOCs under EPA's definition found in 40 CFR 51.100 and add up the weight percents of these ingredients to obtain the total weight percent VOC.

b. Particulate Matter and Inorganic HAPs - PM and inorganic HAP emissions from spray-applied surface coatings operations are also calculated using a mass balance approach. To calculate emissions of PM and individual inorganic HAPs, the volume of coating sprayed is first multiplied by the coating density to obtain the mass of coating sprayed. Once the mass of coating sprayed is determined, emissions of the applicable pollutants (PM or individual inorganic HAPs) are calculated based on the weight percent of the pollutant in the coating, the transfer efficiency of the coating operation, and the efficiency of any particulate/inorganic HAP control device used (e.g., dry filters, waterwash booth, etc.). For paint booths/hangars with cross draft ventilation (as opposed to down draft ventilation), the estimated amount of paint overspray which falls out on the floor prior to reaching the control device may also be taken into consideration. Emissions are calculated using the following equation:

$$E_{pol} = VC * D * (WP/100) * [1 - (TE/100)] * [1 – (FO/100)] * [1- (CE/100)]$$

Where,

E_{pol} = Emissions of a particular pollutant (lb/yr) [note: pollutant must be PM or an inorganic HAP]
VC = Volume of coating applied (gal/yr)
D = Density of the coating (lb/gal) [note: density equals specific gravity times 8.33]
WP = Weight percent of the pollutant in the coating (%) [note: for PM use the weight percent solids content]
100 = Factor for converting "percent" into a fraction

TE = Estimated Transfer Efficiency of the spray coating operation (%) [note – the transfer efficiency will depend on the type of paint spray equipment used, the skill of the equipment operator, and the configuration/size of the part being sprayed]

FO = Estimated amount of paint overspray which falls out onto the floor prior to reaching the control device (%) [note: use zero for down draft ventilation systems. Also, use zero for cross draft ventilation systems if the amount of overspray which falls onto the floor can not be reasonably estimated and/or if a conservative value is desired]

CE = Efficiency of the PM/inorganic HAP control system (%) [note: CE equals zero if no PM/inorganic HAP control device is used]

30.3 Information Resources: Most information required to calculate the emissions from surface coating applications can be obtained from the shops which apply the surface coatings. Information on the quantity of each specific coating delivered to a shop should be available from records/databases maintained by the Hazardous Materials Pharmacy (note - the quantity delivered to a shop should be approximately the same as the amount used by the shop). Information on the VOC content, solids content, HAP composition, and density (or specific gravity) of the solvent can usually be obtained from either the product literature (e.g., MSDS, container label, technical specification sheet, etc.) or the coating manufacturer. If the solids content of a coating is unknown, it can be estimated by subtracting out the volatile portion of the coating (i.e., wt % solids = 100 – wt % volatiles) . The volatile constituents (volatiles) in a coating include solvents (both VOCs and "exempt solvents") and water.

Many coatings used in the Air Force are purchased through the General Services Administration (GSA). Information on these coatings (such as VOC content) can be obtained from GSA via one or more of the following:

- GSA's Environmental Products Guide (can be viewed/downloaded from the following internet site: http://pub.fss.gsa.gov/environmental.html)
- GSA's Supply Catalog
- GSA's website for paints (http://r6.gsa.gov/hac/paint_main.htm)
- Contacting GSA's Hardware & Appliances Center in Kansas City MO (Ph: 816-926-7398 or Email: r6-6feb@gsa.gov)

The estimated efficiency of a control system can usually be obtained either from product literature or by contacting the manufacturer of the control system. In some cases, the efficiency of the control system may have been previously determined via on-site testing. For spray applications, information on the estimated transfer efficiency of the spray gun system can usually be obtained either from product literature or by contacting the manufacturer of the spray gun equipment (note - the manufacture will probably need to know the type(s) of object(s) being coated). In those cases where manufacturer's information is not available, the "typical" transfer efficiencies listed in Table 30-1 below can be used.

Table 30-1. Typical Transfer Efficiencies for Various Types of Surface Coating Application Methods

Coating Application Method	Typical Transfer Efficiency (%)
Air Atomizing	30[a]
Airless	40[a]
Air-Assisted Airless	45[a]
High Volume, Low Pressure (HVLP)	65[a]
Electrostatic	80[a]
Dip-Coating	85[b]
Flow-Coating	85[b]
Electrodeposition (EDP)	95[b]

[a] This is the minimum value of a range listed in the Hickam AFB's 1997 Air Emissions Inventory prepared by Pacific Environmental Services (PES). PES cited an EPA paper titled "VOC Pollution Prevention Operations in the Surface Coating Industry" as the reference. This paper was presented at the 9th World Clean Air Congress in 1992.

[b] Value was obtained from the Air & Waste Management Association document titled "Air Pollution Engineering Manual"

30.4 Example Problem: The corrosion control shop on base applies an epoxy primer on intact (completely assembled) aircraft prior to applying topcoats. All primer is applied using HVLP spray guns and is performed inside an aircraft paint hangar which is equipped with a down draft ventilation system and dry filters for controlling particulate matter and inorganic HAP emissions. According to the filter manufacturer, the overall particulate control efficiency of the dry filter system is approximately 90%. According to the spray gun manufacturer, the estimated transfer efficiency of the HVLP spray guns when used to coat aircraft is approximately 70%. A review of the MSDS for the epoxy primer reveals that it has a specific gravity of 1.2 and is composed of the following ingredients and corresponding weight percents:

Zinc Chromate 22%
Petroleum Solvent 20%
Isopropyl Alcohol 15%
Xylenes 5%
Toluene 5%
Isobutyl Alcohol 5%
VM&P Naphtha 5%
n-Heptane 5%
Talc 5%

According to the manufacturer of the epoxy primer, the solvent has a VOC content of 490 g/L and a solids content of 35% by weight. According to the shop supervisor, 65 gallons of the primer were used during the year. Calculate the criteria pollutant and HAP emissions from the use of this primer.

a. The first step is to calculate the density of the primer using the specific gravity:

Density = Specific Gravity * 8.33 lb/gal
Density = 1.2 * 8.33 lb/gal = 10.0 lb/gal

b. The second step is to determine if there are any organic HAP constituents in the primer, and if so, to calculate their emissions. A review of the ingredients shows that the primer contains two organic HAPs, xylenes and toluene. The organic HAP emissions are calculated as follows:

E_{pol} = VC * D * (WP/100) * [1- (CE/100)]
$E_{xylenes}$ = 65 gal/yr * (10.0 lb/gal) * (5% / 100) * [1- (0% / 100)] = **32.5 lb/yr**
$E_{toluene}$ = 65 gal/yr * (10.0 lb/gal) * (5% / 100) * [1- (0% / 100)] = **32.5 lb/yr**

c. Next calculate the VOC emissions based on the VOC content of 490 grams per liter:

E_{VOC} = VC * (C_{VOC} * 3.785 * 0.002205) * [1- (CE/100)]
E_{VOC} = 65 gal/yr * (490 g/L * 3.785 L/gal* 0.002205 lb/g) * [1- (0/100)] = **266 lb/yr**

d. The fourth step is to determine if there are any inorganic HAP constituents in the primer, and if so, to calculate their emissions. Since "chromium compounds" is listed as a HAP, the zinc chromium found in the primer is an inorganic HAP. The emissions of the zinc chromate are calculated as follows:

E_{pol} = VC * D * (WP/100) * [1- (TE/100)] * [1 – (FO/100)] * [1- (CE/100)]
$E_{zinc\ chromate}$ = 65 gal/yr * 10.0 lb/gal * (22% / 100) * [1- (70% / 100)] *[1- (0% / 100)]
* [1- (90% / 100)] = **4.3 lb/yr**

e. The final step is to calculate the PM emissions using the weight percent solids content:

E_{pol} = VC * D * (WP/100) * [1- (TE/100)] * [1 – (FO/100)] * [1- (CE/100)]
E_{PM} = 65 gal/yr * 10.0 lb/gal * (35% / 100) * [1- (70% / 100)] * [1- (0% / 100)]
* [1- (90% / 100)] = **6.9 lb/yr**

30.5 References

1. U.S. Air Force, *Application and Removal of Organic Coatings, Aerospace and Non-Aerospace Equipment*, Technical Order 1-1-8, September 1989.

2. U.S. Environmental Protection Agency, *Guideline Series: Control of Volatile Organic Compound Emissions from Coating Operations of Aerospace Manufacturing and Rework Operations*, EPA-453/R-97-004, December 1997.

3. Emissions Inventory Improvement Program (EIIP), *Volume II: Chapter 7, "Preferred and Alternative Methods for Estimating Air Emissions from Surface Coating Operations,"* October 1997.

4. Ron Joseph & Associates, Inc., *Environmental Paints and Coatings Training Program for United States Air Force*.

5. U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources* (AP-42), Section 4.2.2.1, April 1981 (Reformatted January 1995).

6. Air & Waste Management Association, *Air Pollution Engineering Manual*, 1992.

7. Pacific Environmental Services, *Air Emissions Assessment Report/Title V Air Emissions Inventory for 1997, Hickam Air Force Base, Hawaii*, March 1998.

SECTION 31

WASTE SOLVENT RECLAMATION

31.1 Background: As a pollution prevention initiative, some bases perform on-site reclamation of certain waste solvents generated at their facility (e.g., methyl ethyl ketone). Reclamation is the process of restoring a waste solvent to a condition that permits its reuse, either for its original purpose or for other industrial needs. In general, a typical waste solvent reclamation operation consists of the following individual processes: solvent storage and handing, initial treatment, distillation, purification, and waste disposal. The following is a summary of each individual process:

a. Solvent Storage and Handling - Solvents are stored before and after reclamation in containers ranging in size from 55-gallon drums to large tanks. Storage tanks are usually of fixed roof design, although larger tanks may be of floating-roof design. Fixed roof tanks are equipped with venting systems to prevent solvent vapors from creating excessive pressure or vacuum inside. Handling includes loading waste solvent into process equipment and filling drums and tanks prior to transport and storage. The filling is most often done through submerged or bottom loading.

b. Initial Treatment - Initial treatment of liquid waste solvents is accomplished by mechanical separation methods. This includes both removing water by decanting and removing undissolved solids by filtering, draining, settling, and/or centrifuging.

c. Distillation - After initial treatment, waste solvents are distilled to remove dissolved impurities and to separate solvent mixtures. Separation of dissolved impurities is accomplished by simple batch, simple continuous, or steam distillation. In simple distillation, waste solvent is charged to an evaporator. Vapors are then continuously removed and condensed, and the resulting sludge or still bottoms are drawn off. In steam distillation, solvents are vaporized by direct contact with steam which is injected into the evaporator. Mixed solvents are separated by multiple simple distillation methods, such as batch or continuous rectification. In batch rectification, solvent vapors pass through a fractionating column, where they contact condensed solvent (reflux) entering at the top of the column. Solvent not returned as reflux is drawn off as overhead product. In continuous rectification, the waste solvent feed enters continuously at an intermediate point in the column. The more volatile solvents are drawn off at the top, while those with higher boiling points collect at the bottom. Design criteria for evaporating vessels depend on waste solvent composition. Scraped surface stills or agitated thin film evaporators are the most suitable for heat sensitive or viscous materials. Condensation is accomplished by barometric or shell and tube condensers. Azeotropic solvent mixtures are separated by the addition of a third solvent component, while solvents with higher boiling points (> 300 °F), are most effectively distilled under vacuum. After distillation, water is removed from solvent by decanting or salting. Decanting is accomplished with immiscible solvent and water which, when condensed, form separate liquid layers, one or the other of which can be drawn off mechanically. Additional cooling of the solvent/water mix before decanting increases the separation of the two components by reducing their solubility. In salting, solvent is passed through a calcium chloride bed, and water is removed by absorption.

d. Purification - After distillation, water is removed from solvent by decanting or salting. Decanting is accomplished with immiscible solvent and water which, when condensed, form separate liquid layers, one or the other of which can be drawn off mechanically. Additional cooling of the solvent/water mix before decanting increases the separation of the two components by reducing their solubility. In salting, solvent is passed through a calcium chloride bed, and water is removed by absorption. If necessary, reclaimed solvents are stabilized during purification by using special additives.

e. Waste Disposal - Waste materials separated from solvents during initial treatment and distillation are disposed of by either incineration, landfilling, or deep well injection. The composition of such waste varies, depending on the original use of the solvent. However, up to 50 percent is unreclaimed solvent with the remainder consisting of components such as oils, greases, waxes, detergents, pigments, metal fines, dissolved metals, organics, vegetable fibers, and resins.

The emissions of concern from waste solvent reclamation include VOCs and any organic HAPs in the waste solvents. Emission points include storage tank vents, condenser vents, and fugitive losses (e.g., solvent loading, solvent spills, equipment leaks, open solvent sources, etc.).

31.2 Emission Calculations: VOC emissions from waste solvent reclamation can be calculated using either a mass-balance approach or through the use of emission factors. The mass-balance approach is the primary method and should be used whenever possible (i.e., when the appropriate information is available). Both of these methods are described below.

a. Mass-Balance Method (Primary Method) - Using the mass-balance approach, VOC emissions can be calculated by knowing the mass of waste solvent distilled and subtracting from it the mass of waste material (i.e., sludge) disposed of and the mass of solvent reclaimed.

$$E_{VOC} = MSD - MMD - MSR$$

Where,

E_{VOC} = Emissions of VOC (lb/yr)
MSD = Mass of Waste Solvent Distilled (lb/yr)[a]
MMW = Mass of Waste Material Disposed (lb/yr)[a]
MSR = Mass of Solvent Reclaimed (lb/yr)[b]

Notes

[a] In some cases the mass of waste solvent distilled and/or the mass of waste material (i.e., sludge) disposed of during the year may not be known but their volumes are. If this is the case, then the mass can be calculated by multiplying the annual volume (gal/yr) by the density (lb/gal). Since both the waste solvent to be distilled and the waste material to be disposed of contain a combination of solvent and undesired components (oils, greases, metals, etc.), the density of both will have to be estimated on-site by weighing out known volumes.

[b] If mass of solvent reclaimed is not known but the volume is, then the mass can be calculated by multiplying the annual volume (gal/yr) by the density (lb/gal). Since the reclaimed solvent should be very close in composition to the virgin solvent purchased from the manufacturer, the density of the virgin solvent (listed on the MSDS or other product literature) can be used as the density of the reclaimed solvent. If the specific gravity is given instead of the density, then the density can be calculated by multiplying the specific gravity times the density of water (8.33 lb/gal).

b. Emission Factor Method (Secondary Method) - In the event there is insufficient data to calculate the emissions using the mass balance approach (e.g., the quantity of waste solvent distilled and/or the quantity of sludge disposed of is unknown),VOC emissions from waste solvent reclamation can be calculated by using emission factors published in AP-42. A specific emission factor is listed for each source of emissions which is associated with the solvent reclamation process. Each emission factor is multiplied times the mass of solvent reclaimed. The values are then added up to obtain the total VOC emissions. This method is not as accurate as the mass-balance method since the emission factors are only average values and the actual emissions will depend greatly on the type of reclamation system being used and the type of solvent being reclaimed (e.g., solvents with higher vapor pressures will result in higher

emissions). In addition, no emission factors are currently available for a few types of fugitive emission sources, such as equipment leaks and open solvent sources.

$$E_{VOC} = E_{stv} + E_{cv} + E_{spill} + E_{load} + E_{leak} + E_{os}$$

Where,

E_{VOC} = Emissions of VOC (lb/yr)
E_{stv} = Emissions from storage tank vents (lb/yr)
E_{cv} = Emissions from condenser vents (lb/yr)
E_{spill} = Emissions from solvent spills (lb/yr) [Note - these are classified as fugitive]
E_{load} = Emissions from solvent loading (lb/yr) [Note - these are classified as fugitive]
E_{leak} = Emissions from equipment leaks (lb/yr) [Note - these are classified as fugitive]
E_{os} = Emissions from open sources (lb/yr) [Note - these are classified as fugitive]

The values for E_{stv}, E_{cv}, E_{spill}, E_{load}, E_{leak}, and E_{os} are calculated as follows:

$$E_{source} = MSR * (1/2000) * EF$$

Where,

E_{source} = Emissions from a specific type of emission source in the reclamation process (lb/yr)
MSR = Mass of Solvent Reclaimed (lb/yr)[a]
1/2000 = Unit conversion factor (1 ton/2000 lb)
EF = Emission Factor associated with the specific type of emission source (lb/ton)

[a]**Note** - If mass of solvent reclaimed is not known but the volume is, then the mass can be calculated by multiplying the annual volume (gal/yr) by the density (lb/gal). Since the reclaimed solvent should be very close in composition to the virgin solvent purchased from the manufacturer, the density of the virgin solvent (listed on the MSDS or other product literature) can be used as the density of the reclaimed solvent. If the specific gravity is given instead of the density, then the density can be calculated by multiplying the specific gravity times the density of water (8.33 lb/gal).

Emission factors associated with waste solvent reclamation are listed in Table 31-1 below.

Table 31-1. VOC Emission Factors for Solvent Reclamation Processes

Source	Average VOC Emission Factor (lb/ton)[a]
Storage Tank Vent[b]	0.02
Condenser Vent	3.30
Fugitive Emissions	
Spillage	0.20
Loading	0.72
Leaks	ND[c]
Open Sources	ND[c]

[a] Emission factors are in units of pounds VOC emitted per ton of solvent reclaimed. All emission factors are for uncontrolled process equipment.
[b] Storage tank is of fixed roof design.
[c] ND = No data available.

c. HAP Emissions - Once the emissions of VOCs are determined, emissions of HAPs can be estimated by multiplying the VOC emissions by the weight fraction (weight percent divided by 100) of each HAP ingredient found in the virgin solvent.

$$E_{HAP} = E_{VOC} * WP_{HAP}/100$$

Where,

E_{HAP} = Emissions of a HAP ingredient (lb/yr)
E_{VOC} = Emissions of VOC (lb/yr)
WP_{HAP} = Weight Percent of the HAP ingredient in virgin solvent (%)

31.3 Information Resources: Information needed to calculate emissions from waste solvent reclamation can be obtained from the organization(s) on base responsible for operating the system(s). For most Air Force installations, this is usually the maintenance squadron.

31.4 Example Problem: The maintenance organization on base operates a solvent reclamation system which is used to reclaim waste methyl ethyl ketone (MEK). According to records kept by the maintenance squadron, 650 gallons of waste MEK were distilled during the year which produced 1,210 pounds of waste material (sludge) and 535 gallons of reclaimed solvent (MEK). According to product literature, the typical specific gravity of the virgin MEK is around 0.80. To estimate the density of the waste MEK, a few representative 1-gallon samples were weighed with the average coming out to be 7.4 lb/gal. Calculate the VOC and HAP emissions.

a. The first step is to calculate the mass of waste solvent distilled (MSD)

MSD = volume * density
MSD = 650 gal/yr * 7.4 lb/gal = 4,810 lb/yr

b. The next step is to calculate the mass of solvent reclaimed (MSR)

MSR = volume * (specific gravity * density of water)
MSR = 535 gal/yr * (0.80 * 8.33 lb/gal) = 3,565 lb/yr

c. The VOC emissions can now be calculated as follows:

E_{VOC} = MSD - MMD - MSR
E_{VOC} = 4,810 lb/yr - 1,210 lb/yr - 3,565 lb/yr = **35 lb/yr**

d. Since the solvent is 100% MEK and since MEK is a HAP, the HAP (MEK) emissions will be equal to the VOC emissions.

$E_{HAP} = E_{VOC} * WP_{HAP}/100$
E_{MEK} = 35 lb/yr * 100%/100 = **35 lb/yr**

31.5 References

1. U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources* (AP-42), Section 4.7, February 1980 (Reformatted January 1995).

SECTION 32

WASTEWATER TREATMENT PLANTS

32.1 Background: Many Air Force installations operate their own waste water treatment plant(s) to treat domestic (household) and/or industrial wastewater prior to discharging off-base. The main air pollutants of concern from wastewater treatment plants are the VOC and organic HAPs found in the water. A portion of the VOC and organic HAPs volatilize into the atmosphere as the wastewater travels through the plant. Another possible air pollutant from wastewater treatment plants is chlorine. Chlorine is usually added to disinfect the wastewater prior to discharging off-base. Although the chlorine is injected directly into the water, a small amount may be emitted into the atmosphere. Finally, most wastewater treatment plants include a sludge digester. These sludge digesters are usually equipped with a flare which is used to burn the off-gas. Combustion of the off-gas results in emissions of both criteria pollutants and HAPs.

32.2 Emission Calculations

a. <u>VOC and Organic HAPs</u>

The simplest way to calculate the VOC and organic HAP emissions from wastewater treatment plants is by material balance. Emissions are calculated based on the wastewater flow rate and on the influent and effluent pollutant concentrations in the wastewater. Most wastewater treatment plants are required to perform initial and/or periodic sampling of their wastewater for permitting or other reasons. This sampling usually involves a chemical analyses for Total Organic Compounds (TOC) and specific organic compounds (note - for emission inventory purposes, TOC is considered synonymous with VOC). Some of the specific organic compounds which are sampled for may include HAPs such as toluene, xylenes, 1,1,1-trichloroethane (methyl chloroform), methylene chloride, phenol, etc. Emissions are calculated as follows:

$$E_{pol} = [IC_{pol} - EC_{pol}] * (3.785) * (2.205 \times 10^{-9}) * QWT$$

Where,

E_{pol} = Emission of a particular pollutant (lb/yr)
IC_{pol} = Influent concentration of the pollutant (μg/L)
EC_{pol} = Effluent concentration of the pollutant (μg/L) [note - if effluent data is unavailable, assume concentration is 0 μg/L]
3.785 = Unit conversion factor (L/gal)
2.205×10^{-9} = Unit conversion factor (lb/μg)
QWT = Quantity of wastewater treated by the plant (gal/yr)

Note - using this material balance procedure will usually overestimate VOC and organic HAP emissions as it assumes that the amount of each pollutant removed from the water (difference between the influent and effluent concentrations) is attributed entirely to evaporation. It does not take into consideration other possible (in-water) pollutant removal mechanisms, such as sorption, oxidation, and biodegradation.

b. <u>Chlorine</u>

Since virtually all the chlorine added to water is chemically reduced to a soluble form, very little is emitted into the atmosphere. The best way to estimate the air emissions associated with chlorination is to multiply the amount of chlorine added to the water times an emission factor.

$$E_{Cl} = M_{Cl} * EF$$

Where,

E_{Cl} = Emissions of chlorine (lb/yr)
M_{Cl} = Quantity (mass) of chlorine added to the wastewater (lb/yr)
EF = Emission factor (lb/lb) [i.e., pounds chlorine emitted per pounds chlorine added to the wastewater]

No published EPA emission factor could be found for chlorine emissions associated with wastewater treatment systems. However, an emission factor was derived by a contractor (CH2M Hill) based on a source test they conducted at a wastewater treatment plant located in Sacramento CA. The chlorine emission factor they derived was 1.62×10^{-6} lb/lb. This emission factor can be used if a more appropriate (e.g., site specific) emission factor is not available.

c. Sludge Digester Gas Flare Emissions

Emissions from flares burning sludge digester off-gas can be calculated by multiplying the quantity of gas combusted times the appropriate emission factor.

$$E_{pol} = QG * D * 10^{-6} * EF$$

Where,

E_{pol} = Emissions of a particular pollutant (lb/yr)
QG = Average daily quantity of gas combusted (ft^3/day)
D = Number of days during the year in which the flare was in operation (days/yr)
10^{-6} = Factor for converting "ft^3" to "million ft^3"
EF = Emission factor (lb/million ft^3)

Although there are two SCCs associated with sludge digester gas flares (SCC 5-01-007-89 and 5-03-007-89), the EPA currently does not have any published emission factors for this source. Therefore, emission factors for landfill gas flares can be used if no site specific emissions data is available. Landfill gas flare emission factors are found in Table 19-2 of this document.

32.3 Information Resources: The wastewater treatment plant should have most, if not all, the information required to calculate emissions from their plant. The wastewater treatment plant usually maintains records of the volume of water treated by the plant and the amount of chlorine added for disinfection. If the plant has a sludge digester equipped with a flare, they should know the number of days during the year the flare was operating and be able to estimate the amount of off-gas burned by the flare. The treatment plant may or may not have a copy of analytical results which provide pollutant concentrations in the wastewater. If the treatment plant does not have a copy of analytical results, the base bioenvironmental engineering office should be contacted as they are usually responsible for performing the sampling.

32.4 Example Problem: A base has a wastewater treatment plant which treats both domestic and industrial wastewater. According to the plant supervisor, approximately 262,545,000 gallons of wastewater were treated at the plant during the year and approximately 9,500 pounds of chlorine were added for disinfection. The wastewater treatment plant has a sludge digester equipped with a flare. According to the plant supervisor, the flare was operated continuously all year long and burns approximately 350 cubic feet of off-gas per day. The wastewater treatment plant did not have analytical results of chemical sampling performed on the wastewater so the base bioenvironmental engineer (BEE) was contacted for this information. A review of the BEE's analytical results shows that past sampling had been performed for Total Organic Compounds (TOC) and for two chemicals (toluene and xylenes) which are on the list of HAPs. The following is a summary of the most recent analytical results:

Pollutant	Influent Concentration (μg/L)	Effluent Concentration (μg/L)
TOC	225	102
Toluene	8	3
Xylenes	9	6

Calculate both criteria pollutant and HAP emissions from the plant.

a. First calculate the VOC and organic HAP emissions from the wastewater (note - as mentioned above, TOC is considered the same as VOC):

E_{pol} = [IC_{pol} - EC_{pol}] * (3.785) * (2.205 x 10^{-9}) * QWT
E_{VOC} = (225 μg/L - 102 μg/L) * 3.785 L/gal * 2.205 x 10^{-9} lb/μg * 262,545,000 gal/yr = **<u>270 lb/yr</u>**
$E_{toluene}$ = (8 μg/L - 3 μg/L) * 3.785 L/gal * 2.205 x 10^{-9} lb/μg * 262,545,000 gal/yr = **<u>11 lb/yr</u>**
$E_{xylenes}$ = (9 μg/L - 6 μg/L) * 3.785 L/gal * 2.205 x 10^{-9} lb/μg * 262,545,000 gal/yr = **<u>6.6 lb/yr</u>**

b. Next, calculate the chlorine emissions associated with disinfection (note - no site specific chlorine emission factor is available):

E_{Cl} = M_{Cl} * EF
E_{Cl} = 9,500 lb * (1.62 x 10^{-6} lb/lb) = **<u>0.015 lb</u>**

c. Finally, calculate the emissions associated with the sludge digester gas flare (note - no site specific emissions sampling has been performed on this flare so the emission factors for landfill gas flares are used):

E_{pol} = QG * D * 10^{-6} * EF
E_{pol} = 350 ft^3/day * 365 days/yr * 10^{-6} * EF
E_{pol} = 0.128 million ft^3/yr * EF

Pollutant	Gas Burned (million ft^3/yr)		Emission Factor (lb/million ft^3)		Emissions (lb/yr)
CO	0.128	*	3.47	=	**0.44**
NO_X	0.128	*	28.3	=	**3.62**
PM	0.128	*	53.0	=	**6.78**
SO_2	0.128	*	5.75	=	**0.74**
VOC	0.128	*	5.6	=	**0.71**
Benzene	0.128	*	3.97 x 10^{-3}	=	**5.08 x 10^{-4}**

Pollutant	Gas Burned (million ft^3/yr)		Emission Factor (lb/million ft^3)		Emissions (lb/yr)
Carbon Tetrachloride	0.128	*	4.03×10^{-4}	=	**5.16×10^{-5}**
Chlorobenzene	0.128	*	1.53×10^{-3}	=	**1.96×10^{-4}**
Chloroform	0.128	*	1.43×10^{-3}	=	**1.83×10^{-4}**
Dibenzofurans	0.128	*	1.36×10^{-6}	=	**1.74×10^{-7}**
Methylene Chloride	0.128	*	1.19×10^{-1}	=	**1.52×10^{-2}**
Naphthalene	0.128	*	5.55×10^{-3}	=	**7.10×10^{-4}**
PCB's	0.128	*	3.39×10^{-5}	=	**4.34×10^{-6}**
Polycyclic Organic Matter	0.128	*	5.44×10^{-1}	=	**6.96×10^{-2}**
Tetrachloroethylene	0.128	*	1.93×10^{-3}	=	**2.47×10^{-4}**
Toluene	0.128	*	6.83×10^{-2}	=	**8.74×10^{-3}**
1,1,1 Trichloroethane	0.128	*	5.66×10^{-3}	=	**7.24×10^{-4}**
Trichloroethylene	0.128	*	6.99×10^{-4}	=	**8.95×10^{-5}**
Vinyl Chloride	0.128	*	2.31×10^{-3}	=	**2.96×10^{-4}**
o-Xylene	0.128	*	7.27×10^{-3}	=	**9.31×10^{-4}**
Xylene (mixed isomers)	0.128	*	1.24×10^{-2}	=	**1.59×10^{-3}**

32.5 References

1. U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources* (AP-42), Section 4.3, September 1991 (Reformatted January 1995)

2. U.S. Environmental Protection Agency, *Factor Information Retrieval System* (FIRE), Version 6.01, May 1998.

3. Emissions Inventory Improvement Program (EIIP), *Volume II: Chapter 5, "Preferred and Alternative Methods for Estimating Air Emissions from Wastewater Collection and Treatment,"* March 1997.

4. CH2MHill, *1996 Air Emission Inventory Report for Ellsworth Air Force Base, South Dakota*, November 1997.

SECTION 33

WELDING

33.1 Background: Welding operations are typically performed at various maintenance, transportation, and civil engineering shops on Air Force installations. Although there are numerous different types of welding operations (e.g., oxyfuel welding, arc welding, brazing, soldering, thermal cutting, etc.), electric arc welding is by far the most common type and the method with the greatest potential to emit pollutants. Electric arc welding is also the only type in which the EPA has issued emission factors. For these reasons, electric arc welding is usually the only type of welding addressed in an air emissions inventory.

There are several process types associated with electric arc welding. The four main process types include Shielded Metal Arc Welding (SMAW), Gas Metal Arc Welding (GMAW), Flux Cored Arc Welding (FCAW), and Submerged Arc Welding (SAW). The following are brief descriptions of these four process types taken from AP-42:

a. SMAW - this process uses heat produced by an electric arc to melt a covered electrode and the welding joint at the base metal. During operation, the rod core both conducts electric current to produce the arc and provides filler metal for the joint. The core of the covered electrode consists of either a solid metal rod of drawn or cast material or a solid metal rod fabricated by encasing metal powders in a metallic sheath. The electrode covering provides stability to the arc and protects the molten metal by creating shielding gases by vaporization of the cover.

b. GMAW - this is a consumable electrode welding process that produces an arc between the pool of weld and a continuously supplied filler metal. An externally supplied gas is used to shield the arc.

c. FCAW - this is a consumable electrode welding process that uses the heat generated by an arc between the continuous filler metal electrode and the weld pool to bond the metals. Shielding gas is provided from flux contained in the tubular electrode. This flux cored electrode consists of a metal sheath surrounding a core of various powdered materials. During the welding process, the electrode core material produces a slag cover on the face of the weld bead. The welding pool can be protected from the atmosphere either by self-shielded vaporization of the flux core or with a separately supplied shielding gas.

d. SAW - this process produces an arc between a bare metal electrode and the work contained in a blanket of granular fusible flux. The flux submerges the arc and welding pool. The electrode generally serves as the filler material. The quality of the weld depends on the handling and care of the flux. The SAW process is limited to the downward and horizontal positions, but it has an extremely low fume formation rate.

The pollutants of concern associated with welding operations include particulate matter and a few inorganic metal HAPs. Most of the particulate matter produced by welding is less than 1 micron in size. For this reason, all particulate matter emissions from welding are considered to be PM_{10}. In regards to HAPs, the metals of concern include manganese (Mn), nickel (Ni), chromium (Cr), cobalt (Co), and lead (Pb).

33.2 Emissions Calculations: In order to calculate the emissions from electric arc welding, the amount (mass) of electrodes consumed by each process type must be known. The amount of a particular pollutant emitted is calculated by simply multiplying the mass of electrodes consumed by the appropriate emission factor, as shown in the following equation:

E_{pol} = EC * EF

Where,

E_{pol} = Emissions of pollutant (lb)
EC = Mass of Electrode Consumed (10^3 lb)
EF = Emission Factor (lb/10^3 lb)

PM_{10} emission factors for welding operation are listed in Table 33-1 below while HAP emission factors are listed in Table 33-2.

Table 33-1. PM_{10} Emission Factors for Welding Operations

Welding Process	Electrode Type (With Last 2 Digits Of SCC)		Total Fume Emission Factor[a] ($lb/10^3$ lb)[b]
SMAW[c] (SCC 3-09-051)	14Mn-4Cr	(-04)	81.6
	E11018	(-08)	16.4
	E308	(-12)	10.8
	E310	(-16)	15.1
	E316	(-20)	10.0
	E410	(-24)	13.2
	E6010	(-28)	25.6
	E6011	(-32)	38.4
	E6012	(-36)	8.0
	E6013	(-40)	19.7
	E7018	(-44)	18.4
	E7024	(-48)	9.2
	E7028	(-52)	18.0
	E8018	(-56)	17.1
	E9015	(-60)	17.0
	E9018	(-64)	16.9
	ECoCr	(-68)	27.9
	ENi-Cl	(-72)	18.2
	ENiCrMo	(-76)	11.7
	ENi-Cu	(-80)	10.1
GMAW[c] (SCC 3-09-052)	E308L	(-12)	5.4
	E70S	(-54)	5.2
	ER1260	(-10)	20.5
	ER5154	(-26)	24.1
	ER316	(-20)	3.2
	ERNiCrMo	(-76)	3.9
	ERNiCu	(-80)	2.0
FCAW[c] (SCC 3-09-053)	E110	(-06)	20.8
	E11018	(-08)	57.0
	E308LT	(-12)	9.1
	E316LT	(-20)	8.5
	E70T	(-54)	15.1
	E71T	(-55)	12.2
SAW[c] (SCC 3-09-054)	EM12K	(-10)	0.05

[a] All welding fumes are considered to be PM_{10}.
[b] Mass of pollutant emitted per unit mass of electrode consumed.
[c] SMAW = shielded metal arc welding; GMAW = gas metal arc welding; FCAW = flux cored arc welding; SAW = submerged arc welding.

Table 33-2. Hazardous Air Pollutant Emission Factors for Welding Operations[a]

Welding Process	Electrode Type (With Last 2 Digits of SCC)		HAP Emission Factor (lb/10^3 lb)[b]				
			Cr	Co	Mn	Ni	Pb
SMAW[c] (SCC 3-09-051)	14Mn-4Cr	(-04)	1.39	ND	23.2	1.71	ND
	E11018	(-08)	ND	ND	1.38	ND	ND
	E308	(-12)	0.393	0.001	0.252	0.043	ND
	E310	(-16)	2.53	ND	2.20	0.196	0.024
	E316	(-20)	0.522	ND	0.544	0.055	ND
	E410	(-24)	ND	ND	0.685	0.014	ND
	E6010	(-28)	0.003	ND	0.991	0.004	ND
	E6011	(-32)	0.005	0.001	0.998	0.005	ND
	E6012	(-36)	ND	ND	ND	ND	ND
	E6013	(-40)	0.004	< 0.001	0.945	0.002	ND
	E7018	(-44)	0.006	< 0.001	1.03	0.002	ND
	E7024	(-48)	0.001	ND	0.629	ND	ND
	E7028	(-52)	0.013	ND	0.846	ND	0.162
	E8018	(-56)	0.017	ND	0.03	0.051	ND
	E9016	(-60)	ND	ND	ND	ND	ND
	E9018	(-64)	0.212	ND	0.783	0.013	ND
	ECoCr	(-68)	ND	ND	ND	ND	ND
	ENi-Cl	(-72)	ND	ND	0.039	0.890	ND
	ENiCrMo	(-76)	0.420	ND	0.043	0.247	ND
	ENi-Cu-2	(-80)	ND	ND	0.212	0.423	ND
GMAW[c] (SCC 3-09-052)	E308	(-12)	0.524	< 0.001	0.346	0.184	ND
	E70S	(-54)	0.001	< 0.001	0.318	0.001	ND
	ER1260	(-10)	0.004	ND	ND	ND	ND
	ER5154	(-26)	0.010	ND	0.034	ND	ND
	ER316	(-20)	0.528	ND	0.245	0.226	ND
	ERNiCrMo	(-76)	0.353	ND	0.070	1.25	ND
	ERNiCu	(-80)	< 0.001	ND	0.022	0.451	ND
FCAW[c] (SCC 3-09-053	E110	(-06)	0.002	ND	2.02	0.112	ND
	E11018	(-08)	0.969	ND	0.704	0.102	ND
	E308	(-12)	ND	ND	ND	ND	ND
	E316	(-20)	0.970	ND	0.590	0.093	ND
	E70T	(-54)	0.004	ND	0.891	0.005	ND
	E71T	(-55)	0.002	<0.001	0.662	0.004	ND
SAW[c] (SCC 3-09-054)	EM12K	(-10)	ND	ND	ND	ND	ND

[a] ND = No Data
[b] Mass of pollutant emitted per unit mass of electrode consumed.
[c] SMAW = shielded metal arc welding; GMAW = gas metal arc welding; FCAW = flux cored arc welding; SAW = submerged arc welding.

33.3 Information Resources: The information required to calculate emissions from welding operations (i.e., types and quantities of electrodes consumed) can be obtained directly from each individual shop on base which performs arc welding. These shops typically fall under the Maintenance, Civil Engineering, and Transportation organizations.

33-4 Example Problem: A shop on base performs shielded metal arc welding (SMAW) using an E11018 electrode. The quantity of electrodes consumed during the year was estimated by the shop supervisor to be 1,700 pounds. Calculate the annual emissions of particulate matter and HAPs.

a. First calculate the PM_{10} emissions using the emission factor found in Table 33-1.

$$E_{pol} = EC * EF$$
$$E_{PM10} = (1.7 \times 10^3 \text{ lb}) * (16.4 \text{ lb}/10^3 \text{ lb}) = \underline{\mathbf{27.9\ lb}}$$

b. The next step is to review Table 33-2 to see which HAPs are emitted. According to the table, the only HAP emitted from SMAW with the E11018 electrode is manganese. The manganese emissions are calculated using the emission factor listed in the table.

$$E_{pol} = EC * EF$$
$$E_{Mn} = (1.7 \times 10^3 \text{ lb}) * (1.38 \text{ lb}/10^3 \text{ lb}) = \underline{\mathbf{2.35\ lb}}$$

33.5 References

1. U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources* (AP-42), Section 12.19, January 1995.

SECTION 34

WET COOLING TOWERS

34.1 Background: Wet cooling towers are devices that are used to remove heat from a cooling liquid, typically water, by contacting the fluid with ambient air. In general there are two major types of cooling towers; industrial and comfort. As the name implies, industrial cooling towers are used to remove heat that is produced as an input or output of chemical or industrial processes. On the other hand, comfort cooling towers are used to cool heating, ventilation, and air conditioning (HVAC) systems. Most cooling towers located at Air Force installations are comfort cooling towers. Cooling towers can be more specifically categorized based on several parameters, including: the type of heat transfer, the type of draft and location of the draft relative to the heat transfer system, the type of heat transfer medium, the relative direction of air and water contact, and the type of water distribution system.

Since wet cooling towers provide direct contact between the cooling water and the air passing through the tower, some of the liquid water may be entrained in the air stream and be carried out of the tower as "drift" droplets. Therefore, any dissolved solids in the drift droplets are considered to be particulate matter emissions. Dissolved solids found in cooling tower drift can consist of mineral matter, chemicals for corrosion inhibition, etc. To reduce the drift from cooling towers, drift eliminators are usually incorporated into the tower design to remove as many droplets as practical from the air stream before exiting the tower. The drift eliminators used in cooling towers rely on inertial separation caused by direction changes while passing through the eliminators. Types of drift eliminator configurations include herringbone (blade-type), wave form, and cellular (or honeycomb) designs.

34.2 Emission Calculations: Particulate matter emissions from cooling towers can be calculated by multiplying the circulation water flow times a total liquid drift factor and then times the fraction of total dissolved solids (TDS) in the circulating water. Since there is no PM_{10} data for this source, assume PM_{10} is equal to PM.

$$E_{PM} = WFR * D * 0.001 * LDF * TDS/10^6$$

Where,

E_{PM} = Emissions of particulate matter (lb/yr)
WFR = Circulating water flow rate (gal/day)
D = Number of days cooling tower was in operation during the year (day/yr)
0.001 = Factor for converting “gallons” to “10^3 gallons”
LDF = Total liquid drift factor (lb/10^3 gal)
TDS = Concentration of Total Dissolved Solids in the circulating water (ppm) [Note - if the TDS concentration is unknown, use a typical value of 12,000 ppm]
10^6 = Factor for converting “ppm” into “weight fraction”

Total liquid drift factors (LDFs) are listed in Table 34-1 below.

Table 34-1. Total Liquid Drift Factors for Wet Cooling Towers

Cooling Tower Type	Applicable Source Classification Codes (SCCs)	Total Liquid Drift Factor ($lb/10^3$ gal)[a]
Induced (Mechanical)Draft	3-85-001-01, 3-85-001-20, 3-85-002-01	1.7
Natural Draft	3-85-001-02, 3-85-002-02	0.073

[a] Factor is in units of pounds drift (i.e., pounds water droplets entrained in the cooling tower exit air stream) per thousand gallons of circulating water flow.

34.3 Information Resources: The base HVAC shop should be contacted for the information needed to calculate PM emissions from comfort cooling towers (e.g., circulating water flow rate, number of days in operation, average TDS content of the water). If the base has any industrial cooling tower, the particular shop(s) responsible for operating the cooling tower should be contacted for the necessary information.

34.4 Example Problem: A base has a comfort cooling tower located at the HVAC shop. According to the shop supervisor, the cooling tower uses induced (mechanical) draft, was operated constantly throughout the year, and has an average circulating water flow rate of around 20,000 gallons per day. According to past analytical results, the average Total Dissolved Solids concentration in the cooling tower water is approximately 14,000 ppm. Calculate the annual PM emissions.

E_{PM} = WFR * D * 0.001 * LDF * TDS/10^6
E_{PM} = (20,000 gal/day) * 365 days/yr * 0.001 * (1.7 lb/10^3 gal)* (14,000 ppm/10^6)
= **<u>174 lb/yr</u>** [Note - as mentioned above, assume PM_{10} is equal to PM]

34.5 References

1. U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources* (AP-42), Section 13.4, January 1995.

SECTION 35

WOODWORKING

35.1 Background: Most Air Force installations have a few organizations which operate woodworking equipment (e.g., saws, sanders, etc.). Typical woodworking shops on an Air Force base include Wood Hobby, Packing & Crating, and some Civil Engineering shops such as Vertical Construction. The use of woodworking equipment generates airborne particulate matter in the form of sawdust. In most cases, the airborne sawdust is captured by a ventilation system and control device. Typically, the control device used is either a cyclone, a baghouse (fabric filter), or a cyclone and baghouse in series. The sawdust captured by the control device is then collected in a bin or other container which is emptied when full.

35.2 Emission Calculations: Calculating the PM emissions from woodworking operations is based on the efficiency of the control device and the amount of sawdust captured/collected. The following procedures are used to perform the calculations.

a. The first step is to calculate the total amount (mass) of airborne sawdust generated by the woodworking equipment by dividing the amount (mass) of sawdust collected by the efficiency of the control device. If the mass of sawdust collected is unknown, it can be estimated by multiplying the volume collected by the density of sawdust. According to Perry's Chemical Engineers' Handbook, the average density of sawdust is approximately 11.5 lb/ft^3.

$$SD_{total} = (SD_{col}) / (eff/100)$$

Where,

SD_{total} = Total amount of sawdust generated by the woodworking equipment (lb/yr)
SD_{col} = Amount of sawdust captured by the control device (lb/yr)
eff = Efficiency of control device (%)

b. The second and final step is to calculate the PM emissions (E_{PM}) by subtracting the amount of sawdust collected from the total amount of airborne sawdust generated.

$$E_{PM} = SD_{total} - SD_{col}$$

35.3 Information Resources: Information on woodworking operations can be obtained from the specific shops/organizations which operate woodworking equipment (e.g., Wood Hobby Shop, Civil Engineering, Packing & Crating Shop, etc.)

35.4 Example Problem: A base has a Wood Hobby shop which vents its sawdust emissions to a cyclone. The cyclone manufacturer estimates the efficiency of the cyclone (in regards to collecting sawdust) to be approximately 95%. The total mass of sawdust collected is not directly known. However, the rectangular bin used to collect the sawdust captured by the cyclone is 3 ft wide, 4 ft long, and 6 ft high. According to the shop supervisor, the bin is emptied once a month (12 times a year) and the height of the sawdust in the bin is typically 5 ft at the time it is emptied. Calculate the annual PM emissions.

a. Since the total mass of sawdust collected in the collection bin is unknown, it must be calculated based on the volume of sawdust collected and the density of sawdust. The total volume is calculated by multiplying the volume of sawdust contained in the bin at the time it's emptied times the number of times during the year in which the bin is emptied.

Total Volume of Sawdust Collected = (3 ft * 4 ft * 5 ft) * 12 = 720 ft^3

The total mass of sawdust collected is then calculated by multiplying the total volume by the density of sawdust.

Total Mass of Sawdust Collected (SD_{col}) = 720 ft^3 * 11.5 lb/ft^3 = 8,280 lb/yr

c. The total amount of saw dust generated by the woodworking equipment can now be calculated as follows:

SD_{total} = (SD_{col}) / (eff/100)
SD_{total} = (8,280 lb/yr) / (95%/100) = <u>8,716 lb/yr</u>

d. Finally, the particulate matter emissions can be calculated as follows:

E_{PM} = SD_{total} - SD_{col}
E_{PM} = 8,716 lb/yr – 8,280 lb/yr = **<u>436 lb/yr</u>**

35.5 References

1. Radian Corporation, *1994 Air Pollutant Emissions Inventory for Holloman Air Force Base, New Mexico*, 13 November 1995.

SECTION 36

OTHER SOURCES

36.1 The previous sections of this document address some of the most common source types found at Air Force installations. However, any other source of regulated air pollutants (e.g., criteria pollutants, HAPs, etc.) located on the installation should also be included in the air emissions inventory. Most of these "other" source types are unique to a small number of installations in the Air Force. A few examples of "other" source types which should be included in an air emissions inventory include the following:

a. Printing Operations – The emissions of concern from printing operations include VOC and organic HAPs which originate from the chemicals associated with printing (e.g., inks, solvents used to thin inks, and cleaning solvents). Emissions are dependent on the types of chemicals used, the type of printing process (e.g., rotogravure, flexography, offset lithography, letterpress, screen, planographic, etc.), and whether or not a control device (e.g., carbon adsorption system, incinerator, etc.) is used. Emissions can usually be calculated using a mass balance approach similar to the way emissions from solvent cleaning machines are calculated. Additionally, the EPA's FIRE program contains some emission factors for printing operations. These emission factors are for those items with SCC's beginning with the numbers 4-05-00. Further guidance on printing operations can be found in Sections 4.9.1 and 4.9.2 of AP-42, and in the Emissions Inventory Improvement Program (EIIP) technical report titled "Graphic Arts" (Volume III: Chapter 7, November 1996). EIIP technical reports can be found at the following internet address: http://www.epa.gov/ttn/chief/eiip/techrep.htm

b. Hot Mix Asphalt Plants – guidance on calculating emissions from hot mix asphalt plants can be found in Section 11.1 of AP-42. In addition, there is an Emissions Inventory Improvement Program (EIIP) technical report titled "Preferred and Alternative Methods for Estimating Air Emissions from Hot-Mix Asphalt Plants" (Volume II: Chapter 3, July 1996).

c. Foundries – foundries are typically found at the Air Logistics Center (ALC) installations. Guidance on calculating emissions from iron foundries can be found in Section 12.10 of AP-42 while guidance on calculating emissions from steel foundries can be found in Section 12.13 of AP-42.

d. Bombing Ranges – no specific methodologies could be found for calculating emissions from bombing range activities. However, emissions can be estimated by using the methodologies found in Section 22 of this document for the open detonation of energetic materials.

e. Rocket Engine Testing – Gaseous emissions from rocket engine testing can be estimated using the Rocket Exhaust Effluent Diffusion Model (REEDM). This model is used by both the Air Force and the National Aeronautics Space Administration (NASA) to assess pollutant emissions from rocket launches. The following is a good point of contact for the REEDM model:

Mr. Randy Nyman
ACTA, Inc. (Vandenberg AFB Contractor)
Phone: (805) 734-8232 ext 65566
E-mail: rnyman@actawr.com

SECTION 37

RECOMMENDED METHODS FOR CALCULATING POTENTIAL TO EMIT (PTE)

37.1 Background: A source's potential to emit (PTE) is an essential part of an air emissions inventory. Potential emissions are used to categorize a source as either "major" or "minor" for criteria air pollutants and either "major" or "area" for hazardous air pollutants. Compliance costs vary greatly depending on the source's regulatory status. Under Titles III and V of the 1990 Clean Air Act Amendments, complex and lengthy requirements were established for facilities classified as a "major source," as defined under 40 CFR 63 and 70, respectively. Both Title III and V could conceivably have tremendous economic and operational impacts at U.S. Air Force (USAF) installations. Avoiding major source status can save a facility millions of dollars in manpower costs, equipment modifications, and fees. However, all too often inventories contain overly conservative (and sometimes unrealistic) calculation methods, which result in greatly inflated PTEs and an incorrect classification of the facility as a major source of emissions. This section provides recommended methods for calculating PTE from typical Air Force processes, in a manner which is both realistic and reasonably conservative.

The EPA's definition for potential emissions according to 40 CFR 70.2 is: "*the maximum capacity of a stationary source to emit any air pollutant under its physical and operational design. Any physical or operational limitation on the capacity of a source to emit an air pollutant, including air pollution control equipment and restrictions on hours of operation or on the type or amount of material combusted, stored or processed, shall be treated as part of its design if the limitation is enforceable by the administration*." For many emission sources, however, this definition does not lend itself to a clear PTE calculation method. As a result, many sources currently interpret the PTE definition to mean 24 hour-a-day operation, 365 days a year (or 8,760 hrs/yr). For most of these sources, this is an invalid assumption and results in an overestimation of potential emissions.

To help eliminate some of the confusion associated with PTE, the EPA has addressed the quantification of potential emissions from a few source types. For example, in the case of emergency generators they issued a 6 September 1995 policy memorandum on acceptable limits. More recently, on 14 April 1998, EPA published a policy memorandum which provides PTE guidance on eight different source categories, seven of which may be found at Air Force installations (i.e., gasoline service stations; gasoline bulk plants; boilers; coating sources; printing, publishing, and packaging operations; degreasors using volatile organic solvents; hot mix asphalt plants). Unfortunately, no specific PTE guidance has been issued at this time for any of the other types of sources typically found at Air Force installations.

With few exceptions, most emission sources on an Air Force base are related to maintenance activities and are not proportional to hours of shop operations. Technicians perform the required maintenance for each piece of equipment according to highly regulated and standardized procedures. Technical Orders (TOs) dictate the maintenance procedures for each piece of equipment along designated timelines. Therefore a maintenance shop's workload, and consequently the level of emissions, is determined by the number of items to be maintained and the type of maintenance required and not the number of shop hours. Using this approach, PTE calculation methodologies have been developed for those maintenance processes supporting flightline operations and those supporting the base infrastructure. Some sources are included in both flightline and infrastructure maintenance categories since processes may often overlap. For instance a base may have surface coating operations involving aircraft, vehicles, and buildings. PTE methodologies for flightline maintenance should be used for the surface coating operations done on aircraft, whereas infrastructure maintenance PTE methodologies should be used for vehicle and building surface coating. A few processes on a typical Air Force base (e.g., external combustion sources, gasoline service stations, incinerators, etc.) are not directly related to maintenance

activities. Consequently, different PTE methodologies have been developed for these non-maintenance sources.

In addition to employing more realistic calculation methodologies, many sources have been successful in reducing their PTEs by taking limits on their processes. Limits to potential emissions vary depending on the source. The common criteria for an approved limit is defined by the EPA as "sufficient quality and quantity to ensure accountability." Thus a limit is a definable condition/criteria which a user can record and a regulator can enforce. Some examples of PTE limits include the following:

- Restricting paint usage in surface coating operations (e.g., the limit identifies the maximum gallons of paint that can be used in a paint booth per week or month)
- Restricting the quantity of refuse burned in an incinerator (e.g., the limit identifies a specific maximum weight of refuse that can be burned in an incinerator per month or year)
- Restricting the time an electrical generator can operate (e.g., the limit identifies the maximum hours the generator can operate per month or year)

It's important to remember that all PTE limitations must be federally-enforceable. Federal enforceability ensures the conditions placed to limit a source's potential to emit are enforceable by EPA and citizens as a legal and practical matter. Federal enforceability also provides source owners with assurances that limitations they have obtained from a State or local agency will be recognized by the EPA. In general, federally-enforceable limitations can be established through one of the following programs [note - a summary of each of these programs can be found in EPA's 25 January 1995 policy memorandum titled "Options for Limiting the Potential to Emit (PTE) of a Stationary Source Under Section 112 and Title V of the Clean Air Act (Act)"]:

- Title V permits
- Federally enforceable state operating permits (FESOPs)
- Construction permits
- General permits
- Limitations established by rules

As mentioned in subsection 1.7a of this document, on 10 July 1998 the EPA published a memorandum titled "Second Extension of January 25, 1995 Potential to Emit Transition Policy and Clarification of Interim Policy" in which they state they are currently engaged in a rulemaking which will further address/clarify federal enforceability issues.

The PTE calculation methods discussed in this section have been developed through detailed analysis of the processes found at Air Force installations and through negotiations with Federal, State, and local regulatory compliance officials. Further, these PTE methods have been used successfully at many installations. Every attempt has been made to quantify realistic potential emissions in a manner consistent with the EPA definition. When using these PTE methodologies it is important to consider the installation's unique situation as well as the requirements of the State or local regulatory agency. Generally, regulatory officials welcome suggestions on how to calculate PTE in a manner other than simply increasing hours of operation to 8,760 hrs/yr. Accordingly, each facility would do well to actively pursue negotiations with their State and local regulators on alternative PTE calculation methods. The PTE methodologies presented here can be used as a starting point for such negotiations.

37.2 Methodologies:

a. Flightline Maintenance Processes

Many emission sources on an Air Force base are due to maintenance activities of aircraft and related equipment in support of flightline operations. Flightline maintenance processes include, but are not limited to, surface coating, solvent degreasing, waste solvent reclamation, miscellaneous chemical use, non-destructive inspection (NDI), chromium electroplating and chromic acid anodizing, abrasive blasting, fuel spills, aircraft engine testing, and fuel cell repair. These activities are conducted due to routine maintenance requirements and not for production purposes. Consequently, emissions are not proportional to hours of maintenance shop operations. For example, the removal, inspection, and repair of aircraft components is conducted on a scheduled basis and triggered by factors such as the number of aircraft flight hours. Maintenance shops are only able to service the number of parts available for rework, regardless of the number of hours the shop stays open. Therefore, the potential emissions from maintenance operations correlate more with the potential number of aircraft and related equipment than the potential number of shop hours.

Often, PTE is overestimated by assuming emissions will increase if maintenance shop hours increase to 8,760 hrs/yr (24 hours a day, seven days a week) as a worst case. A more realistic method for calculating PTE for flightline maintenance activities ties potential emissions to the operational capacity of the base. The ratio of potential operational capacity to actual operations can be used to determine PTE for flightline maintenance activities. To estimate the base's potential operational capacity, a comparison can be made of the actual versus potential flight operations. To determine potential emissions in this manner, it is necessary to compare the actual number of aircraft assigned to the base to the potential number of aircraft which may be assigned to the base without changes in infrastructure. The Director of Operations should have a record of the number of aircraft on the installation and should be able to determine the maximum number of aircraft the installation can support/maintain without changes in infrastructure. The ratio of potential to actual flight operations can then be used as the scaling factor for flightline maintenance sources on the base when determining PTE.

As an example, let's assume Base X has a wing with ten KC-135's. The Director of Operations reports that the current infrastructure can support an additional ten aircraft of like type. Therefore, the ratio of potential operational capacity to actual operations in this example is two. This ratio of two can be used as the scaling factor to calculate potential emissions from actual emissions. In this example, potential emissions would be calculated as double actual emissions for flightline maintenance activities. As a final check, however, the PTE calculated from this scaling factor must be compared to the operational capacity of each process. This is to ensure that the PTE does not exceed the operational capacity of any one process. Some sources may already be operating at or near peak capacity. One Air Force base is known to operate their paint spray booth around the clock, five days per week. As such, the scaling factor of two would have to be reduced for this source.

b. Infrastructure Maintenance Processes

Many emission sources exist on a typical Air Force base due to maintenance requirements of the facilities, roadways, and vehicles on the installation. These infrastructure maintenance processes include, but are not limited to, asphalt paving, pesticide application, vehicle surface coating, solvent cleaning, miscellaneous chemical use, waste solvent reclamation, open/prescribed burning, use of ozone depleting substances, welding, and woodworking. These activities are conducted due to routine maintenance requirements and not for production purposes. Consequently, emissions are not proportional to hours of maintenance shop operations. For instance, the repair of base roadways, the application of pesticides, and

the repainting of base vehicles are conducted as part of a scheduled maintenance program or on an as needed basis. Maintenance activities are limited by the number of items available to be serviced regardless of the number of hours the shop stays open. Therefore, the potential emissions from maintenance operations correlate more with the potential number of items or areas to be serviced than the potential number of shop hours.

Often, PTE is overestimated by assuming emissions will increase if maintenance shop hours increase to 8,760 hrs/yr (24 hours a day, 7 days a week) as a worst case. A more realistic method for calculating PTE for infrastructure maintenance activities ties potential emissions to the potential growth of base infrastructure. The ratio of potential infrastructure growth to actual operations can be used to determine PTE for maintenance activities. To estimate the base's potential infrastructure growth, a worst case growth prediction can be determined by communicating with the process owners and Civil Engineering planners on foreseeable base and workload changes. Usually, a five year projection is considered adequate. The projected increase in workload will serve as the scaling factor for infrastructure maintenance sources when determining PTE. As an example, let's consider how this methodology would work for a base woodshop. At Base X, Civil Engineering planners and woodshop personnel predict a 5% annual workload growth trend over the next five years. Thus, woodshop personnel may see a potential workload increase and corresponding potential emissions increase of 25% over the next five years. Therefore, potential woodshop emissions would be estimated at a 25% increase over actual emissions as a worst case. A similar procedure would be accomplished for each infrastructure maintenance process.

c. Non-Maintenance Operations

A few processes on a typical Air Force base are not directly related to maintenance activities or may be operated in a continuous mode. Consequently, different PTE methodologies have been developed for these non-maintenance sources. The source types in this category include, but are not limited to, dry cleaning operations, equipment leaks, ethylene oxide sterilizers, external combustion sources, fire fighter training, fuel spills, fuel storage, fuel transfer, gasoline service stations, heavy construction operations, incinerators, laboratory chemicals, landfills, open burning/open detonation, site restoration, small arms firing, stationary internal combustion engine equipment, wastewater treatment plants, and wet cooling towers.

(1) *Dry Cleaning Operations*

The Army & Air Force Exchange Service (AAFES) operates a retail dry cleaning business on many installations. Potential emissions from this source are based on the potential demand for dry cleaning services. Since most dry cleaning customers are military personnel (or their dependents), the maximum number of military personnel which may be assigned to the base can be used to determine the potential demand for dry cleaning services. The Personnel Employments Section of each base's Consolidated Base Personnel Office (CBPO) maintains a listing of both the total current number of military personnel assigned and the maximum number authorized. The maximum number of personnel authorized for assignment to the base should not change significantly with an increase in the number of aircraft assigned to the base. Therefore, the ratio of the maximum number of military personnel authorized for the base to the number of personnel currently assigned can be used as the scaling factor in determining PTE. This ratio is multiplied by the actual emissions to get potential emissions.

(2) *Equipment Leaks*

Emissions from this source are based on the amount of time the fuel transfer equipment (e.g. pipelines, pumphouses, hydrants, etc) is in operation. Since most fuel transfer equipment is

considered to be in continuous operation, potential and actual emissions will be equivalent for this source category.

(3) *Ethylene Oxide Sterilizers*

The potential to emit for ethylene oxide sterilizers is based on the potential number of patients and procedures that would require sterilized medical equipment. The maximum number of military personnel which may be assigned to the base will determine the potential number of patients. The Personnel Employments Section of each base's CBPO maintains a listing showing both the total current number of military personnel assigned and the maximum number authorized. The maximum number of personnel authorized for assignment to the base should not change significantly with an increase in the number of aircraft assigned to the base. Therefore, the ratio of the maximum number of military personnel authorized for the base to the number of personnel currently assigned can be used as the scaling factor in determining PTE. This ratio is multiplied by the actual emissions to get potential emissions.

(4) *External Combustion*

External combustion sources include boilers, furnaces, and heaters used for power production and/or heating purposes. Most small external combustion units are located at individual buildings on base (e.g., in building mechanical rooms), while larger boilers are usually located at the base heat (or heat/power) plant. The emissions from external combustion units depend on a variety of factors including the type/size of the combustor, firing configuration, fuel type, control devices used, operating capacity, and whether the system is properly operated/maintained.

The potential to emit for this source has traditionally been calculated by assuming a boiler operates at peak capacity (maximum heat input capacity) for 8,760 hrs/yr. This is not a realistic assumption and results in exaggerated PTEs. A boiler simply cannot operate at peak capacity 24 hours a day, 7 days a week. Physical limitations and required maintenance are just a few of the factors reducing the real capacity of a boiler. A more realistic method for calculating PTE would take into consideration the real operating limitations of boiler systems. A conservative maximum operational potential of a boiler is 90% of peak capacity for 85% of the year. These values are derived from considering boilers' design limitations and need for routine maintenance.

To calculate PTE using this technique, first determine the maximum heat input capacity for each boiler (usually in Btu/hr). Multiply this value by 0.90 to account for the physical limitations of the boiler. Multiply this value by 8,760 (the number of hours in a year) and then by 0.85 to account for downtime due to required maintenance. This yields the number of Btu's per year which can be divided by the heating value of the fuel (e.g. Btu/lb, Btu/gal, Btu/scf, etc.) to arrive at total quantity of fuel for the year. The appropriate emission factor can then be multiplied by this value to arrive at potential annual emissions from each boiler. Summing these values for all boilers results in potential annual emissions from this source category.

State and local regulatory officials may be open to other PTE calculation methodologies from this source type. Each facility should actively pursue negotiations with regulators on alternative PTE calculation methods. One base has successfully negotiated with State regulatory officials to allow a unique PTE calculation method for their boilers. The base is located in a temperate climate and most of the boilers are only used for heating purposes during winter months. Consequently, state officials have allowed the base to calculate PTE by assuming a peak operating capacity for 6 months (i.e., the maximum length of the heating season).

(5) *Fire Fighter Training*

Potential emissions for this source are based on the potential amount of fuel burned during fire training for the year. The potential amount of fuel burned during any given year depends on the potential number of fire fighters trained at the facility and the type of training conducted. The potential number of fire fighters will depend on the fire training policy at each base. Some bases restrict the use of the fire training facility to in-house staff, while others open the facility to off-base agencies.

For those bases that restrict the use of the fire training facility to in-house staff, the potential number of firefighters which may be assigned to the base will determine the amount of training required, the potential amount of fuel burned, and the potential emissions. The Personnel Employments Section of each base's CBPO maintains a listing of both the total current number of personnel assigned and the maximum number authorized for each job classification. The maximum number of personnel authorized for assignment to the base will not change significantly with an increase in the number of aircraft assigned to the base. Therefore, the ratio of the maximum number of firefighters authorized for the base to the number of firefighters currently assigned can be used as the scaling factor in determining PTE. This ratio is multiplied by the actual emissions to get potential emissions.

For those bases that allow off-base agencies to use the fire training facility, a worst case prediction can be determined by communicating with the fire chief on potential increases in the quantity of training. A training plan may be available showing a projected training schedule to allow for coordination between off-base and on-base groups. Usually, a five year projection is considered adequate. The projected increase in fire training will serve as the scaling factor for this source when determining PTE. As an example, at Base X the fire chief predicts a 5% annual increase in training over the next five years. Thus, emissions from this source may potentially increase 25% over the next five years. Therefore, potential fire fighter training emissions would be estimated at a 25% increase over actual emissions, as a worst case.

(6) *Fuel Storage*

Storage tanks exhibit two types of losses: standing storage losses and working losses. The potential and actual emissions from standing storage losses will be equivalent since these losses are a function of the size and type of tank. The potential emissions from working losses, however, are determined by the potential fuel throughput.

Potential emissions from gasoline storage tanks are covered under the "Gasoline Services Station" source category. Since most non-gasoline storage tanks relate to flightline operations, potential working loss emissions from these tanks correlate with the potential number of aircraft and related equipment on the installation. This may be referred to as the flightline operational capacity and represents the maximum number of aircraft that may be stationed on a given installation. In addition to the aircraft stationed on a given installation, transient aircraft may loiter briefly to obtain fuel. However, the number of transient aircraft should remain relatively constant from year to year.

To determine potential emissions from non-gasoline storage tanks, it is necessary to compare the actual number of aircraft assigned to the base to the potential number of aircraft which may be assigned to the base. The Director of Operations should have a record of the number of aircraft on the installation and be able to determine the maximum number of aircraft the installation can support/maintain, without changes in infrastructure. The ratio of potential to actual flight operations can then be used as the scaling factor for fuel storage when determining PTE.

As an example, let's assume Base X has a wing with ten KC-135's. The Director of Operations reports that the current infrastructure can support an additional ten aircraft of like type. Therefore, the ratio of potential operational capacity to actual operations in this example is two and potential emissions would be calculated as double actual emissions. Likewise, potential fuel throughput will be double actual fuel throughput. As a final check, however, the PTE calculated from this scaling factor must be compared to the operational capacity of the process to determine if the fueling system is capable of handling this amount of fuel. This is to ensure that the PTE does not exceed the operational capacity of the process. Some base fuel systems may already be operating near peak capacity.

(7) *Fuel Transfer*

Fuel transfer operations involve the loading of fuel into tanker trucks, aircraft, vehicles/equipment, and bowsers. On an Air Force installation, the filling of tanker trucks is performed at fuel loading docks and involves the transfer of fuel from large storage tanks into the tanker trucks. Vehicles/equipment typically located on Air Force installations include, but are not limited to: automobiles, heavy duty equipment, aerospace ground support equipment (AGSE), etc. As mentioned in Section 14.1 of this document, the refueling of automobiles is addressed under the "Gasoline Service Stations" source category.

The potential emissions from this source are based on the maximum amount of fuel that may be transferred in a given year. Since this source category mainly pertains to flightline operations, potential emissions correlate with the potential number of aircraft and related equipment on the installation. This may be referred to as the flightline operational capacity and represents the maximum number of aircraft that may be stationed on a given installation. In addition to the aircraft stationed on a given installation, transient aircraft may loiter briefly to obtain fuel. However, the number of transient aircraft should remain relatively constant from year to year.

To determine potential emissions from fuel transfer, it is necessary to compare the actual number of aircraft assigned to the base to the potential number of aircraft which may be assigned to the base. The Director of Operations should have a record of the number of aircraft on the installation and be able to determine the maximum number of aircraft the installation can support/maintain, without changes in infrastructure. The ratio of potential to actual flight operations can then be used as the scaling factor for fuel transfer when determining PTE.

As an example, let's assume Base X has a wing with ten KC-135's. The Director of Operations reports that the current infrastructure can support an additional ten aircraft of like type. Therefore, the ratio of potential operational capacity to actual operations in this example is two and potential emissions would be calculated as double actual emissions. Likewise, potential fuel transferred will be double the actual fuel transferred. As a final check, however, the PTE calculated from this scaling factor must be compared to the operational capacity of the process to determine if the fueling system is capable of handling this amount of fuel. This is to ensure that the PTE does not exceed the operational capacity of the process. Some base fuel systems may already be operating near peak capacity.

(8) *Gasoline Service Stations*

The potential emissions from this source are based on the maximum amount of fuel that may be dispensed in a given year. Most Air Force installations have multiple gasoline service stations refueling both privately owned vehicles (POVs) and government owned vehicles (GOVs). Typically, each installation will have at least one AAFES gasoline station for refueling of POVs and at least one

military service station (operated by either the base Supply Squadron or the base Logistics Squadron) for refueling of GOVs.

Since most AAFES gasoline station customers are military personnel (or their dependents), the maximum number of military personnel which may be assigned to the base can be used to determine the potential amount of fuel dispensed. The Personnel Employments Section of each base's Consolidated Base Personnel Office (CBPO) maintains a listing of both the total current number of military personnel assigned and the maximum number authorized. The maximum number of personnel authorized for assignment to the base will not change significantly with an increase in the number of aircraft assigned to the base. Therefore, the ratio of the maximum number of military personnel authorized for the base to the number of personnel currently assigned can be used as the scaling factor in determining PTE. This ratio is multiplied by the actual emissions to get potential emissions.

For military gasoline stations, the maximum potential number of government vehicles assigned to the base can be used to determine the potential amount of fuel transferred. As the process owner, base Transportation should be able to project the maximum number of government vehicles which could be assigned to the base in the near future (i.e., in the next 5 years). The ratio of potential to actual number of government vehicles would be multiplied by the actual emissions to get potential emissions.

(9) *Heavy Construction Operations*

Heavy construction operations involve the construction/demolition of buildings and/or roads. These operations can be expected to occur during the year at virtually all Air Force installations. The potential emissions of this source category are based on the maximum amount of demolition, site preparation, and general construction required at the installation. The base's Civil Engineering planners should have a five-year plan for construction projects. As the process owners, they should be able to give a fairly accurate estimate of the maximum potential construction operations in the near future (i.e., in the next 5 years). The ratio of potential to actual construction projects would be multiplied by the actual emissions to get potential emissions.

(10) *Incinerators*

Two types of incinerators are typically found on Air Force installations; medical (hospital) waste incinerators and classified waste incinerators. Many incinerators are permitted by State or local regulatory agencies. These permits may have prescribed burn limitations. If so, the limits specified in the permit should be used to calculate PTE. If a limit does not exist, potential emissions must be calculated by determining the maximum operational potential for the incinerator. A conservative maximum operational potential of an incinerator is peak capacity (maximum loading) for 85% of the year. This is to take into account down time required for maintenance and inspection. For continuous feed incinerators, the design allows for loading and unloading in a safe manner so that the incinerator can be run continuously, except for down time required for maintenance and inspection. Therefore, the maximum loading rate of the incinerator (in pounds per hour) is multiplied by 8,760 hours and then by 0.85 to obtain the potential amount of waste which can be burned. For batch incinerators, the capacity for the incinerator should be determined per charge cycle. A charge-cycle may include time periods for loading the incinerator, preheating, safety procedures, burning, cooling, and removal of waste. Typically a cycle may last an entire day. Potential emissions should then be based on the number of cycles run in 85% of the total number of hours in a year. For example, if each cycle is 24 hours then there would be 310 cycles per year (0.85 * 365 days/yr). Assuming the maximum amount of waste burned per batch is 100 pounds, the potential amount of waste burned is 31,000 pounds.

(11) *Laboratory Chemicals*

Chemical laboratories commonly found at Air Force installations are used for analytical, medical, and/or research purposes. A large variety of chemicals are used in these laboratories; including solvents, acids/bases, and other reagents. Each laboratory process must be evaluated in order to determine potential to emit. For many processes, the ratio of potential laboratory services growth to actual operations can be used to determine PTE.

To estimate the base's potential laboratory services growth, a worst case growth prediction can be determined by communicating with the process owners and Civil Engineering planners on foreseeable base and workload changes. The projected increase in workload will serve as the scaling factor when determining PTE. As an example, laboratory personnel at Base X predict a 5% annual growth in laboratory services over the next five years. Thus, emissions from this source may potentially increase 25% over the next five years. Therefore, potential emissions from the use of laboratory chemicals would be estimated at a 25% increase over actual emissions, as a worst case.

(12) *Landfills*

Landfill emissions emanate from decomposing waste placed in the site during prior years and do not change appreciably from year to year. Further, emissions are released 24 hours a day. Therefore, potential and actual emissions from landfills are assumed to be equivalent.

(13) *Open Burning/Open Detonation of Munitions*

Air Force bases due not typically burn or detonate large quantities of munitions. PTE is determined by identifying the largest quantity of munitions projected to be burned and detonated. A worst case prediction can be determined by communicating with the Explosive Ordinance Disposal (EOD) shop on the potential increases in the quantity of munitions to be disposed. Often a disposal plan is available which will specify the quantity of munitions targeted for disposal in the upcoming years. Usually, a five year projection is considered adequate. The projected increase in munitions disposal will serve as the scaling factor for this source when determining PTE. As an example, at Base X the EOD shop predicts a 5% annual increase in munitions disposal over the next five years. Thus, emissions from this source may potentially increase 25% over actual emissions, as a worst case.

(14) *Site Restoration*

Emissions from this source emanate from chemicals deposited on the site during prior years. Further, emissions are released 24 hours a day. Therefore, potential and actual emissions from this source category are assumed to be equivalent.

(15) *Small Arms Firing*

Small arms firing on an Air Force base is conducted to maintain proficiency of the security police and other personnel assigned to mobility status. A limited number of personnel require training each year, regardless of the number of hours the range could be open. Therefore, potential emissions from small arms firing will be based on the potential number of people requiring training, which in turn is based on the potential number of people who are on mobility and/or who are security police.

Each base Readiness Office will have a listing of the number of people currently assigned to mobility status and should be able to give a prediction of the potential number of personnel which

could be assigned to mobility status. Also, the Personnel Employments Section of CBPO maintains a listing of both the total present number of security police assigned and the maximum number authorized. Since security police personnel may also be on mobility status, subtract the security police from the mobility listing to avoid double counting. Next, add the number of people on the mobility listing to the number of security police to obtain the total number of people requiring training. The maximum number of personnel authorized for assignment to the base will not change significantly with an increase in the number of aircraft assigned to the base. Therefore, the ratio of the maximum potential number of people requiring training to the actual number of people currently being trained can be used as the scaling factor in determining PTE for this source. This ratio is multiplied by the actual emissions to get potential emissions.

(16) *Stationary Internal Combustion Equipment*

Several types of stationary internal combustion engine equipment are found on Air Force installations. Examples include emergency generators, pumps (e.g., fire water system pumps), and compressors. Emergency generators are the most common type of stationary internal combustion engine found on an Air Force installation. They are placed at various locations across an installation to provide emergency backup power to facilities/systems when the primary electrical power is not available (e.g., power outages caused by natural disasters, equipment breakdowns, etc.). These generators are limited to emergency use and are usually only operated a few hours per year for maintenance reasons. Other generators, not designated for emergencies, are operated routinely throughout the year for various activities like construction projects and base training exercises.

The potential emissions from generators, pumps, and compressors are based on potential usage. For emergency generators, EPA has published specific guidance for calculating PTE. On 6 September 1995, EPA published a Memorandum titled "Calculating Potential to Emit (PTE) for Emergency Generators" which allows sources to limit the potential hours of operation for emergency generators to 500 hr/yr. This guidance should be used to calculate PTE for all generators designated for emergency use and operated fewer than 500 hrs/yr. Although this memo addresses only emergency generators, sources may be able to gain State approval to apply this methodology to other types of equipment (e.g. pumps, compressors, etc.), if used for emergency purposes.

For all other stationary internal combustion engine equipment not designated for emergencies, the potential to emit has traditionally been calculated by assuming maximum rated capacity for 8,760 hrs/yr. This is not a realistic assumption and results in exaggerated PTEs. An internal combustion engine simply cannot operate at maximum rated capacity 24 hours a day, 7 days a week. Physical limitations and required maintenance are just a few of the factors reducing the real capacity of an engine. A more realistic method for calculating PTE would take into consideration the real operating limitations. A conservative maximum operational potential of an internal combustion engine is 75% of maximum rated capacity for 85% of the total number of hours in a year. These values are derived from considering engines' design limitations and need for routine maintenance.

(17) *Wastewater Treatment Plants*

Potential emissions from this source are dependent on the maximum potential flow rate through the wastewater treatment facility. A reasonably conservative approach is to base the maximum potential flow rate on the maximum observed daily rate during the previous year. The process owners should select the highest daily flow rate which represents the current process. For instance, if the base population was recently cut in half, a maximum daily flow rate should be selected from the period after the changes occurred. Also keep in mind that daily flow rates observed more than twelve months

previous may not be representative of the current process. Once the highest daily flowrate representing the current process is identified, it can be multiplied by 365 to yield a maximum potential flow rate for the year. The maximum potential flow rate should then be divided by the annual flow rate used in determining actual emissions. This ratio can be multiplied by the actual emissions to determine the potential emissions.

(18) *Wet Cooling Towers*

Potential emissions for this source are based on the maximum amount of time the cooling liquid is circulating in the tower. Since the cooling liquid typically circulates continuously, potential and actual emissions from wet cooling towers should be equivalent.

APPENDIX A

Listings of Hazardous Air Pollutants (HAPs)

Hazardous Air Pollutants (Alphabetical Order)

CAS Number	Chemical Name
75-07-0	Acetaldehyde
60-35-5	Acetamide
75-05-8	Acetonitrile
98-86-2	Acetophenone
53-96-3	2-Acetylaminofluorene
107-02-8	Acrolein
79-06-1	Acrylamide
79-10-7	Acrylic acid
107-13-1	Acrylonitrile
107-05-1	Allyl chloride
92-67-1	4-Aminobiphenyl
62-53-3	Aniline
90-04-0	o-Anisidine
	Antimony Compounds
	Arsenic Compounds (inorganic including arsine)
1332-21-4	Asbestos
71-43-2	Benzene (including benzene from gasoline)
92-87-5	Benzidine
98-07-7	Benzotrichloride
100-44-7	Benzyl chloride
	Beryllium Compounds
92-52-4	Biphenyl
117-81-7	Bis(2-ethylhexyl)phthalate (DEHP)
542-88-1	Bis(chloromethyl)ether
75-25-2	Bromoform
106-99-0	1,3-Butadiene
	Cadmium Compounds
156-62-7	Calcium cyanamide
133-06-2	Captan
63-25-2	Carbaryl
75-15-0	Carbon disulfide
56-23-5	Carbon tetrachloride
463-58-1	Carbonyl sulfide
120-80-9	Catechol
133-90-4	Chloramben
57-74-9	Chlordane
7782-50-5	Chlorine
79-11-8	Chloroacetic acid
532-27-4	2-Chloroacetophenone
108-90-7	Chlorobenzene
510-15-6	Chlorobenzilate
67-66-3	Chloroform
107-30-2	Chloromethyl methyl ether
126-99-8	Chloroprene
	Chromium Compounds
	Cobalt Compounds
	Coke Oven Emissions

CAS Number	Chemical Name
1319-77-3	Cresols/Cresylic acid (isomers and mixture)
95-48-7	o-Cresol
108-39-4	m-Cresol
106-44-5	p-Cresol
98-82-8	Cumene
	Cyanide Compounds[1]
94-75-7	2,4-D, salts and esters
3547-04-4	DDE
334-88-3	Diazomethane
132-64-9	Dibenzofurans
96-12-8	1,2-Dibromo-3-chloropropane
84-74-2	Dibutylphthalate
106-46-7	1,4-Dichlorobenzene(p)
91-94-1	3,3-Dichlorobenzidene
111-44-4	Dichloroethyl ether (Bis(2-chloroethyl)ether)
542-75-6	1,3-Dichloropropene
62-73-7	Dichlorvos
111-42-2	Diethanolamine
121-69-7	N,N-Diethyl aniline (N,N-Dimethylaniline)
64-67-5	Diethyl sulfate
119-90-4	3,3-Dimethoxybenzidine
60-11-7	Dimethyl aminoazobenzene
119-93-7	3,3'-Dimethyl benzidine
79-44-7	Dimethyl carbamoyl chloride
68-12-2	Dimethyl formamide
57-14-7	1,1-Dimethyl hydrazine
131-11-3	Dimethyl phthalate
77-78-1	Dimethyl sulfate
534-52-1	4,6-Dinitro-o-cresol, and salts
51-28-5	2,4-Dinitrophenol
121-14-2	2,4-Dinitrotoluene
123-91-1	1,4-Dioxane (1,4-Diethyleneoxide)
122-66-7	1,2-Diphenylhydrazine
106-89-8	Epichlorohydrin (l-Chloro-2,3-epoxypropane)
106-88-7	1,2-Epoxybutane
140-88-5	Ethyl acrylate
100-41-4	Ethyl benzene
51-79-6	Ethyl carbamate (Urethane)
75-00-3	Ethyl chloride (Chloroethane)
106-93-4	Ethylene dibromide (Dibromoethane)
107-06-2	Ethylene dichloride (1,2-Dichloroethane)
107-21-1	Ethylene glycol
151-56-4	Ethylene imine (Aziridine)
75-21-8	Ethylene oxide
96-45-7	Ethylene thiourea
75-34-3	Ethylidene dichloride (1,1-Dichloroethane)
50-00-0	Formaldehyde
	Glycol ethers[2]
76-44-8	Heptachlor

CAS Number	Chemical Name
118-74-1	Hexachlorobenzene
87-68-3	Hexachlorobutadiene
77-47-4	Hexachlorocyclopentadiene
67-72-1	Hexachloroethane
822-06-0	Hexamethylene-1,6-diisocyanate
680-31-9	Hexamethylphosphoramide
110-54-3	Hexane
302-01-2	Hydrazine
7647-01-0	Hydrochloric acid
7664-39-3	Hydrogen fluoride (Hydrofluoric acid)
123-31-9	Hydroquinone
78-59-1	Isophorone
	Lead Compounds
58-89-9	Lindane (all isomers)
108-31-6	Maleic anhydride
	Manganese Compounds
	Mercury Compounds
67-56-1	Methanol
72-43-5	Methoxychlor
74-83-9	Methyl bromide (Bromomethane)
74-87-3	Methyl chloride (Chloromethane)
71-55-6	Methyl chloroform (1,1,1-Trichloroethane)
78-93-3	Methyl ethyl ketone (2-Butanone)
60-34-4	Methyl hydrazine
74-88-4	Methyl iodide (Iodomethane)
108-10-1	Methyl isobutyl ketone (Hexone)
624-83-9	Methyl isocyanate
80-62-6	Methyl methacrylate
1634-04-4	Methyl tert butyl ether
101-14-4	4,4-Methylene bis(2-chloroaniline)
75-09-2	Methylene chloride (Dichloromethane)
101-68-8	Methylene diphenyl diisocyanate (MDI)
101-77-9	4,4'-Methylenedianiline
	Mineral fibers (fine)[3]
91-20-3	Naphthalene
	Nickel Compounds
98-95-3	Nitrobenzene
92-93-3	4-Nitrobiphenyl
100-02-7	4-Nitrophenol
79-46-9	2-Nitropropane
684-93-5	N-Nitroso-N-methylurea
62-75-9	N-Nitrosodimethylamine
59-89-2	N-Nitrosomorpholine
56-38-2	Parathion
82-68-8	Pentachloronitrobenzene (Quintobenzene)
87-86-5	Pentachlorophenol
108-95-2	Phenol
106-50-3	p-Phenylenediamine
75-44-5	Phosgene

CAS Number	Chemical Name
7803-51-2	Phosphine
7723-14-0	Phosphorus
85-44-9	Phthalic anhydride
1336-36-3	Polychlorinated biphenyls (Aroclors)
	Polycylic Organic Matter[4]
1120-71-4	1,3-Propane sultone
57-57-8	beta-Propiolactone
123-38-6	Propionaldehyde
114-26-1	Propoxur (Baygon)
78-87-5	Propylene dichloride (1,2-Dichloropropane)
75-56-9	Propylene oxide
75-55-8	1,2-Propylenimine (2-Methyl aziridine)
91-22-5	Quinoline
106-51-4	Quinone
	Radionuclides (including radon)[5]
	Selenium Compounds
100-42-5	Styrene
96-09-3	Styrene oxide
1746-01-6	2,3,7,8-Tetrachlorodibenzo-p-dioxin
79-34-5	1,1,2,2-Tetrachloroethane
127-18-4	Tetrachloroethylene (Perchloroethylene)
7550-45-0	Titanium tetrachloride
108-88-3	Toluene
95-80-7	2,4-Toluene diamine
584-84-9	2,4-Toluene diisocyanate
95-53-4	o-Toluidine
8001-35-2	Toxaphene (chlorinated camphene)
120-82-1	1,2,4-Trichlorobenzene
79-00-5	1,1,2-Trichloroethane
79-01-6	Trichloroethylene
95-95-4	2,4,5-Trichlorophenol
88-06-2	2,4,6-Trichlorophenol
121-44-8	Triethylamine
1582-09-8	Trifluralin
540-84-1	2,2,4-Trimethylpentane
108-05-4	Vinyl acetate
593-60-2	Vinyl bromide
75-01-4	Vinyl chloride
75-35-4	Vinylidene chloride (1,1-Dichloroethylene)
1330-20-7	Xylenes (isomers and mixture)
95-47-6	o-Xylenes
108-38-3	m-Xylenes
106-42-3	p-Xylenes

NOTE: For all listings above which contain the word "compounds" and for glycol ethers, the following applies: Unless otherwise specified, these listings are defined as including any unique chemical substance that contains the named chemical (i.e., antimony, arsenic, etc.) as part of that chemical's infrastructure.

[1]X'CN where X = H' or any other group where a formal dissociation may occur. For example KCN or $Ca(CN)_2$

[2]Includes mono- and di- ethers of ethylene glycol, diethylene glycol, and triethylene glycol $R-(OCH2CH2)_n-OR'$ where:

n = 1, 2, or 3
R = alkyl or aryl groups
R' = R, H, or groups which, when removed, yield glycol ethers with the structure: R-(OCH2CH)$_n$-OH. Polymers are excluded from the glycol category.

[3]Includes mineral fiber emissions from facilities manufacturing or processing glass, rock, or slag fibers (or other mineral derived fibers) of average diameter 1 micrometer or less.

[4]Includes organic compounds with more than one benzene ring, and which have a boiling point greater than or equal to 100°C.

[5]A type of atom which spontaneously undergoes radioactive decay.

Hazardous Air Pollutants (CAS Number Order)

CAS Number	Chemical Name
50-00-0	Formaldehyde
51-28-5	2,4-Dinitrophenol
51-79-6	Ethyl carbamate (Urethane)
53-96-3	2-Acetylaminofluorene
56-23-5	Carbon tetrachloride
56-38-2	Parathion
57-14-7	1,1-Dimethyl hydrazine
57-57-8	beta-Propiolactone
57-74-9	Chlordane
58-89-9	Lindane (all isomers)
59-89-2	N-Nitrosomorpholine
60-11-7	Dimethyl aminoazobenzene
60-34-4	Methyl hydrazine
60-35-5	Acetamide
62-53-3	Aniline
62-73-7	Dichlorvos
62-75-9	N-Nitrosodimethylamine
63-25-2	Carbaryl
64-67-5	Diethyl sulfate
67-56-1	Methanol
67-66-3	Chloroform
67-72-1	Hexachloroethane
68-12-2	Dimethyl formamide
71-43-2	Benzene (including benzene from gasoline)
71-55-6	Methyl chloroform (1,1,1-Trichloroethane)
72-43-5	Methoxychlor
74-83-9	Methyl bromide (Bromomethane)
74-87-3	Methyl chloride (Chloromethane)
74-88-4	Methyl iodide (Iodomethane)
75-00-3	Ethyl chloride (Chloroethane)
75-01-4	Vinyl chloride
75-05-8	Acetonitrile
75-07-0	Acetaldehyde
75-09-2	Methylene chloride (Dichloromethane)
75-15-0	Carbon disulfide
75-21-8	Ethylene oxide
75-25-2	Bromoform
75-34-3	Ethylidene dichloride (1,1-Dichloroethane)
75-35-4	Vinylidene chloride (1,1-Dichloroethylene)
75-44-5	Phosgene
75-55-8	1,2-Propylenimine (2-Methyl aziridine)
75-56-9	Propylene oxide
76-44-8	Heptachlor
77-47-4	Hexachlorocyclopentadiene
77-78-1	Dimethyl sulfate
78-59-1	Isophorone
78-87-5	Propylene dichloride (1,2-Dichloropropane)

CAS Number	Chemical Name
78-93-3	Methyl ethyl ketone (2-Butanone)
79-00-5	1,1,2-Trichloroethane
79-01-6	Trichloroethylene
79-06-1	Acrylamide
79-10-7	Acrylic acid
79-11-8	Chloroacetic acid
79-34-5	1,1,2,2-Tetrachloroethane
79-44-7	Dimethyl carbamoyl chloride
79-46-9	2-Nitropropane
80-62-6	Methyl methacrylate
82-68-8	Pentachloronitrobenzene (Quintobenzene)
84-74-2	Dibutylphthalate
85-44-9	Phthalic anhydride
87-68-3	Hexachlorobutadiene
87-86-5	Pentachlorophenol
88-06-2	2,4,6-Trichlorophenol
90-04-0	o-Anisidine
91-20-3	Naphthalene
91-22-5	Quinoline
91-94-1	3,3-Dichlorobenzidene
92-52-4	Biphenyl
92-67-1	4-Aminobiphenyl
92-87-5	Benzidine
92-93-3	4-Nitrobiphenyl
94-75-7	2,4-D, salts and esters
95-47-6	o-Xylenes
95-48-7	o-Cresol
95-53-4	o-Toluidine
95-80-7	2,4-Toluene diamine
95-95-4	2,4,5-Trichlorophenol
96-09-3	Styrene oxide
96-12-8	1,2-Dibromo-3-chloropropane
96-45-7	Ethylene thiourea
98-07-7	Benzotrichloride
98-82-8	Cumene
98-86-2	Acetophenone
98-95-3	Nitrobenzene
100-02-7	4-Nitrophenol
100-41-4	Ethyl benzene
100-42-5	Styrene
100-44-7	Benzyl chloride
101-14-4	4,4-Methylene bis(2-chloroaniline)
101-68-8	Methylene diphenyl diisocyanate (MDI)
101-77-9	4,4¬-Methylenedianiline
106-42-3	p-Xylenes
106-44-5	p-Cresol
106-46-7	1,4-Dichlorobenzene(p)
106-50-3	p-Phenylenediamine
106-51-4	Quinone

CAS Number	Chemical Name
106-88-7	1,2-Epoxybutane
106-89-8	Epichlorohydrin (l-Chloro-2,3-epoxypropane)
106-93-4	Ethylene dibromide (Dibromoethane)
106-99-0	1,3-Butadiene
107-02-8	Acrolein
107-05-1	Allyl chloride
107-06-2	Ethylene dichloride (1,2-Dichloroethane)
107-13-1	Acrylonitrile
107-21-1	Ethylene glycol
107-30-2	Chloromethyl methyl ether
108-05-4	Vinyl acetate
108-10-1	Methyl isobutyl ketone (Hexone)
108-31-6	Maleic anhydride
108-38-3	m-Xylenes
108-39-4	m-Cresol
108-88-3	Toluene
108-90-7	Chlorobenzene
108-95-2	Phenol
110-54-3	Hexane
111-42-2	Diethanolamine
111-44-4	Dichloroethyl ether (Bis(2-chloroethyl)ether)
114-26-1	Propoxur (Baygon)
117-81-7	Bis(2-ethylhexyl)phthalate (DEHP)
118-74-1	Hexachlorobenzene
119-90-4	3,3-Dimethoxybenzidine
119-93-7	3,3¬-Dimethyl benzidine
120-80-9	Catechol
120-82-1	1,2,4-Trichlorobenzene
121-14-2	2,4-Dinitrotoluene
121-44-8	Triethylamine
121-69-7	N,N-Diethyl aniline (N,N-Dimethylaniline)
122-66-7	1,2-Diphenylhydrazine
123-31-9	Hydroquinone
123-38-6	Propionaldehyde
123-91-1	1,4-Dioxane (1,4-Diethyleneoxide)
126-99-8	Chloroprene
127-18-4	Tetrachloroethylene (Perchloroethylene)
131-11-3	Dimethyl phthalate
132-64-9	Dibenzofurans
133-06-2	Captan
133-90-4	Chloramben
140-88-5	Ethyl acrylate
151-56-4	Ethylene imine (Aziridine)
156-62-7	Calcium cyanamide
302-01-2	Hydrazine
334-88-3	Diazomethane
463-58-1	Carbonyl sulfide
510-15-6	Chlorobenzilate
532-27-4	2-Chloroacetophenone

CAS Number	Chemical Name
534-52-1	4,6-Dinitro-o-cresol, and salts
540-84-1	2,2,4-Trimethylpentane
542-75-6	1,3-Dichloropropene
542-88-1	Bis(chloromethyl)ether
584-84-9	2,4-Toluene diisocyanate
593-60-2	Vinyl bromide
624-83-9	Methyl isocyanate
680-31-9	Hexamethylphosphoramide
684-93-5	N-Nitroso-N-methylurea
822-06-0	Hexamethylene-1,6-diisocyanate
1120-71-4	1,3-Propane sultone
1319-77-3	Cresols/Cresylic acid (isomers and mixture)
1330-20-7	Xylenes (isomers and mixture)
1332-21-4	Asbestos
1336-36-3	Polychlorinated biphenyls (Aroclors)
1582-09-8	Trifluralin
1634-04-4	Methyl tert butyl ether
1746-01-6	2,3,7,8-Tetrachlorodibenzo-p-dioxin
3547-04-4	DDE
7550-45-0	Titanium tetrachloride
7647-01-0	Hydrochloric acid
7664-39-3	Hydrogen fluoride (Hydrofluoric acid)
7723-14-0	Phosphorus
7782-50-5	Chlorine
7803-51-2	Phosphine
8001-35-2	Toxaphene (chlorinated camphene)
	Antimony Compounds
	Arsenic Compounds (inorganic including arsine)
	Beryllium Compounds
	Cadmium Compounds
	Chromium Compounds
	Cobalt Compounds
	Coke Oven Emissions
	Cyanide Compounds[1]
	Glycol ethers[2]
	Lead Compounds
	Manganese Compounds
	Mercury Compounds
	Fine mineral fibers[3]
	Nickel Compounds
	Polycylic Organic Matter[4]
	Radionuclides (including radon)[5]
	Selenium Compounds

NOTE: For all listings above which contain the word "compounds" and for glycol ethers, the following applies: Unless otherwise specified, these listings are defined as including any unique chemical substance that contains the named chemical (i.e., antimony, arsenic, etc.) as part of that chemical's infrastructure.

[1]X'CN where X = H' or any other group where a formal dissociation may occur. For example KCN or $Ca(CN)_2$

[2]Includes mono- and di- ethers of ethylene glycol, diethylene glycol, and triethylene glycol $R\text{-}(OCH2CH2)_n\text{-}OR'$ where:

n = 1, 2, or 3
R = alkyl or aryl groups
R' = R, H, or groups which, when removed, yield glycol ethers with the structure: R-(OCH2CH)$_n$-OH. Polymers are excluded from the glycol category.

[3]Includes mineral fiber emissions from facilities manufacturing or processing glass, rock, or slag fibers (or other mineral derived fibers) of average diameter 1 micrometer or less.

[4]Includes organic compounds with more than one benzene ring, and which have a boiling point greater than or equal to 100°C.

[5]A type of atom which spontaneously undergoes radioactive decay.

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APPENDIX B

Air Emissions Inventory Data Elements for Stationary Sources

Source Type	Data Elements
Abrasive Blasting	1. Actual emissions (stack) sampling results, if available 2. If stack sampling results are available, approximate time (hours) blasting was performed during the year 3. Type of blasting media used (e.g., sand, plastic beads, glass beads, etc.) 4. Type of control device(s) used 5. Make, model number, and manufacturer of each control device 6. Efficiency of the control device(s) which collects waste material 7. Amount (in pounds) of material collected by control device(s) during the year 8. Amount (in pounds) of blasting media used during the year
Aircraft Engine Testing	1. Type of engine(s) tested 2. Type of fuel used by each engine (e.g., JP-8, JP-5) 3. The different operating modes (power settings) each engine was tested at during the year (e.g., idle, approach, intermediate, military, afterburner, etc.) 4. The number of tests performed on each engine during the year 5. For each test, the approximate time in each operating mode 6. For each engine, the fuel flow rate for each operating mode
Asphalt Paving Operations	1. Types of cutback asphalt used during the year (e.g., rapid cure, medium cure, slow cure) 2. Quantity (pounds) of each type of cutback asphalt applied during the year 3. Volume percent solvent in each type of cutback asphalt used
Chromium Electroplating and Chromic Acid Anodizing	Chromium Electroplating 1. Type(s) of plating tanks at the electroplating facility (i.e., hard, decorative) 2. The number of each type of tank 3. Actual emissions (stack) sampling results, if available 4. The total ampere-hours (amp-hrs) applied to each tank during the year 5. The type of control device(s) used (e.g., packed-bed scrubber, composite-mesh pad system, chevron-blade mist eliminator, fume suppressants, polypropylene balls, etc.) 6. Make, model #, and manufacturer of each control device Chromic Acid Anodizing 1. The surface area of each tank (in square feet) 2. The time each tank was operated during the year 3. Actual emissions (stack) sampling results, if available 4. The type of control device(s) used (e.g., packed-bed scrubber, composite-mesh pad system, chevron-blade mist eliminator, fume suppressants, polypropylene balls, wet scrubber with moisture extractor and particulate filter, etc.) 5. Make, model #, and manufacturer of each control device

Source Type	Data Elements
Dry Cleaning Operations	1. Type(s) of dry cleaning machines used (e.g., transfer, dry-to-dry) 2. Type(s) of solvents used (e.g., perchloroethylene, petroleum, trichlorotrifluoroethane) 3. Density of each solvent used 4. For each solvent type, the volume of fresh solvent added to the dry cleaning process during the year 5. For each solvent type, the volume of waste solvent removed from the process during the year 6. If a carbon adsorption control device is used, then the following additional information is required • Mass of solvent which is captured by the carbon adsorption system <u>and not</u> reintroduced back in to the process
Equipment Leaks	1. Locations on base where there are fuel distribution equipment containing any of the following components: pump seals, valves, compressor seals, pressure relief valves, flanges, connectors, open-ended lines, sampling connections [Note - locations where fuel distribution equipment are typically found include places like pumphouses, refueling hydrants, fill stands for loading/unloading tank trucks, service stations, bulk storage tanks, etc.] 2. The number of each type of component (listed in item # 1 above) at each site where fuel distribution equipment is located 3. The type of fuel contained in each different fuel distribution equipment 4. The amount of time during the year in which each fuel distribution equipment contained fuel
Ethylene Oxide Sterilizers	1. Make, model number, and manufacturer of each machine (sterilizer) 2. Quantity of sterilant used during the year in each machine 3. Weight percent of ethylene oxide in sterilant 4. Type of control device used, if applicable (e.g., acid-water scrubber, thermal oxidizer, catalytic oxidizer, etc.) 5. Make, model number, and manufacturer of each control device 6. The manufacturer's rated efficiency for each control device

Source Type	Data Elements
External Combustion Sources	1. Make, model number, and manufacturer of combustion unit 2. Actual emissions (stack) sampling results, if available [Note - this may be in the form of on-site testing and/or testing performed by the manufacturer] 3. Type of fuel(s) burned during the year [e.g., bituminous coal; subbituminous coal; anthracite coal; fuel oil (No. 6, No. 5, No. 4, or Distillate); natural gas; liquified petroleum gas (propane or butane); etc.] by the combustion unit 4. If coal fired, the exact type of boiler/furnace (e.g., pulverized coal, dry bottom, wall fired; pulverized coal, dry bottom, tangentially fired; pulverized coal, wet bottom; cyclone furnace; spreader stoker; overfeed stoker; underfeed stoker; hand-fed unit; fluidized bed combustor, circulating bed; fluidized bed combustor, bubbling bed; etc.) 5. If coal fired, the typical ash content and sulfur content of the coal (wt%) 6. If fuel oil fired, the typical sulfur content of the fuel oil (wt%) 7. Rated capacity of the combustion unit (MMBtu/hr) 8. Amount of each fuel type burned during the year in the combustion unit 9. Amount of time (hours) the combustion unit was operated during the year 10. Type of control device(s) used for the combustion unit, if applicable (e.g., multiple cyclones, scrubber, ESP, bag house, etc.) 11. Make, model number, and manufacturer of each control device 12. Type of control technique(s) used for the combustion unit, if applicable (e.g., low NO_X burners, flue gas recirculation, low excess air, burners out of service, selective noncatalytic reduction, selective catalytic reduction, overfire air, etc.)
Fire Fighter Training	1. Types of fuels burned (e.g., JP-8, propane, etc.) 2. Approximate quantity of each fuel type burned during the year
Fuel Cell Maintenance	Note – the data elements for "Fuel Cell Maintenance" do not include the transfer of liquid fuel from fuel cells to bowsers as these emissions are usually addressed under "Fuel Transfer" instead 1. Volume capacity of each different type of fuel cell which was entered for maintenance during the year 2. The number of maintenance operations performed during the year on each different type of fuel cell 3. For each different type of fuel cell, is there explosion suppression foam which is removed prior to performing maintenance? 4. If explosion suppression foam is removed prior to maintenance, is it allowed to air dry? If so, then the following additional information is needed: • Number of foam blocks (of the same size) which were removed from fuel cells and allowed to air dry during the year • Estimated weight of a saturated foam block removed from a fuel cell (prior to air drying) • Estimated weight of a foam block after air drying (prior to placing back into the fuel cell)

Source Type	Data Elements
Fuel Spills	1. Types of fuels involved in reported/recorded spills during the year 2. Total quantity of each type of fuel spilled during the year 3. Total quantity of each type of fuel recovered from spills
Fuel Storage - Vertical Fixed Roof Tanks	Data elements are based on EPA's TANKS program. The following information is required for each tank: 1. Shell Height (ft) 2. Diameter (ft) 3. Maximum Liquid Height (ft) 4. Average Liquid Height (ft) 5. Working Volume (gal) 6. Turnovers per Year 7. Is Tank Heated (yes or no) 8. If tank is heated, then the following additional information will be required: • Average Liquid Surface Temperature (° F) • Minimum Liquid Surface Temperature (° F) • Maximum Liquid Surface Temperature (° F) 9. Shell Color/Shade (choose one of the following: white/white, aluminum/specular, aluminum/diffuse, gray/light, gray/medium, or red/primer) 10. Shell Condition (good or poor) 11. Roof Color/Shade (same options as for shell color/shade) 12. Roof Condition (good or poor) 13. Roof Type (cone or dome) 14. Roof Height (ft) 15. Roof Radius (ft) [for dome roof only] 16. Roof Slope (ft/ft) [for cone roof only] 17. Breather Vent Vacuum Setting (TANKS default is -0.03 psig) 18. Breather Vent Pressure Setting (TANKS default is 0.03 psig) 19. Nearest Major City (choose from list in TANKS Program) 20. Chemical Category of Liquid Stored in Tank (choose one of the following: organic liquid, petroleum distillates, or crude oil) 21. Is Liquid a Single or Multi-Component Liquid (note - fuels are considered "Single" component liquids) 22. Name of Liquid or Liquid Components (note - TANKS contains listings of various chemicals and fuels to choose from. For JP-8, the "Jet Kerosene" option is typically used) 23. Weight Percent of Components (for multi-component liquids)

Source Type	Data Elements
Fuel Storage - Horizontal Fixed Roof Tanks (Including USTs)	Data elements are based on EPA's TANKS program. The following information is required for each tank: 1. Shell Length (ft) 2. Diameter (ft) 3. Working Volume (gal) 4. Number of Turnovers per Year 5. Is Tank Underground (yes or no) 6. Is Tank Heated (yes or no) 7. If tank is heated, then the following additional information will be required: • Average Liquid Surface Temperature (° F) 8. Shell Color/Shade (choose one of the following: white/white, aluminum/specular, aluminum/diffuse, gray/light, gray/medium, or red/primer) 9. Shell Condition (good or poor) 10. Breather Vent Vacuum Setting (TANKS default is -0.03 psig) 11. Breather Vent Pressure Setting (TANKS default is 0.03 psig) 12. Nearest Major City (choose from list in TANKS Program) 13. Chemical Category of Liquid Stored in Tank (choose one of the following: organic liquid, petroleum distillates, or crude oil) 14. Is Liquid a Single or Multi-Component Liquid (note - fuels are considered "Single" component liquids) 15. Name of Liquid or Liquid Components (note – TANKS contains listings of various chemicals and fuels to choose from. For JP-8, the "Jet Kerosene" option is typically used) 16. Weight Percent of Components (for multi-component liquids)

Source Type	Data Elements
Fuel Storage - External Floating Roof Tanks	Data elements are based on EPA's TANKS program. The following information is required for each tank: 1. Tank Diameter (ft) 2. Tank Volume (gal) 3. Turnovers per Year 4. Shell Condition (choose one of the following: light rust, dense rust, or gunite lining) 5. Paint Color/Shade (choose one of the following: white/white, aluminum/specular, aluminum/diffuse, gray/light, gray/medium, or red/primer) 6. Paint Condition (good or poor) 7. Roof Type (pontoon or double deck) 8. Roof Fitting Category (typical or detail) 9. Tank Construction (welded or riveted) 10. Primary Rim-seal (liquid-mounted, mechanical shoe, or vapor mounted) 11. Secondary Seal (none, rim-mounted, or shoe-mounted) 12. Nearest Major City (choose from list in TANKS Program) 13. Chemical Category of Liquid Stored in Tank (choose one of the following: organic liquid, petroleum distillates, or crude oil) 14. Is Liquid a Single or Multi-Component Liquid (note – fuels are considered "Single" component liquids) 15. Name of Liquid or Liquid Components (note – TANKS contains listings of various chemicals and fuels to choose from. For JP-8, the "Jet Kerosene" option is typically used) 16. Weight Percent of Components (for multi-component liquids)

Source Type	Data Elements
Fuel Storage - Internal Floating Roof Tanks	Data elements are based on EPA's TANKS program. The following information is required for each tank: 1. Tank Diameter (ft) 2. Tank Volume (gal) 3. Turnovers per Year 4. Self-Supporting Roof (yes or no) 5. Number of Columns 6. Effective Column Diameter (ft) 7. Shell Condition (light rust, dense rust, or gunite lining) 8. Shell Color/Shade (choose one of the following: white/white, aluminum/specular, aluminum/diffuse, gray/light, gray/medium, or red/primer) 9. Shell Paint Condition (good or poor) 10. Roof Color/Shade (same options as for shell color/shade) 11. Roof Paint Condition (good or poor) 12. Primary Rim-seal (liquid-mounted, mechanical shoe, or vapor mounted) 13. Secondary Seal (none or rim-mounted) 14. Deck Type (bolted or welded) 15. Deck Fitting Category (typical or detail) 16. Deck Construction (for bolted decks only) [choose one of the following: 5 ft wide continuous sheet, 6 ft wide continuous sheet, 7 ft wide continuous sheet, 5 x 7.5 rectangular panel, or 5 x 12 ft rectangular panel) 17. Nearest Major City (choose from list in TANKS Program) 18. Chemical Category of Liquid Stored in Tank (choose one of the following: organic liquid, petroleum distillates, or crude oil) 19. Is Liquid a Single or Multi-Component Liquid (note - fuels are considered "Single" component liquids) 20. Name of Liquid or Liquid Components (note – TANKS contains listings of various chemicals and fuels to choose from. For JP-8, the "Jet Kerosene" option is typically used) 21. Weight Percent of Components (for multi-component liquids)

Source Type	Data Elements
Fuel Transfer	1. Types of fuel transfer processes (e.g., loading fuel into tanker trucks, loading fuel into aircraft, loading fuel into AGSE, loading fuel into bowers, etc.) 2. Type of fuel transferred at each process 3. Quantity of fuel transferred at each process during the year 4. Average temperature of fuel transferred 5. Method of loading at each process (Choose one of the following: submerged loading of a clean cargo tank; submerged loading - dedicated normal service; submerged loading - dedicated vapor balance; splash loading of a clean cargo tank; splash loading - dedicated normal service; or splash loading – dedicated vapor balance service) 6. Is a vapor recovery system used when fuel is loaded into tanker trucks? If so, then the following information is required: • Capture efficiency of vapor control system • Control efficiency of vapor control system [Note - if the capture and/or control efficiencies are unknown, use guidance found in Section 5.2 of AP-42 or in the "Fuel Transfer" section of this document]
Gasoline Service Stations	1. Throughput of gasoline at the service station 2. Method in which USTs are filled [Choose one of the following: submerged filling; splash filling; or balanced submerged filling (i.e., Type I vapor recovery)] 3. Is Stage II vapor recovery used for automobile refueling?
Heavy Construction Operations	1. Estimated number of full (8-hour equivalent) working days during the year in which construction activities are performed on 2. Average area of property in which daily construction projects are typically performed on
Incinerators	1. Make, model number, and manufacturer of incinerator 2. Actual emissions (stack) sampling results, if available [Note - this may be in the form of on-site testing and/or testing performed by the manufacturer] 3. Type of waste burned (e.g., medical/hospital, pathological, classified, municipal, waste fuel, waste solvent, etc.) [Note - if waste is mixed, obtain typical mixture percentages (by weight)] 4. Rated capacity of the incinerator (lb/hr) 5. For batch incinerators, the number of loads of waste burned during the year 6. For batch incinerators, the average quantity (pounds) of waste burned per load 7. Quantity of waste burned during the year [Note - for batch incinerators, this can be estimated by multiplying the number of loads burned per year times the quantity of waste burned per load] 8. Type of control device(s) used, if applicable 9. Make, model number, and manufacturer of each control device

Source Type	Data Elements
Laboratory Chemicals	1. The name, stock number, and manufacturer of each laboratory chemical used 2. Quantity of each chemical used during the year 3. The density of each chemical used 4. The VOC content of each chemical used (weight %) 5. The name and weight % of each HAP constituent in each chemical used
Landfills	<u>Gaseous Emissions</u> 1. Is landfill active or closed? 2. If landfill is closed, date of closure 3. Date of initial refuse placement into landfill 4. Average annual refuse acceptance rate during active life (tons/year) 5. Average annual amount of rainfall received by the base (inches) 6. Specific types of wastes disposed of in the landfill (e.g., household solid waste, industrial organic wastes, etc.) 7. Sampling results (if available) which provide landfill gas constituent concentrations (e.g., for Total Non-Methane Organic Compounds (TNMOC) and organic HAPs) [Note - if sampling results are unavailable, typical values listed in Section 2.4 of AP-42, or in the "Landfills" section of this document, can be used] 8. The estimated average temperature of the landfill gas 9. Is the landfill equipped with a gas collection system? If so, the efficiency of the gas collection system is required [Note - if unknown, assume 75%] 10. Is a control device (e.g., flare) used to control emissions from the gas collection system? <u>Particulate Emissions</u> 1. Type of heavy duty equipment used to cover the waste with soil (e.g., bulldozer, graders, etc.) 2. Estimated time (hours) which bulldozers were operating at the landfill during the year 3. Estimated miles which graders traveled at the landfill during the year
Miscellaneous Chemical Use	1. The name, stock number, and manufacturer of each miscellaneous chemical used 2. Quantity of each chemical used during the year 3. The density of each chemical used 4. The VOC content of each chemical used (weight %) 5. The name and weight % of each HAP constituent in each chemical used
Non-Destructive Inspection (NDI) Operations	1. The name, stock number, and manufacturer of each chemical used 2. Quantity of each chemical used during the year 3. Quantity of each chemical removed from the process during the year (i.e., quantity disposed of or recycled) 4. The density of each chemical used 5. The VOC content of each chemical used (weight %) 6. The name and weight % of each HAP constituent in each chemical used

Source Type	Data Elements
Open Burning/Open Detonation of Energetic Materials	1. Types of energetic materials disposed of via open burning 2. Types of energetic materials disposed of via open detonation 3. For open burning or open detonation of bulk energetic materials, the following information is required: • Total mass of energetic material which is open burned or open detonated during the year (lb/yr) 4. For open burning of assembled energetic materials (i.e., munitions), the following information is required: • Mass of energetic material contained in the munition item (grams/item or grams/round) • Quantity of the munition open burned during the year (items/yr or rounds/yr) 5. For open detonation of assembled energetic materials (i.e., munitions), the following information is required: • Mass of energetic material contained in the munition item (grams/item or grams/round) • Quantity of the munition open detonated during the year (items/yr or rounds/yr) • Estimated mass of donor charge used per munition item (grams/item or grams/round) 6. The following additional information may be needed if emissions are calculated using alternative methods (described in subsection 22.2b) instead of the EPA's emission factor database: • Metal HAP content (%) in the energetic material which is burned or detonated • Carbon content (%) in the energetic material which is burned or detonated • Nitrogen content (%) in the energetic material which is burned or detonated
Open/Prescribed Burning	1. Types of agricultural/forest material (i.e., vegetation) burned during the year 2. The approximate acres of each type of vegetation burned during the year 3. The approximate mass of each type of vegetation burned per acre (e.g., tons/acre) [Note - may need to contact one or more of the following in order to obtain this information: local forestry officials, State forestry agency, or State land management agency. Some typical values are provided in the Section 13.1 of AP-42 and in the "Open/Prescribed Burning" section of this document. Other possible sources of this information are References 5 and 15 of AP-42 Section 13.1]

Source Type	Data Elements
Ozone Depleting Substances	1. The name, stock number, and manufacturer of all ODS-containing products used 2. The weight percent ODS in each applicable product 3. The identity of the processes (operations) which use the ODS-containing products 4. The annual quantity (pounds) of ODS-containing product used at each process 5. The annual quantity (pounds) of ODS-containing product removed from each process for purposes of disposal, recycling, or reclamation 6. Efficiency of control devices used to control ODS emissions, if applicable
Pesticide Application	1. The name, stock number, and manufacturer of all pesticides/herbicides applied during the year which contain VOCs and/or organic HAPs 2. The quantity (pounds) of each applicable pesticide/herbicide applied during the year 3. The VOC content of each applicable pesticide/herbicide used (weight %) 4. If the weight % VOC (item # 4 above) is not known, then the following information is required: • weight % of Active Ingredient portion in the pesticide • weight % of Inert portion in the pesticide • weight % VOC in the Inert portion of the pesticide [Note - if unknown, use the average values found in Section 9.2.2 of AP-42 or in the "Pesticide Application" section of this document] 5. The weight percent of each HAP constituent in each pesticide used

Source Type	Data Elements
Site Restoration	<u>Soil Vapor Extraction</u> 1. Flow rate of the extracted air (ft^3/min) 2. Concentration of each contaminant (e.g., VOC, organic HAPs) in the extracted air (ppmv) 3. Molecular weight of each contaminant 4. Time during the year in which the soil vapor extraction process was performed (hr/yr) 5. Type of control device used to treat the extracted air, if applicable 6. Make, model number, and manufacturer of the control device 7. Manufacturer's rated efficiency of the control device <u>Pump and Treat Utilizing Air Stripping</u> 1. Groundwater pumping rate (gal/min) 2. Average concentration of each contaminant (e.g., VOC, organic HAPs) in the groundwater (mg/l) 3. Make, model number, and manufacturer of the air stripper used 4. Rated removal efficiency of the air stripper 5. Time during the year in which the "Pump and Treat" process was performed (hr/yr) 6. Type of control device used to control emissions from the air stripper, if applicable 7. Make, model number, and manufacturer of the control device 8. Manufacturer's rated efficiency of the control device
Small Arms Firing	1. Types of rounds used during the year (e.g., 5.56 mm, 9 mm, 7.62 mm, 40 mm, 12 gauge, etc.) 2. For each type, the number of rounds fired during the year 3. For each type, the amount of energetic material contained in each round (grains/round) [Note - values for 5.56 mm, 9 mm, 7.62 mm, 40 mm, and 12 gauge ammunition are listed in the "Small Arms Firing" section of this document. Values for other types of munitions can be obtained from the Army's "MIDAS" program] 4. The type of control device used, if applicable (e.g., dry filters to control lead emissions from an indoor firing range) 5. Make, model #, and manufacturer of the control device 6. The manufacturer's rated efficiency for the control device 7. The quantity of lead compounds (i.e., lead styphnate and lead azide) contained in each round (grains/round) [Note - values for 5.56 mm, 9 mm, 7.62 mm, 40 mm, and 12 gauge ammunition are listed in the "Small Arms Firing" section of this document. Values for other types of munitions can be obtained from the Army's "MIDAS" program]

Source Type	Data Elements
Solvent Cleaning Machines	1. Make, model number, and manufacturer of each machine 2. Name, stock number, and manufacturer of the solvent (cleaner) used in each tank/machine 3. Quantity of solvent used in each tank/machine during the year 4. Quantity of waste solvent removed from each tank/machine during the year (e.g., total amount disposed of and/or recycled) 5. The density of each solvent used 6. The VOC content of each solvent used (either in weight %, g/l, or lb/gal) 7. The name and weight % of each HAP constituent in each solvent used 8. Type of control device(s) used, if applicable (e.g., carbon adsorber) 9. Make, model number, and manufacturer of each control device 10. The quantity of solvent captured by each control device during the year
Stationary Internal Combustion Engine Equipment	1. Type of equipment (emergency generator, compressor, pump, etc.) 2. Make, model number, and manufacturer of the equipment [Note - for emergency generators, obtain this information for both the engine and the electric generator] 3. Actual emissions (stack) sampling results, if available [Note - this may be in the form of on-site testing and/or testing performed by the manufacturer] 4. The approximate time (hours) the equipment (engine) was operated during the year 5. Rated power output of the engine (hp) 6. The loading factor (% of maximum power) the engine is typically operated at [Note - if unknown, use typical values listed in the "Stationary Internal Combustion Equipment" section of this document] 7. Approximate time (hours) the equipment was operated during the year 8. Type of fuel combusted by the engine 9. Quantity of fuel combusted by the engine during the year (gal/yr) 10. For emergency generators, obtain the rated power output of the electric generator (kW) 11. For emergency generators, obtain the peak electrical demand during the year (kW)

Source Type	Data Elements
Surface Coatings	1. Actual emissions (stack) sampling results for each paint booth and paint hangar, if available 2. For those paint booths/hangars which have emissions sampling results, the approximate time (hours) painting was performed in the booth (or hangar) during the year 3. The name, stock number, and manufacturer of all coatings used at each paint booth and paint hangar 4. The quantity of each coating used at each booth/hangar during the year 5. The density of each coating used 6. The VOC content of each coating used (either in weight %, g/l, or lb/gal) 7. The solids content (wt %) of each coating used 8. The name and weight percent of each HAP constituent in each coating used 9. The method in which each coating is applied (e.g., conventional spray guns, HVLP spray guns, electrostatic spray guns, brush coating, roll coating, etc.) 10. The rated transfer efficiency of each type of spray gun used 11. The type of particulate control device used, if applicable [i.e., dry filters (include # of stages) or waterwash system] 12. The type of VOC control device used, if applicable (e.g., carbon adsorber, incinerator, etc.) 13. Make, model number, and manufacturer of each control device 14. The manufacturer's rated efficiency of each control device 15. Type of ventilation system (i.e., cross draft or down draft) 16. The estimated percentage of paint overspray which falls out onto the floor prior to reaching the particulate control device (note – this is usually very difficult to estimate. For this reason, 0 % is typically used for worst-case purposes)
Waste Solvent Reclamation	1. The name and stock number of each solvent recycled 2. Quantity of waste solvent recycled (e.g., quantity distilled) 3. Quantity of solvent recovered 4. Density of each solvent 5. Quantity of sludge produced

Source Type	Data Elements
Wastewater Treatment Plant	<u>Wastewater Emissions</u> 1. The quantity of wastewater treated by the plant during the year [Note - if this is unknown it can be estimated by multiplying the typical daily flow rate (gal/day) times the number of days during the year the plant was operating (usually 365)] 2. Average concentration of contaminants (e.g., VOC, organic HAPs) in the Influent (μg/l) 3. Average concentration of contaminants (e.g., VOC, organic HAPs) in the Effluent (μg/l) 4. Quantity (pounds) of chlorine added to the wastewater during the year <u>Sludge Digester Gas Flare Emissions</u> 1. Average daily quantity of gas combusted 2. Number of days during the year in which the flare was in operation
Welding	1. Type of welding process(es) being performed [i.e., shielded metal arc welding (SMAW), gas metal arc welding (GMAW), flux cored arc welding (FCAW), or submerged arc welding (SAW)] 2. The types of electrodes used in each welding process (see Section 12.19 of AP-42, or the "Welding" section of this document, for listing of electrode types) 3. The quantity (in pounds) of each type of electrode consumed during the year
Wet Cooling Towers	1. Type of cooling tower (i.e., induced draft or natural draft) 2. Typical circulating water flow rate through the cooling tower (gal/day) 3. Number of days cooling tower was in operation during the year 4. The typical Total Dissolved Solids (TSD) content in the cooling water, if available
Woodworking	1. Type of control device used to capture sawdust emissions (e.g., cyclone) 2. Make, model number, and manufacturer of the control device 3. Estimated efficiency of the control device 4. Amount (in pounds) of sawdust collected by control device during the year. This can be estimated using the following information: • Typical volume of sawdust in collection bin at the time the bin is emptied (cubic feet) • Approximate number of times bin was emptied during the year • Estimated density of the sawdust (lb/ft^3) [Note - if unknown, use 11.5 lb/ft^3]

APPENDIX C

Recommended Inventory Format

REPORT OUTLINE

Cover Page

Report Documentation Page (Standard Form 298) [Note - only if required by the government]

Table of Contents

List of Figures

List of Tables

Abbreviations and Acronyms

Executive Summary

Section 1: Introduction
- Background
- Discussion
- Summary of Results
- Conclusions and Recommendations
- Points of Contact
- References

Section 2: *Name of the first source type*
- Title V Source Designation(s) [Note – only applicable if inventory is for Title V purposes]
- Standard Industrial Classification Code (or North American Industry Classification System Code)
- Source Classification Code(s)
- Discussion
- Actual Emissions
- Potential Emissions
- References

Section 3: *Name of the second source type*
- Title V Source Designation(s) [Note – only applicable if inventory is for Title V purposes]
- Standard Industrial Classification Code (or North American Industry Classification System Code)
- Source Classification Code(s)
- Discussion
- Actual Emissions
- Potential Emissions
- References

Repeat for all other source types

Appendixes

Glossary of Terms [optional]

The following is a brief description of the information which the main sections of the inventory should contain:

Section 1: Introduction

- Background – This should contain the following information:
  - Statement as to what the document is (e.g., air emissions inventory for ___ base for calendar year __)
  - Identity (name and office symbol) of the government organizations involved (e.g., base organization(s), MAJCOM organization, contracting organization, etc.)
  - Overall purpose of the inventory
  - General description of the base (e.g., size, location, primary mission, etc.)

- Discussion – This should include the following information:
  - General summary of how the inventory was conducted and any significant problems encountered
  - Summary of the applicable Federal, State, and local air quality rules/regulations which require the inventory as well as the rules/regulations which may impact the base depending on the results of the inventory
  - Summary of the types of pollutants addressed in the inventory (e.g., criteria pollutants, HAPs, ODSs, etc.), types of sources addressed (e.g., stationary point, stationary fugitive, mobile, etc.), types of emissions addressed (i.e., actual only, actual and potential)
  - Attainment/non-attainment status of the base with respect to the National Ambient Air Quality Standards
  - Summary of any applicable Federal, State, or local policies which were utilized when conducting the inventory (e.g., EPA policy memorandums on subjects such as determining major/non-major source status, avoiding major source status, determining PTE, etc.)

- Summary of Results – this should include tables which summarize the annual pollutant emissions calculated in the inventory. Examples of two recommended tables are included in this appendix. One table summarizes the HAP emissions while the other table summarizes criteria pollutant and "Total HAP" emissions. Separate tables should be prepared for both actual and potential emissions, as applicable. In addition to these tables, this subsection should also include a written summary of the results which highlights the key emission sources on the installation.

- Conclusions and Recommendation – this subsection should include a written summary of what the results mean to the base. For example, based on the results, is the base considered a "Major Source" under one or more regulatory programs (e.g. CAAA-90 Title III, CAAA-90 Title V, NSR, etc.)? Does the base now have to comply with any specific rules/regulations because of their inventory results? Similarly, can the base now avoid compliance with specific rules/regulations because of their inventory results? This subsection should also provide recommendations on how the base should utilize the information in the inventory, as well as identify obvious (already known) actions the base can take to reduce emissions in the future.

- Points of Contact – this subsection should be include a listing (e.g., table) which contains the name, shop, office symbol, and phone number of all base points of contact (POCs) associated with each source type addressed in the inventory.

- References – this subsection should include a list of all references which are applicable to the emissions inventory document as a whole (e.g., regulatory rules/regulations and policy documents, general inventory references, etc.).

<u>Sections 2 through ? – *Specific Source Types*</u>

- Title V Source Designation(s) – Most State Title V Operating Permit programs identify source types which are considered "Insignificant" and thus not required to be addressed in Title V permits. Therefore, if the inventory is being accomplished as a requirement of CAAA-90 Title V, or to determine if the installation is a "Major Source" under Title V, then the source type being addressed should be labeled as either "Significant" or "Insignificant." It's important to note that in certain cases some units of a source type may be considered "Significant" while other units are considered "Insignificant." For example, most Title V programs consider boilers "Significant" only if they are greater than or equal to a specific size. Those boilers less than that specific size would be considered "Insignificant."

- Standard Industrial Classification (SIC) Code – As mentioned in Section 1.7B of this document, on 2 Aug 96 the EPA published a policy memo which gives State/local regulatory agencies the option of allowing military installations to be divided up into industrial groupings (i.e., classifying activities by two-digit SIC codes) for purposes of Major Source determination under CAAA-90 Title V and NSR permitting programs. Therefore, the two-digit SIC code which is most applicable to the source type should be stated [Note - a two-digit SIC code of 97 ("National Security") should be used if the applicable State/local regulatory agency does not accept the policy in EPA's 2 Aug 96 memo, or if there is not a more applicable SIC code for the source type]. A listing of two-digit SIC codes is provided in Appendix D.

- Source Classification Code(s) – All SCCs which are applicable to the source type should be listed. SCCs can be found in the EPA's FIRE program, or they can also be downloaded from the following EPA website: http://www.epa.gov/ttn/chief/scccodes.html

- Discussion – This subsection should include general information about the source type, including the number of emission units on the base which fall under the applicable source type, the name and/or ID number of each emission unit, location of each emission unit (e.g., building #), applicable data elements associated with each emission unit (e.g., operating time, fuel consumption, etc.). For those source types with many emission units (e.g., boilers, generators, storage tanks, etc.), it is a good idea to summarize the information in table format. [Note – if desired, the data elements may be addressed in the "Actual Emissions" and/or the "Potential Emissions" subsections instead of this "Discussion" subsection.]

- Actual Emissions – This subsection should address the approach used to calculate actual emissions for the source type. The flowing information should be included:
  - description of the methodology used
  - algorithms/equations used to calculate the emissions [note – if an approved computer problem (e.g., EPA's TANKS program) was used to calculate emissions, simply reference the program used]
  - listing of applicable emission factors used
  - applicable data elements (if not already addressed in the "Discussion" subsection]
  - assumptions made
  - example calculations

- sources of information/data used (e.g., shop records, manufacturer's specifications, MSDSs, etc.)
- summary of the total emissions from the source type

- Potential Emissions – This subsection should address the approach used to calculate potential emissions for the source type. The same kind of information recommended for the "Actual Emissions" subsection above should also be included in this subsection. Additionally, since assumptions are commonly made when determining potential emissions, all assumptions used should be specified.

- References – List all references applicable to the source type which were utilized to calculate emissions.

Appendixes

The information contained in appendixes is highly variable and should be left to the discretion of the inventory preparer. Some typical types of information included in the appendixes of air emissions inventories include the following:

- Listings of pollutants
- Computer program printouts
- Raw data or other miscellaneous data/information applicable to certain source types (e.g., shop records, manufacturer's specifications, etc.)
- Excerpts from reference documents
- Copies of (or excerpts from) applicable rules/regulations

EXAMPLE
Summary of Criteria Pollutant and Total HAP Emissions

	CO		Lead		NO_X	
SOURCE CATEGORY	**tons/yr**	**% of Total**	**tons/yr**	**% of Total**	**tons/yr**	**% of Total**
Abrasive Blasting						
Aircraft Engine Testing						
Asphalt Paving Operations						
Chromium Electroplating and Chromic Acid Anodizing						
Dry Cleaning Operations						
Equipment Leaks						
Ethylene Oxide Sterilizers						
External Combustion Sources						
Fire Fighter Training						
Fuel Cell Maintenance						
Fuel Spills						
Fuel Storage						
Fuel Transfer						
Gasoline Service Stations						
Heavy Construction Operations						
Incinerators						
Laboratory Chemicals						
Landfills						
Miscellaneous Chemical Use						
Non-Destructive Inspection (NDI) Operations						
Open Burning/Open Detonation of Energetic Materials						
Open/Prescribed Burning						
Ozone Depleting Substances						
Pesticide Application						
Site Restoration						
Small Arms Firing						
Solvent Cleaning Machines						
Stationary Internal Combustion Engine Equipment						
Surface Coatings						
Waste Solvent Reclamation						
Wastewater Treatment Plants						
Welding						
Wet Cooling Towers						
Woodworking						
All Other Sources						
Total						

SOURCE CATEGORY	PM		PM_{10}		SO_X	
	tons/yr	**% of Total**	**tons/yr**	**% of Total**	**tons/yr**	**% of Total**
Abrasive Blasting						
Aircraft Engine Testing						
Asphalt Paving Operations						
Chromium Electroplating and Chromic Acid Anodizing						
Dry Cleaning Operations						
Equipment Leaks						
Ethylene Oxide Sterilizers						
External Combustion Sources						
Fire Fighter Training						
Fuel Cell Maintenance						
Fuel Spills						
Fuel Storage						
Fuel Transfer						
Gasoline Service Stations						
Heavy Construction Operations						
Incinerators						
Laboratory Chemicals						
Landfills						
Miscellaneous Chemical Use						
Non-Destructive Inspection (NDI) Operations						
Open Burning/Open Detonation of Energetic Materials						
Open/Prescribed Burning						
Ozone Depleting Substances						
Pesticide Application						
Site Restoration						
Small Arms Firing						
Solvent Cleaning Machines						
Stationary Internal Combustion Engine Equipment						
Surface Coatings						
Waste Solvent Reclamation						
Wastewater Treatment Plants						
Welding						
Wet Cooling Towers						
Woodworking						
All Other Sources						
Total						

SOURCE CATEGORY	VOC		Total HAPs	
	tons/yr	% of Total	tons/yr	% of Total
Abrasive Blasting				
Aircraft Engine Testing				
Asphalt Paving Operations				
Chromium Electroplating and Chromic Acid Anodizing				
Dry Cleaning Operations				
Equipment Leaks				
Ethylene Oxide Sterilizers				
External Combustion Sources				
Fire Fighter Training				
Fuel Cell Maintenance				
Fuel Spills				
Fuel Storage				
Fuel Transfer				
Gasoline Service Stations				
Heavy Construction Operations				
Incinerators				
Laboratory Chemicals				
Landfills				
Miscellaneous Chemical Use				
Non-Destructive Inspection (NDI) Operations				
Open Burning/Open Detonation of Energetic Materials				
Open/Prescribed Burning				
Ozone Depleting Substances				
Pesticide Application				
Site Restoration				
Small Arms Firing				
Solvent Cleaning Machines				
Stationary Internal Combustion Engine Equipment				
Surface Coatings				
Waste Solvent Reclamation				
Wastewater Treatment Plants				
Welding				
Wet Cooling Towers				
Woodworking				
All Other Sources				
Total				

EXAMPLE
Summary of HAP Emissions (lb/yr)

SOURCE CATEGORY	Acetaldehyde	Acrolein	Antimony Compounds	Arsenic Compounds	Benzene	Beryllium Compounds	1,3-Butadiene	Cadmium Compounds	Carbon tetrachloride
Abrasive Blasting									
Aircraft Engine Testing									
Asphalt Paving Operations									
Chromium Electroplating and Chromic Acid Anodizing									
Dry Cleaning Operations									
Equipment Leaks									
Ethylene Oxide Sterilizers									
External Combustion Sources									
Fire Fighter Training									
Fuel Cell Maintenance									
Fuel Spills									
Fuel Storage									
Fuel Transfer									
Gasoline Service Stations									
Heavy Construction Operations									
Incinerators									
Laboratory Chemicals									
Landfills									
Miscellaneous Chemical Use									
Non-Destructive Inspection (NDI) Operations									
Open Burning/Open Detonation of Energetic Materials									
Open/Prescribed Burning									
Ozone Depleting Substances									
Pesticide Application									
Site Restoration									
Small Arms Firing									
Solvent Cleaning Machines									
Stationary Internal Combustion Engine Equipment									
Surface Coatings									
Waste Solvent Reclamation									
Wastewater Treatment Plants									
Welding									
Wet Cooling Towers									
Woodworking									
All Other Sources									
Total Emissions (lb/yr)									
Total Emissions (tons/yr)									

SOURCE CATEGORY	Chlorine	Chlorobenzene	Chloroform	Chromium Compounds	Cumene	Cyanide Compounds	Dibenzofurans	Diethanolamine	Ethyl benzene
Abrasive Blasting									
Aircraft Engine Testing									
Asphalt Paving Operations									
Chromium Electroplating and Chromic Acid Anodizing									
Dry Cleaning Operations									
Equipment Leaks									
Ethylene Oxide Sterilizers									
External Combustion Sources									
Fire Fighter Training									
Fuel Cell Maintenance									
Fuel Spills									
Fuel Storage									
Fuel Transfer									
Gasoline Service Stations									
Heavy Construction Operations									
Incinerators									
Laboratory Chemicals									
Landfills									
Miscellaneous Chemical Use									
Non-Destructive Inspection (NDI) Operations									
Open Burning/Open Detonation of Energetic Materials									
Open/Prescribed Burning									
Ozone Depleting Substances									
Pesticide Application									
Site Restoration									
Small Arms Firing									
Solvent Cleaning Machines									
Stationary Internal Combustion Engine Equipment									
Surface Coatings									
Waste Solvent Reclamation									
Wastewater Treatment Plants									
Welding									
Wet Cooling Towers									
Woodworking									
All Other Sources									
Total Emissions (lb/yr)									
Total Emissions (tons/yr)									

SOURCE CATEGORY	Ethylene glycol	Ethylene oxide	Formaldehyde	Glycol ethers	Hexane	Hydrazine	Hydrochloric acid	Hydrogen fluoride	Hydroquinone
Abrasive Blasting									
Aircraft Engine Testing									
Asphalt Paving Operations									
Chromium Electroplating and Chromic Acid Anodizing									
Dry Cleaning Operations									
Equipment Leaks									
Ethylene Oxide Sterilizers									
External Combustion Sources									
Fire Fighter Training									
Fuel Cell Maintenance									
Fuel Spills									
Fuel Storage									
Fuel Transfer									
Gasoline Service Stations									
Heavy Construction Operations									
Incinerators									
Laboratory Chemicals									
Landfills									
Miscellaneous Chemical Use									
Non-Destructive Inspection (NDI) Operations									
Open Burning/Open Detonation of Energetic Materials									
Open/Prescribed Burning									
Ozone Depleting Substances									
Pesticide Application									
Site Restoration									
Small Arms Firing									
Solvent Cleaning Machines									
Stationary Internal Combustion Engine Equipment									
Surface Coatings									
Waste Solvent Reclamation									
Wastewater Treatment Plants									
Welding									
Wet Cooling Towers									
Woodworking									
All Other Sources									
Total Emissions (lb/yr)									
Total Emissions (tons/yr)									

SOURCE CATEGORY	Lead Compounds	Manganese Compounds	Mercury Compounds	Methanol	Methyl chloroform	Methyl ethyl ketone	Methyl isobutyl ketone	Methyl tert butyl ether	Methylene chloride
Abrasive Blasting									
Aircraft Engine Testing									
Asphalt Paving Operations									
Chromium Electroplating and Chromic Acid Anodizing									
Dry Cleaning Operations									
Equipment Leaks									
Ethylene Oxide Sterilizers									
External Combustion Sources									
Fire Fighter Training									
Fuel Cell Maintenance									
Fuel Spills									
Fuel Storage									
Fuel Transfer									
Gasoline Service Stations									
Heavy Construction Operations									
Incinerators									
Laboratory Chemicals									
Landfills									
Miscellaneous Chemical Use									
Non-Destructive Inspection (NDI) Operations									
Open Burning/Open Detonation of Energetic Materials									
Open/Prescribed Burning									
Ozone Depleting Substances									
Pesticide Application									
Site Restoration									
Small Arms Firing									
Solvent Cleaning Machines									
Stationary Internal Combustion Engine Equipment									
Surface Coatings									
Waste Solvent Reclamation									
Wastewater Treatment Plants									
Welding									
Wet Cooling Towers									
Woodworking									
All Other Sources									
Total Emissions (lb/yr)									
Total Emissions (tons/yr)									

SOURCE CATEGORY	Naphthalene	Nickel Compounds	Phenol	Polychlorinated biphenyls	Polycyclic Organic Matter	Selenium Compounds	Styrene	2,3,7,8-Tetrachlorodibenzo-p-dioxin	Tetrachloroethylene
Abrasive Blasting									
Aircraft Engine Testing									
Asphalt Paving Operations									
Chromium Electroplating and Chromic Acid Anodizing									
Dry Cleaning Operations									
Equipment Leaks									
Ethylene Oxide Sterilizers									
External Combustion Sources									
Fire Fighter Training									
Fuel Cell Maintenance									
Fuel Spills									
Fuel Storage									
Fuel Transfer									
Gasoline Service Stations									
Heavy Construction Operations									
Incinerators									
Laboratory Chemicals									
Landfills									
Miscellaneous Chemical Use									
Non-Destructive Inspection (NDI) Operations									
Open Burning/Open Detonation of Energetic Materials									
Open/Prescribed Burning									
Ozone Depleting Substances									
Pesticide Application									
Site Restoration									
Small Arms Firing									
Solvent Cleaning Machines									
Stationary Internal Combustion Engine Equipment									
Surface Coatings									
Waste Solvent Reclamation									
Wastewater Treatment Plants									
Welding									
Wet Cooling Towers									
Woodworking									
All Other Sources									
Total Emissions (lb/yr)									
Total Emissions (tons/yr)									

SOURCE CATEGORY	Toluene	1,1,2-Trichloroethane	Trichloroethylene	2,2,4-Trimethylpentane	Xylenes (mixed isomers)	o-Xylenes	m-Xylenes	p-Xylenes	**Total HAPs**
Abrasive Blasting									
Aircraft Engine Testing									
Asphalt Paving Operations									
Chromium Electroplating and Chromic Acid Anodizing									
Dry Cleaning Operations									
Equipment Leaks									
Ethylene Oxide Sterilizers									
External Combustion Sources									
Fire Fighter Training									
Fuel Cell Maintenance									
Fuel Spills									
Fuel Storage									
Fuel Transfer									
Gasoline Service Stations									
Heavy Construction Operations									
Incinerators									
Laboratory Chemicals									
Landfills									
Miscellaneous Chemical Use									
Non-Destructive Inspection (NDI) Operations									
Open Burning/Open Detonation of Energetic Materials									
Open/Prescribed Burning									
Ozone Depleting Substances									
Pesticide Application									
Site Restoration									
Small Arms Firing									
Solvent Cleaning Machines									
Stationary Internal Combustion Engine Equipment									
Surface Coatings									
Waste Solvent Reclamation									
Wastewater Treatment Plants									
Welding									
Wet Cooling Towers									
Woodworking									
All Other Sources									
Total Emissions (lb/yr)									
Total Emissions (tons/yr)									

APPENDIX D

Listing of Two-Digit SIC Codes

Two-Digit SIC Code	Major Industrial Group
01	Agricultural production crops
02	Agricultural production livestock
07	Agricultural services
08	Forestry
09	Fishing, hunting, and trapping
10	Metal mining
12	Coal mining
13	Oil and gas extraction
14	Mining and quarrying of nonmetallic minerals, except fuels
15	Building construction general contractors and operative builders
16	Heavy construction other than building construction contractors
17	Construction special trade contractors
20	Food and kindred products
21	Tobacco products
22	Textile mill products
23	Apparel and other finished products made from fabrics and similar materials
24	Lumber and wood products, except furniture
25	Furniture and fixtures
26	Paper and allied products
27	Printing, publishing, and allied industries
28	Chemicals and allied products
29	Petroleum refining and related industries
30	Rubber and miscellaneous plastics products
31	Leather and leather products
32	Stone, clay, glass, and concrete products
33	Primary metal industries
34	Fabricated metal products, except machinery and transportation equipment
35	Industrial and commercial machinery and computer equipment
36	Electronic and other electrical machinery and equipment, except computer equipment
37	Transportation equipment
38	Measuring, analyzing, and controlling instruments; photographic, medical and optical goods; watches and clocks
39	Miscellaneous manufacturing industries
40	Railroad transportation
41	Local and suburban transit and interurban highway passenger transportation
42	Motor freight transportation and warehousing
43	US Postal Service
44	Water transportation
45	Transportation by air
46	Pipelines, except natural gas
47	Transportation services
48	Communications
49	Electric, gas, and sanitary services

Two-Digit SIC Code	Major Industrial Group
50	Wholesale trade durable goods
51	Wholesale trade non-durable goods
52	Building materials, hardware, garden supply, and mobile home dealers
53	General merchandise stores
54	Food stores
55	Automotive dealers and gasoline service stations
56	Apparel and accessory stores
57	Home furniture, furnishings, and equipment stores
58	Eating and drinking places
59	Miscellaneous retail
60	Depository institutions
61	Non-depository credit institutions
62	Security and commodity brokers, dealers, exchanges, and services
63	Insurance carriers
64	Insurance agents, brokers, and service
65	Real estate
67	Holding and other investment offices
70	Hotels, rooming houses, camps, and other lodging places
72	Personal services
73	Business services
75	Automotive repair, services, and parking
76	Miscellaneous repair services
78	Motion pictures
79	Amusement and recreation services
80	Health services
81	Legal services
82	Educational services
83	Social services
84	Museums, art galleries, and botanical and zoological gardens
86	Membership organizations
87	Engineering, accounting, research, management, and related services
88	Private households
89	Miscellaneous services
91	Executive, legislative, and general government, except finance
92	Justice, public order, and safety
93	Public finance, taxation, and monetary policy
94	Administration of human resource programs
95	Administration of environmental quality and housing programs
96	Administration of economic programs
97	National security and international affairs
99	Non-classifiable establishments

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APPENDIX E

Fuels Data used for Vapor-Phase Speciation
(Revised December 2003)

JP-8 Vapor Partial Pressure Look-Up Table

Partial Pressure in p.s.i.							
	Fuel Temperature °F						
Flash Point °F	**40**	**50**	**60**	**70**	**80**	**90**	**100**
100	0.03	0.04	0.05	0.07	0.09	0.12	0.16
105	0.02	0.03	0.04	0.06	0.08	0.1	0.13
110	0.02	0.03	0.04	0.05	0.07	0.09	0.12
115	0.02	0.02	0.03	0.04	0.06	0.08	0.10
120	0.01	0.02	0.03	0.04	0.05	0.07	0.09
125	0.01	0.02	0.02	0.03	0.04	0.06	0.08
130	0.01	0.02	0.02	0.03	0.04	0.05	0.07
135	0.01	0.01	0.02	0.03	0.03	0.05	0.06
140	0.01	0.01	0.02	0.02	0.03	0.04	0.05
145	0.01	0.01	0.01	0.02	0.03	0.04	0.05
150	0.01	0.01	0.01	0.02	0.02	0.03	0.04
155	0.01	0.01	0.01	0.02	0.02	0.03	0.04
160	0.01	0.01	0.01	0.01	0.02	0.02	0.03

Fuels Data used for Vapor-Phase Speciation

Compound	Liquid Molecular Weight	Vapor Molecular Weight	Vapor Pressure at 70° F (psia)[a]	Weight % of Compound in Liquid Diesel Fuel[b]	Weight % of Compound in Liquid Gasoline[b]	Weight % of Compound in Liquid JP-8 Fuel[c]	Weight % of Compound in Vapor-Phase JP-8[h]
Benzene	78	NA	1.529	0.2	1.8	0.033	0.2
Cumene (Isopropylbenzene)	120	NA	0.15	0.1	0.5	0.179	0.29
Ethylbenzene	106	NA	0.14	0.2	1.4	0.157	0.86
Hexane	86	NA	2.47	0.04	1.0	ND	0.84
Methyl tert-butyl ether	88	NA	4.7[d]	NA	4.5	NA	ND
Naphthalene	128.2	NA	0.001	0.2[e]	0.3[e]	0.264	0.38
Toluene	92	NA	0.43	0.4	7.0	0.216	1.65
2,2,4 Trimethylpentane (Iso-octane)	114.2	NA	0.79	ND	4.0	0.001	0.02
Xylenes	106	NA	0.13	0.8	7.0	1.173	4.74
Diesel Fuel[f]	185	130	0.06	NA	NA	NA	N/A
Gasoline (RVP 9.2)[f, g]	94	67	6.5	NA	NA	NA	N/A
JP-8 (Jet Kerosene)[f]	160	130	h	NA	NA	NA	N/A

NA = Non Applicable
ND = No Data
[a] psia = mm Hg * 0.0193
[b] With the exception of naphthalene, the compound percentages were obtained from the American Petroleum Institute (API) document titled "Manual of Petroleum Measurement Standards, Chapter 19.4 - Recommended Practice for Speciation of Evaporation Losses," dated November 1997.
[c] The compound percentages in JP-8 were obtained from Armstrong Laboratory Report # AL/EQ-TR-1996-0006, "JP-8 Composition and Variability," dated May 1996.
[d] The vapor pressure of methyl tert-butyl ether at a temperature of around 68 - 70° F could not be found. Therefore, the vapor pressure at 77° F was used.
[e] Naphthalene content in diesel and gasoline was obtained from the EPA document titled "Draft Technical Support Document for Development of a Comparable Fuel Exemption," dated February 1996.
[f] Physical property data (i.e., molecular weights and vapor pressure) for diesel, gasoline, and jet kerosene were obtained from the API document referenced in footnote "b" above.
[g] Based on gasoline with a Reid vapor pressure of 9.2.
[h.] See JP-8 Vapor Partial Pressure Look-up Table

APPENDIX F

Emissions Factors for Open Burning/Open Detonation of Energetic Materials

OPEN BURNING

Criteria Pollutant and HAP Emission Factors for Open Burning of Energetic Materials		
Energetic Material	**Pollutant**	**Average Emission Factor (lb/lb)**
Diesel fuel and dunnage	n-Hexane	1.60E-05
Diesel fuel and dunnage	Benzene	7.80E-05
Diesel fuel and dunnage	CO	6.00E-03
Diesel fuel and dunnage	Ethylbenzene	5.50E-05
Diesel fuel and dunnage	NO	8.00E-04
Diesel fuel and dunnage	NO2	4.20E-05
Diesel fuel and dunnage	PM10	5.40E-03
Diesel fuel and dunnage	SO2	1.90E-04
Diesel fuel and dunnage	Toluene	1.20E-04
Diesel fuel and dunnage	Total Non-methane Hydrocarbons	1.20E-02
Diesel fuel and dunnage	1,3-Butadiene	1.20E-06
Manufacturer's waste - aluminized propellant with diesel	n-Hexane	3.70E-06
Manufacturer's waste - aluminized propellant with diesel	Benzene	4.50E-04
Manufacturer's waste - aluminized propellant with diesel	Carbon tetrachloride	5.60E-06
Manufacturer's waste - aluminized propellant with diesel	Chloroform	2.30E-06
Manufacturer's waste - aluminized propellant with diesel	Cl2	2.00E-04
Manufacturer's waste - aluminized propellant with diesel	CO	2.00E-02
Manufacturer's waste - aluminized propellant with diesel	Ethylbenzene	2.40E-06
Manufacturer's waste - aluminized propellant with diesel	HCl	8.30E-02
Manufacturer's waste - aluminized propellant with diesel	Lead	2.80E-04
Manufacturer's waste - aluminized propellant with diesel	Methyl chloride	2.00E-05
Manufacturer's waste - aluminized propellant with diesel	Methylenechloride	1.20E-05
Manufacturer's waste - aluminized propellant with diesel	NO	1.00E-03
Manufacturer's waste - aluminized propellant with diesel	NO2	6.60E-06
Manufacturer's waste - aluminized propellant with diesel	PM10	1.90E+00
Manufacturer's waste - aluminized propellant with diesel	SO2	8.60E-04
Manufacturer's waste - aluminized propellant with diesel	Tetrachloroethylene	1.70E-06
Manufacturer's waste - aluminized propellant with diesel	Toluene	2.80E-05
Manufacturer's waste - aluminized propellant with diesel	Total Non-methane Hydrocarbons	2.90E-03
Manufacturer's waste - aluminized propellant with diesel	1,3-Butadiene	4.00E-06
Propellant, ammonium perchlorate, aluminized	Chromium	1.00E-05
Propellant, ammonium perchlorate, aluminized	Cl2	4.60E-03
Propellant, ammonium perchlorate, aluminized	CO	1.20E-03
Propellant, ammonium perchlorate, aluminized	HCl	2.10E-01
Propellant, ammonium perchlorate, aluminized	Lead	4.00E-05
Propellant, ammonium perchlorate, aluminized	NO	1.90E-03
Propellant, ammonium perchlorate, aluminized	NO2	1.40E-04
Propellant, ammonium perchlorate, aluminized	PM10	4.20E-01
Propellant, ammonium perchlorate, aluminized	SO2	5.00E-05
Propellant, ammonium perchlorate, aluminized	Total Non-methane Hydrocarbons	5.00E-05
Propellant, ammonium perchlorate, nonaluminized	Chromium	1.00E-05
Propellant, ammonium perchlorate, nonaluminized	Cl2	9.20E-03
Propellant, ammonium perchlorate, nonaluminized	CO	1.40E-04
Propellant, ammonium perchlorate, nonaluminized	HCl	2.15E-01

Criteria Pollutant and HAP Emission Factors for Open Burning of Energetic Materials (Cont'd)		
Energetic Material	**Pollutant**	**Average Emission Factor (lb/lb)**
Propellant, ammonium perchlorate, nonaluminized	NO	4.00E-03
Propellant, ammonium perchlorate, nonaluminized	NO2	2.40E-03
Propellant, ammonium perchlorate, nonaluminized	PM10	1.50E-02
Propellant, ammonium perchlorate, nonaluminized	SO2	1.10E-04
Propellant, ammonium perchlorate, nonaluminized	Total Non-methane Hydrocarbons	4.00E-05
Propellant, composite (MK-6) (Sandia)	Benzene	5.70E-05
Propellant, composite (MK-6) (Sandia)	Chromium	4.80E-05
Propellant, composite (MK-6) (Sandia)	CO	4.20E-03
Propellant, composite (MK-6) (Sandia)	HCl	9.40E-02
Propellant, composite (MK-6) (Sandia)	NO	2.10E-03
Propellant, composite (MK-6) (Sandia)	NO2	1.00E-03
Propellant, composite (MK-6) (Sandia)	SO2	1.10E-03
Propellant, double base	CO	1.50E-03
Propellant, double base	Lead	5.60E-03
Propellant, double base	NO	1.70E-03
Propellant, double base	NO2	1.00E-04
Propellant, double base	PM10	1.90E-02
Propellant, double base	SO2	3.00E-05
Propellant, double base	Total Non-methane Hydrocarbons	1.00E-05
Propellant, double base (Sandia)	Benzene	1.20E-04
Propellant, double base (Sandia)	CO	9.50E-04
Propellant, double base (Sandia)	Lead	1.30E-02
Propellant, double base (Sandia)	NO	2.40E-02
Propellant, double base (Sandia)	NO2	2.80E-03
Propellant, double base (Sandia)	SO2	3.20E-03
Propellant, M-3	n-Hexane	1.90E-05
Propellant, M-3	Benzene	1.00E-05
Propellant, M-3	CO	1.40E-02
Propellant, M-3	Ethylbenzene	2.60E-07
Propellant, M-3	Methyl chloride	1.40E-07
Propellant, M-3	Methylenechloride	2.30E-05
Propellant, M-3	PM10	8.60E-03
Propellant, M-3	Toluene	1.80E-06
Propellant, M-3	Total Non-methane Hydrocarbons	9.30E-05
Propellant, M31A1E1	CO	1.30E-04
Propellant, M31A1E1	NO	1.20E-03
Propellant, M31A1E1	NO2	1.00E-04
Propellant, M31A1E1	PM10	9.10E-01
Propellant, M31A1E1	SO2	1.20E-03
Propellant, M31A1E1	Total Non-methane Hydrocarbons	1.00E-04
Propellant, M-43 (USN)	n-Hexane	9.10E-08
Propellant, M-43 (USN)	Benzene	1.70E-06
Propellant, M-43 (USN)	CO	6.60E-04
Propellant, M-43 (USN)	HCl	1.00E-03
Propellant, M-43 (USN)	NO	6.30E-03
Propellant, M-43 (USN)	NO2	4.70E-04

Criteria Pollutant and HAP Emission Factors for Open Burning of Energetic Materials (Cont'd)		
Energetic Material	**Pollutant**	**Average Emission Factor (lb/lb)**
Propellant, M-43 (USN)	PM10	1.20E-03
Propellant, M-43 (USN)	SO2	1.20E-04
Propellant, M-43 (USN)	Toluene	5.40E-07
Propellant, M-43 (USN)	Total Non-methane Hydrocarbons	4.10E-05
Propellant, M-43 (USN)	1,3-Butadiene	9.10E-08
Propellant, M-9	Benzene	3.20E-06
Propellant, M-9	Carbon tetrachloride	2.30E-07
Propellant, M-9	CO	2.70E-03
Propellant, M-9	Methyl chloride	1.50E-07
Propellant, M-9	PM10	1.60E-02
Propellant, M-9	Styrene	4.70E-07
Propellant, M-9	Total Non-methane Hydrocarbons	1.50E-05
Propellant, MK-23	Carbon tetrachloride	1.10E-06
Propellant, MK-23	Chloroform	4.20E-07
Propellant, MK-23	CO	2.70E-04
Propellant, MK-23	Methyl chloride	7.10E-07
Propellant, MK-23	Methylenechloride	6.00E-07
Propellant, MK-23	PM10	5.90E-02
Propellant, MK-23	Vinyl chloride	1.50E-06
Propellant, MK-23	1,3-Butadiene	2.00E-07
Propellant, MK-23 .	HCl	1.90E-03
Propellant, PBXN-110	Benzene	4.90E-06
Propellant, PBXN-110	CO	1.20E-03
Propellant, PBXN-110	Ethylbenzene	8.00E-07
Propellant, PBXN-110	HCl	1.80E-04
Propellant, PBXN-110	Methyl chloride	1.80E-07
Propellant, PBXN-110	NO	2.60E-03
Propellant, PBXN-110	NO2	2.80E-04
Propellant, PBXN-110	PM10	4.90E-01
Propellant, PBXN-110	SO2	3.50E-04
Propellant, PBXN-110	Total Non-methane Hydrocarbons	5.10E-05
Propellant, PBXN-110	Vinyl chloride	2.20E-07
Propellant, PBXN-110	1,3-Butadiene	5.00E-07
Propellant, Smokey Sam	n-Hexane	2.70E-06
Propellant, Smokey Sam	Benzene	6.60E-05
Propellant, Smokey Sam	CO	7.20E-02
Propellant, Smokey Sam	Ethylbenzene	1.20E-06
Propellant, Smokey Sam	HCl	2.90E-02
Propellant, Smokey Sam	Methyl chloride	5.70E-06
Propellant, Smokey Sam	Methylenechloride	1.20E-06
Propellant, Smokey Sam	NO	1.10E-02
Propellant, Smokey Sam	NO2	2.70E-04
Propellant, Smokey Sam	PM10	2.60E-01
Propellant, Smokey Sam	SO2	1.50E-04
Propellant, Smokey Sam	Toluene	8.60E-06
Propellant, Smokey Sam	Total Non-methane Hydrocarbons	1.10E-03
Propellant, Smokey Sam	Vinyl chloride	8.80E-07

Criteria Pollutant and HAP Emission Factors for Open Burning of Energetic Materials (Cont'd)		
Energetic Material	**Pollutant**	**Average Emission Factor (lb/lb)**
Propellant, Smokey Sam	1,3-Butadiene	1.20E-06
Smokeless Powder (Hercules Unique)	n-Hexane	9.60E-07
Smokeless Powder (Hercules Unique)	Benzene	1.20E-06
Smokeless Powder (Hercules Unique)	CO	1.60E-03
Smokeless Powder (Hercules Unique)	Methylenechloride	7.20E-07
Smokeless Powder (Hercules Unique)	PM10	1.80E-03
Smokeless Powder (Hercules Unique)	SO2	6.10E-04
Smokeless Powder (Hercules Unique)	Toluene	3.40E-06

OPEN DETONATION

Criteria Pollutant and HAP Emission Factors for Open Detonation of Energetic Materials		
Energetic Material	**Pollutant**	**Average Emission Factor (lb/lb)**
20 mm HEI Cartridge	n-Hexane	3.50E-06
20 mm HEI Cartridge	Benzene	1.10E-04
20 mm HEI Cartridge	Cadmium	8.60E-04
20 mm HEI Cartridge	Carbon tetrachloride	7.60E-06
20 mm HEI Cartridge	Chromium	3.50E-05
20 mm HEI Cartridge	CO	1.10E-01
20 mm HEI Cartridge	Ethylbenzene	4.60E-06
20 mm HEI Cartridge	Lead	7.00E-04
20 mm HEI Cartridge	Methyl chloride	1.30E-06
20 mm HEI Cartridge	Methyl chloroform	3.30E-06
20 mm HEI Cartridge	Methylenechloride	4.50E-04
20 mm HEI Cartridge	Styrene	3.60E-06
20 mm HEI Cartridge	Toluene	3.00E-05
20 mm HEI Cartridge	Total Non-methane Hydrocarbons	1.20E-03
20 mm HEI Cartridge	1,3-Butadiene	5.10E-06
40 mm HEI Cartridge	n-Hexane	1.90E-05
40 mm HEI Cartridge	Benzene	2.80E-05
40 mm HEI Cartridge	Cadmium	3.20E-05
40 mm HEI Cartridge	Carbon tetrachloride	4.50E-06
40 mm HEI Cartridge	Chromium	8.80E-05
40 mm HEI Cartridge	CO	2.10E-02
40 mm HEI Cartridge	Ethylbenzene	2.50E-06
40 mm HEI Cartridge	Lead	3.70E-04
40 mm HEI Cartridge	Methylenechloride	8.70E-04
40 mm HEI Cartridge	PM10	4.70E-01
40 mm HEI Cartridge	Styrene	4.20E-05
40 mm HEI Cartridge	Toluene	2.60E-05
40 mm HEI Cartridge	Total Non-methane Hydrocarbons	3.30E-04
40 mm HEI Cartridge	1,3-Butadiene	1.90E-06
Amatol surrogate	n-Hexane	5.60E-07
Amatol surrogate	Benzene	2.30E-05
Amatol surrogate	Carbon tetrachloride	3.70E-07
Amatol surrogate	CO	9.70E-03
Amatol surrogate	Ethylbenzene	1.20E-06
Amatol surrogate	Lead	3.30E-05
Amatol surrogate	Methyl chloride	7.50E-07
Amatol surrogate	Methyl chloroform	3.70E-07
Amatol surrogate	Methylenechloride	1.50E-04
Amatol surrogate	NO	1.80E-02
Amatol surrogate	NO2	1.20E-04
Amatol surrogate	PM10	1.90E-02
Amatol surrogate	SO2	2.60E-04
Amatol surrogate	Tetrachloroethylene	3.70E-07
Amatol surrogate	Toluene	6.70E-06

Criteria Pollutant and HAP Emission Factors for Open Detonation of Energetic Materials (Cont'd)		
Energetic Material	**Pollutant**	**Average Emission Factor (lb/lb)**
Amatol surrogate	Total Non-methane Hydrocarbons	4.50E-04
Amatol surrogate with water	n-Hexane	1.10E-05
Amatol surrogate with water	Benzene	2.70E-04
Amatol surrogate with water	Carbon tetrachloride	3.70E-07
Amatol surrogate with water	Chloroform	3.70E-07
Amatol surrogate with water	CO	2.30E-01
Amatol surrogate with water	Ethylbenzene	1.60E-05
Amatol surrogate with water	Methyl chloride	2.20E-06
Amatol surrogate with water	Methyl chloroform	3.70E-07
Amatol surrogate with water	Methylenechloride	2.10E-04
Amatol surrogate with water	NO	7.70E-03
Amatol surrogate with water	NO2	2.40E-04
Amatol surrogate with water	PM10	3.20E-02
Amatol surrogate with water	SO2	1.30E-04
Amatol surrogate with water	Toluene	1.20E-04
Amatol surrogate with water	Total Non-methane Hydrocarbons	3.80E-03
Amatol surrogate with water	1,3-Butadiene	6.30E-06
Cartridge, Impulse, ARD 446-1	n-Hexane	1.50E-06
Cartridge, Impulse, ARD 446-1	Antimony	1.80E-04
Cartridge, Impulse, ARD 446-1	Benzene	6.70E-05
Cartridge, Impulse, ARD 446-1	CO	1.30E-02
Cartridge, Impulse, ARD 446-1	Ethylbenzene	1.90E-06
Cartridge, Impulse, ARD 446-1	Lead	3.10E-04
Cartridge, Impulse, ARD 446-1	Methyl chloride	1.20E-06
Cartridge, Impulse, ARD 446-1	Methyl chloroform	1.20E-06
Cartridge, Impulse, ARD 446-1	Methylenechloride	5.00E-05
Cartridge, Impulse, ARD 446-1	NO	6.40E-03
Cartridge, Impulse, ARD 446-1	NO2	1.70E-03
Cartridge, Impulse, ARD 446-1	PM10	8.30E-02
Cartridge, Impulse, ARD 446-1	Styrene	5.40E-06
Cartridge, Impulse, ARD 446-1	SO2	2.40E-04
Cartridge, Impulse, ARD 446-1	Tetrachloroethylene	3.60E-05
Cartridge, Impulse, ARD 446-1	Toluene	1.70E-05
Cartridge, Impulse, ARD 446-1	Total Non-methane Hydrocarbons	9.80E-04
Cartridge, Impulse, ARD 446-1	1,3-Butadiene	6.70E-06
Cartridge, Impulse, BBU-36/B	n-Hexane	1.70E-06
Cartridge, Impulse, BBU-36/B	Allylchloride	9.30E-06
Cartridge, Impulse, BBU-36/B	Benzene	2.10E-05
Cartridge, Impulse, BBU-36/B	Chromium	2.20E-05
Cartridge, Impulse, BBU-36/B	CO	8.40E-03
Cartridge, Impulse, BBU-36/B	Ethylbenzene	2.40E-06
Cartridge, Impulse, BBU-36/B	Lead	6.80E-05
Cartridge, Impulse, BBU-36/B	Methyl chloride	1.00E-06
Cartridge, Impulse, BBU-36/B	Methylenechloride	1.70E-04
Cartridge, Impulse, BBU-36/B	NO	4.00E-03
Cartridge, Impulse, BBU-36/B	NO2	1.50E-03

Criteria Pollutant and HAP Emission Factors for Open Detonation of Energetic Materials (Cont'd)		
Energetic Material	**Pollutant**	**Average Emission Factor (lb/lb)**
Cartridge, Impulse, BBU-36/B	PM10	1.80E-01
Cartridge, Impulse, BBU-36/B	Styrene	3.60E-06
Cartridge, Impulse, BBU-36/B	SO2	4.00E-04
Cartridge, Impulse, BBU-36/B	Tetrachloroethylene	2.40E-06
Cartridge, Impulse, BBU-36/B	Toluene	9.10E-06
Cartridge, Impulse, BBU-36/B	Total Non-methane Hydrocarbons	7.70E-04
Cartridge, Impulse, BBU-36/B	Vinyl chloride	1.70E-06
Cartridge, Impulse, BBU-36/B	1,3-Butadiene	2.80E-06
Cartridge, Impulse, MK 107	n-Hexane	5.30E-07
Cartridge, Impulse, MK 107	Allylchloride	5.10E-06
Cartridge, Impulse, MK 107	Benzene	6.40E-05
Cartridge, Impulse, MK 107	Cadmium	1.40E-03
Cartridge, Impulse, MK 107	Chromium	3.30E-05
Cartridge, Impulse, MK 107	CO	1.40E-02
Cartridge, Impulse, MK 107	Ethylbenzene	9.70E-07
Cartridge, Impulse, MK 107	Methyl chloride	9.60E-07
Cartridge, Impulse, MK 107	Methylenechloride	2.30E-04
Cartridge, Impulse, MK 107	NO	1.50E-02
Cartridge, Impulse, MK 107	NO2	6.10E-04
Cartridge, Impulse, MK 107	PM10	2.50E-01
Cartridge, Impulse, MK 107	Styrene	9.40E-06
Cartridge, Impulse, MK 107	SO2	2.60E-04
Cartridge, Impulse, MK 107	Toluene	9.00E-06
Cartridge, Impulse, MK 107	Total Non-methane Hydrocarbons	6.40E-04
Cartridge, Impulse, MK 107	Vinyl chloride	2.40E-06
Cartridge, Impulse, MK 107	1,3-Butadiene	2.00E-06
Composition B surrogate	n-Hexane	5.50E-07
Composition B surrogate	Benzene	2.60E-06
Composition B surrogate	Carbon tetrachloride	3.60E-07
Composition B surrogate	CO	4.20E-03
Composition B surrogate	Ethylbenzene	2.00E-06
Composition B surrogate	Methylenechloride	1.40E-04
Composition B surrogate	NO	9.30E-03
Composition B surrogate	NO2	1.90E-04
Composition B surrogate	PM10	1.20E-02
Composition B surrogate	SO2	1.30E-04
Composition B surrogate	Tetrachloroethylene	1.80E-05
Composition B surrogate	Toluene	6.00E-06
Composition B surrogate	Total Non-methane Hydrocarbons	1.10E-04
Detonating train	n-Hexane	1.80E-06
Detonating train	Benzene	2.50E-05
Detonating train	Cadmium	1.10E-05
Detonating train	CO	9.40E-03
Detonating train	Ethyl chloride	6.90E-07
Detonating train	Ethylbenzene	6.00E-07
Detonating train	Lead	1.80E-04
Detonating train	Methyl chloride	7.00E-07

Criteria Pollutant and HAP Emission Factors for Open Detonation of Energetic Materials (Cont'd)		
Energetic Material	**Pollutant**	**Average Emission Factor (lb/lb)**
Detonating train	Methylenechloride	4.20E-05
Detonating train	NO	4.90E-03
Detonating train	NO2	4.40E-03
Detonating train	PM10	3.60E-02
Detonating train	Styrene	4.10E-06
Detonating train	SO2	4.60E-04
Detonating train	Tetrachloroethylene	1.10E-05
Detonating train	Toluene	4.20E-06
Detonating train	Total Non-methane Hydrocarbons	8.50E-04
Detonating train	Vinyl chloride	1.30E-06
Detonating train	1,3-Butadiene	9.00E-06
Flare, IR Countermeasure M206	n-Hexane	6.80E-07
Flare, IR Countermeasure M206	Allylchloride	1.80E-05
Flare, IR Countermeasure M206	Benzene	4.50E-05
Flare, IR Countermeasure M206	Cadmium	3.40E-05
Flare, IR Countermeasure M206	Chromium	1.60E-04
Flare, IR Countermeasure M206	CO	8.30E-03
Flare, IR Countermeasure M206	Ethyl chloride	3.10E-06
Flare, IR Countermeasure M206	Ethylbenzene	2.40E-06
Flare, IR Countermeasure M206	Methyl chloride	1.00E-06
Flare, IR Countermeasure M206	Methylenechloride	4.10E-04
Flare, IR Countermeasure M206	NO	5.30E-03
Flare, IR Countermeasure M206	NO2	2.80E-03
Flare, IR Countermeasure M206	PM10	5.50E-01
Flare, IR Countermeasure M206	Styrene	7.10E-06
Flare, IR Countermeasure M206	SO2	1.00E-03
Flare, IR Countermeasure M206	Toluene	2.80E-05
Flare, IR Countermeasure M206	Total Non-methane Hydrocarbons	6.10E-04
Flare, IR Countermeasure M206	Vinyl chloride	1.50E-06
Flare, IR Countermeasure M206	1,3-Butadiene	3.00E-06
Fuze, Tail Bomb FMU-139 A/B	n-Hexane	6.50E-07
Fuze, Tail Bomb FMU-139 A/B	Allylchloride	3.00E-05
Fuze, Tail Bomb FMU-139 A/B	Antimony	2.20E-04
Fuze, Tail Bomb FMU-139 A/B	Benzene	1.20E-04
Fuze, Tail Bomb FMU-139 A/B	Cadmium	2.30E-03
Fuze, Tail Bomb FMU-139 A/B	Carbon tetrachloride	2.70E-06
Fuze, Tail Bomb FMU-139 A/B	Chromium	1.40E-04
Fuze, Tail Bomb FMU-139 A/B	CO	2.30E-02
Fuze, Tail Bomb FMU-139 A/B	Ethylbenzene	3.20E-06
Fuze, Tail Bomb FMU-139 A/B	Lead	2.60E-03
Fuze, Tail Bomb FMU-139 A/B	Methyl chloride	4.70E-06
Fuze, Tail Bomb FMU-139 A/B	Methyl chloroform	1.60E-05
Fuze, Tail Bomb FMU-139 A/B	Methylenechloride	1.10E-04
Fuze, Tail Bomb FMU-139 A/B	NO	9.90E-03
Fuze, Tail Bomb FMU-139 A/B	NO2	1.70E-02
Fuze, Tail Bomb FMU-139 A/B	PM10	6.00E-01
Fuze, Tail Bomb FMU-139 A/B	Styrene	2.90E-05

Criteria Pollutant and HAP Emission Factors for Open Detonation of Energetic Materials (Cont'd)		
Energetic Material	**Pollutant**	**Average Emission Factor (lb/lb)**
Fuze, Tail Bomb FMU-139 A/B	SO2	1.40E-03
Fuze, Tail Bomb FMU-139 A/B	Toluene	2.30E-05
Fuze, Tail Bomb FMU-139 A/B	Total Non-methane Hydrocarbons	1.40E-03
Fuze, Tail Bomb FMU-139 A/B	Vinyl chloride	1.80E-06
Fuze, Tail Bomb FMU-139 A/B	1,3-Butadiene	2.10E-05
Fuze, Tail Bomb FMU-54 A/B	n-Hexane	4.40E-07
Fuze, Tail Bomb FMU-54 A/B	Allylchloride	1.50E-05
Fuze, Tail Bomb FMU-54 A/B	Benzene	1.10E-04
Fuze, Tail Bomb FMU-54 A/B	Cadmium	3.10E-04
Fuze, Tail Bomb FMU-54 A/B	Chromium	3.90E-05
Fuze, Tail Bomb FMU-54 A/B	CO	1.80E-02
Fuze, Tail Bomb FMU-54 A/B	Ethylbenzene	2.40E-06
Fuze, Tail Bomb FMU-54 A/B	Methyl chloride	3.10E-06
Fuze, Tail Bomb FMU-54 A/B	Methylenechloride	7.40E-04
Fuze, Tail Bomb FMU-54 A/B	NO	7.00E-03
Fuze, Tail Bomb FMU-54 A/B	NO2	2.50E-03
Fuze, Tail Bomb FMU-54 A/B	PM10	3.30E-01
Fuze, Tail Bomb FMU-54 A/B	Styrene	7.80E-06
Fuze, Tail Bomb FMU-54 A/B	SO2	4.10E-04
Fuze, Tail Bomb FMU-54 A/B	Toluene	3.20E-05
Fuze, Tail Bomb FMU-54 A/B	Total Non-methane Hydrocarbons	9.90E-04
Fuze, Tail Bomb FMU-54 A/B	Vinyl chloride	6.80E-07
Fuze, Tail Bomb FMU-54 A/B	1,3-Butadiene	4.50E-06
Gas Generator, GGU-2/A	n-Hexane	9.90E-07
Gas Generator, GGU-2/A	Allylchloride	1.10E-04
Gas Generator, GGU-2/A	Benzene	1.30E-04
Gas Generator, GGU-2/A	Cadmium	1.00E-04
Gas Generator, GGU-2/A	Chloroform	2.60E-06
Gas Generator, GGU-2/A	Chromium	9.60E-05
Gas Generator, GGU-2/A	CO	2.80E-02
Gas Generator, GGU-2/A	Ethyl chloride	4.70E-06
Gas Generator, GGU-2/A	Ethylbenzene	1.20E-06
Gas Generator, GGU-2/A	Lead	3.70E-04
Gas Generator, GGU-2/A	Methyl chloride	1.60E-05
Gas Generator, GGU-2/A	Methylenechloride	8.70E-04
Gas Generator, GGU-2/A	NO	1.60E-03
Gas Generator, GGU-2/A	NO2	2.40E-03
Gas Generator, GGU-2/A	PM10	9.30E-02
Gas Generator, GGU-2/A	Styrene	8.30E-06
Gas Generator, GGU-2/A	SO2	4.00E-04
Gas Generator, GGU-2/A	Tetrachloroethylene	5.90E-06
Gas Generator, GGU-2/A	Toluene	1.30E-05
Gas Generator, GGU-2/A	Total Non-methane Hydrocarbons	1.80E-03
Gas Generator, GGU-2/A	Vinyl chloride	4.40E-05
Gas Generator, GGU-2/A	1,3-Butadiene	2.70E-05
HBX surrogate	n-Hexane	5.50E-07
HBX surrogate	Benzene	7.20E-06

Criteria Pollutant and HAP Emission Factors for Open Detonation of Energetic Materials (Cont'd)		
Energetic Material	**Pollutant**	**Average Emission Factor (lb/lb)**
HBX surrogate	Carbon tetrachloride	3.90E-07
HBX surrogate	Chloroform	3.80E-07
HBX surrogate	CO	5.20E-03
HBX surrogate	Ethylbenzene	1.80E-06
HBX surrogate	Methyl chloride	6.30E-07
HBX surrogate	Methyl chloroform	3.80E-07
HBX surrogate	Methylenechloride	2.70E-04
HBX surrogate	NO	9.90E-03
HBX surrogate	NO2	4.40E-05
HBX surrogate	PM10	1.80E-01
HBX surrogate	SO2	1.10E-03
HBX surrogate	Toluene	3.30E-06
HBX surrogate	Total Non-methane Hydrocarbons	1.80E-04
HBX surrogate	1,3-Butadiene	1.40E-06
Mine, Claymore, M18A1	n-Hexane	1.30E-06
Mine, Claymore, M18A1	Benzene	8.10E-04
Mine, Claymore, M18A1	Cadmium	2.40E-04
Mine, Claymore, M18A1	Chromium	3.80E-05
Mine, Claymore, M18A1	CO	3.00E-02
Mine, Claymore, M18A1	Ethylbenzene	3.80E-05
Mine, Claymore, M18A1	Methyl chloride	4.40E-06
Mine, Claymore, M18A1	Methyl chloroform	2.30E-06
Mine, Claymore, M18A1	Methylenechloride	1.10E-04
Mine, Claymore, M18A1	PM10	2.30E-01
Mine, Claymore, M18A1	Styrene	1.70E-03
Mine, Claymore, M18A1	Toluene	2.50E-04
Mine, Claymore, M18A1	Total Non-methane Hydrocarbons	4.90E-03
Mine, Claymore, M18A1	Vinyl chloride	1.10E-06
Mine, Claymore, M18A1	1,3-Butadiene	2.70E-06
Signal, Illumination, Red Star AN-M43A2	n-Hexane	8.10E-07
Signal, Illumination, Red Star AN-M43A2	Allylchloride	1.80E-05
Signal, Illumination, Red Star AN-M43A2	Benzene	3.40E-05
Signal, Illumination, Red Star AN-M43A2	Cadmium	8.80E-05
Signal, Illumination, Red Star AN-M43A2	Chromium	5.70E-05
Signal, Illumination, Red Star AN-M43A2	CO	2.20E-02
Signal, Illumination, Red Star AN-M43A2	Ethylbenzene	4.60E-07
Signal, Illumination, Red Star AN-M43A2	Lead	7.00E-05
Signal, Illumination, Red Star AN-M43A2	Methyl chloride	1.70E-06
Signal, Illumination, Red Star AN-M43A2	Methylenechloride	8.10E-06
Signal, Illumination, Red Star AN-M43A2	NO	1.30E-02
Signal, Illumination, Red Star AN-M43A2	NO2	1.10E-03
Signal, Illumination, Red Star AN-M43A2	PM10	4.50E-01
Signal, Illumination, Red Star AN-M43A2	Styrene	4.50E-06
Signal, Illumination, Red Star AN-M43A2	SO2	1.30E-02
Signal, Illumination, Red Star AN-M43A2	Toluene	3.00E-05
Signal, Illumination, Red Star AN-M43A2	Total Non-methane Hydrocarbons	7.40E-04
Signal, Illumination, Red Star AN-M43A2	Vinyl chloride	2.30E-06

Criteria Pollutant and HAP Emission Factors for Open Detonation of Energetic Materials (Cont'd)		
Energetic Material	**Pollutant**	**Average Emission Factor (lb/lb)**
Signal, Illumination, Red Star AN-M43A2	1,3-Butadiene	1.90E-06
Signal, Illumination, Red Star M158	n-Hexane	1.10E-06
Signal, Illumination, Red Star M158	Allylchloride	1.60E-05
Signal, Illumination, Red Star M158	Benzene	3.00E-05
Signal, Illumination, Red Star M158	Cadmium	1.10E-03
Signal, Illumination, Red Star M158	Chromium	1.50E-04
Signal, Illumination, Red Star M158	CO	1.20E-02
Signal, Illumination, Red Star M158	Ethylbenzene	7.00E-07
Signal, Illumination, Red Star M158	Methyl chloride	1.30E-06
Signal, Illumination, Red Star M158	Methylenechloride	1.00E-04
Signal, Illumination, Red Star M158	NO	2.60E-03
Signal, Illumination, Red Star M158	NO2	1.50E-03
Signal, Illumination, Red Star M158	PM10	8.20E-02
Signal, Illumination, Red Star M158	Styrene	2.20E-06
Signal, Illumination, Red Star M158	SO2	1.10E-04
Signal, Illumination, Red Star M158	Toluene	2.50E-05
Signal, Illumination, Red Star M158	Total Non-methane Hydrocarbons	7.70E-04
Signal, Illumination, Red Star M158	Vinyl chloride	1.10E-06
Signal, Illumination, Red Star M158	1,3-Butadiene	1.20E-05
T45E7 Adapter Booster	n-Hexane	5.80E-06
T45E7 Adapter Booster	Benzene	1.30E-04
T45E7 Adapter Booster	Cadmium	5.80E-03
T45E7 Adapter Booster	Carbon tetrachloride	3.20E-06
T45E7 Adapter Booster	Chromium	9.40E-05
T45E7 Adapter Booster	CO	2.90E-02
T45E7 Adapter Booster	Ethylbenzene	9.20E-06
T45E7 Adapter Booster	Lead	1.80E-04
T45E7 Adapter Booster	Methyl chloride	2.20E-06
T45E7 Adapter Booster	Methylenechloride	5.00E-04
T45E7 Adapter Booster	PM10	2.60E-01
T45E7 Adapter Booster	Styrene	1.20E-04
T45E7 Adapter Booster	Toluene	5.20E-05
T45E7 Adapter Booster	Total Non-methane Hydrocarbons	1.90E-03
T45E7 Adapter Booster	1,3-Butadiene	2.30E-05
TNT (ACC1)	n-Hexane	9.30E-07
TNT (ACC1)	Benzene	4.10E-06
TNT (ACC1)	CO	1.00E-02
TNT (ACC1)	Ethylbenzene	4.70E-07
TNT (ACC1)	Methylenechloride	1.80E-04
TNT (ACC1)	PM10	7.30E-02
TNT (ACC1)	Toluene	5.10E-06
TNT (ACC1)	Total Non-methane Hydrocarbons	2.80E-05
TNT (ACC1)	1,3-Butadiene	1.70E-06
TNT (ACC2)	Benzene	4.10E-06
TNT (ACC2)	Cadmium	4.00E-05
TNT (ACC2)	Chromium	2.30E-05
TNT (ACC2)	CO	6.70E-03

Criteria Pollutant and HAP Emission Factors for Open Detonation of Energetic Materials (Cont'd)		
Energetic Material	**Pollutant**	**Average Emission Factor (lb/lb)**
TNT (ACC2)	Lead	9.00E-06
TNT (ACC2)	NO	9.20E-03
TNT (ACC2)	NO2	6.60E-05
TNT (ACC2)	PM10	9.30E-02
TNT (ACC2)	Styrene	1.50E-06
TNT (ACC2)	SO2	1.40E-04
TNT (ACC2)	Toluene	1.50E-06
TNT (ACC2)	Total Non-methane Hydrocarbons	4.00E-05
TNT (ACC2)	1,3-Butadiene	3.70E-07
TNT (Sandia)	Antimony	6.70E-07
TNT (Sandia)	Benzene	3.00E-06
TNT (Sandia)	Cadmium	2.70E-06
TNT (Sandia)	Chromium	2.40E-06
TNT (Sandia)	NO	9.70E-03
TNT (Sandia)	NO2	7.60E-04
TNT (Sandia)	SO2	1.40E-04
Tritonal surrogate	Benzene	5.70E-06
Tritonal surrogate	Carbon tetrachloride	3.70E-07
Tritonal surrogate	Chloroform	3.60E-07
Tritonal surrogate	CO	4.70E-03
Tritonal surrogate	Ethylbenzene	2.50E-06
Tritonal surrogate	Lead	1.10E-03
Tritonal surrogate	Methyl chloride	5.60E-07
Tritonal surrogate	Methylenechloride	1.80E-05
Tritonal surrogate	NO	8.20E-03
Tritonal surrogate	NO2	1.50E-04
Tritonal surrogate	PM10	3.70E-01
Tritonal surrogate	SO2	1.60E-04
Tritonal surrogate	Tetrachloroethylene	2.70E-06
Tritonal surrogate	Toluene	1.80E-06
Tritonal surrogate	Total Non-methane Hydrocarbons	2.80E-04
Tritonal surrogate	1,3-Butadiene	9.10E-07
Tritonal surrogate with calcium stearate	Benzene	3.10E-06
Tritonal surrogate with calcium stearate	CO	2.70E-03
Tritonal surrogate with calcium stearate	Ethylbenzene	1.60E-06
Tritonal surrogate with calcium stearate	Lead	9.20E-04
Tritonal surrogate with calcium stearate	Methyl chloride	3.70E-07
Tritonal surrogate with calcium stearate	Methylenechloride	1.60E-04
Tritonal surrogate with calcium stearate	NO	6.60E-03
Tritonal surrogate with calcium stearate	NO2	4.50E-05
Tritonal surrogate with calcium stearate	PM10	2.60E-01
Tritonal surrogate with calcium stearate	SO2	1.20E-04
Tritonal surrogate with calcium stearate	Tetrachloroethylene	3.70E-07
Tritonal surrogate with calcium stearate	Total Non-methane Hydrocarbons	4.00E-05
Tritonal surrogate with calcium stearate	1,3-Butadiene	1.30E-06
Tritonal surrogate with water	n-Hexane	2.60E-06
Tritonal surrogate with water	Benzene	2.00E-04

Criteria Pollutant and HAP Emission Factors for Open Detonation of Energetic Materials (Cont'd)		
Energetic Material	**Pollutant**	**Average Emission Factor (lb/lb)**
Tritonal surrogate with water	Carbon tetrachloride	4.80E-07
Tritonal surrogate with water	CO	2.70E-01
Tritonal surrogate with water	Ethylbenzene	6.30E-06
Tritonal surrogate with water	Methyl chloride	3.80E-06
Tritonal surrogate with water	Methyl chloroform	3.70E-07
Tritonal surrogate with water	Methylenechloride	5.00E-06
Tritonal surrogate with water	NO	4.00E-03
Tritonal surrogate with water	NO2	2.70E-04
Tritonal surrogate with water	PM10	1.90E-01
Tritonal surrogate with water	SO2	4.70E-05
Tritonal surrogate with water	Toluene	7.30E-05
Tritonal surrogate with water	Total Non-methane Hydrocarbons	7.10E-03
Tritonal surrogate with water	1,3-Butadiene	3.00E-05

ABBREVIATIONS AND ACRONYMS

ABBREVIATIONS AND ACRONYMS

A	amp(s)
AAFES	Army and Air Force Exchange Service
AEAR	Air Emissions Assessment Report
AFB	Air Force Base
AFS	AIRS Facility Subsystem
AGSE	aerospace ground support equipment (historically referred to as AGE)
AIRS	Aerometric Information Retrieval System
APCD	Air Pollution Control District
APU	Auxiliary Power Unit
AST	above-ground storage tank
BACT	Best Available Control Technology
BEE	Bioenvironmental Engineer
BSFC	brake-specific fuel consumption
Btu	British thermal unit
BOOS	burners out of service
°C	degrees Celsius
CAA	Clean Air Act
CAAA-90	Clean Air Act Amendments of 1990
CBPO	Consolidated Base Personnel Office
CES	Civil Engineer Squadron
CFC	chlorofluorocarbon
CFM	cubic feet per minute
CFR	Code of Federal Regulations
CI	compression ignition
CO	carbon monoxide
Cr	chromium
Cr^{+6}	hexavalent chromium
CTG	control techniques guideline
DF	diesel fuel
DLA	Defense Logistics Agency
DoD	Department of Defense
DTIC	Defense Technical Information Center
EA	environmental assessment
EF	emission factor
EIS	environmental impact statement
EO	ethylene oxide
EOD	explosive ordnance disposal
ESP	electrostatic precipitator
EPA	U.S. Environmental Protection Agency
EPCRA	Emergency Planning and Community Right-to-Know Act
°F	degrees Fahrenheit
FBC	fluidized bed combustor
FCAW	flux cored arc welding
FF	fabric filter
FGD	flue gas desulfurization
FGR	flue gas recirculation
FIRE	Factor Information Retrieval System
FR	Federal Register

ft^2	square feet
ft^3	cubic feet
g	gram(s)
gal	gallon(s)
GACT	Generally Available Control Technology
GMAW	gas metal arc welding
GOCO	government owned-contractor operated
GOV	government-owned vehicle(s)
GSA	General Services Agency
HAP	hazardous air pollutant
HAZMAT	Hazardous Materials
HCFC	hydrochlorofluorocarbon(s)
HCl	hydrochloric acid
HF	hydrogen fluoride
Hg	mercury
HMIS	Hazardous Material Information System
hp	horsepower
hr	hour(s)
HVAC	heating, ventilation, and air conditioning
HVLP	high volume/low pressure
IC	internal combustion
ID	identification
IERA/RSEQ	Air Quality & Hazardous Waste Branch of the Institute for Environment, Safety & Occupational Health Risk Analysis
IRP	Installation Restoration Program
°K	degrees Kelvin
kg	kilogram(s)
kW	kilowatt(s)
lb	pound(s)
L	liter
LAER	Lowest Achievable Emission Rate
LEA	low excess air
LNB	low NO_X burner(s)
LPG	liquefied petroleum gas
MACT	Maximum Achievable Control Technology
MAJCOM	Major Command
MEK	methyl ethyl ketone
MEM	mass of energetic material
mg	milligram
MIDAS	Munitions Items Disposition Action System
min	minute(s)
ml	milliliter
mm	millimeter
MMBtu	million British thermal units
MOGAS	motor gasoline
MSDS	material safety data sheet(s)
MSW	municipal solid waste
MW	molecular weight
MWC	municipal waste combustor
MWI	medical waste incinerator

NAAQS	National Ambient Air Quality Standard(s)
NESHAP	National Emission Standards for Hazardous Air Pollutants
NEW	net explosive weight
NMOC	nonmethane organic compound(s)
No.	number
NO	nitric oxide
NO_2	nitrogen dioxide
NO_x	oxides of nitrogen (or nitrogen oxides)
NOV	Notice of Violation
NSN	national stock number
NSPS	New Source Performance Standards
NSR	New Source Review
NTE	Not to Exceed
NTIS	National Technical Information Service
O_3	ozone
OA	opportunity assessment
OB	open burning
OD	open detonation
ODP	ozone depletion potential
ODS	ozone depleting substance
OFA	overfire air
P2	pollution prevention
PAH	polycyclic aromatic hydrocarbon(s)
Pb	lead
PC	pulverized coal
PCB	polychlorinated biphenyls
PCDD	polychlorinated dibenzo-p-dioxin(s)
PCDF	polychlorinated dibenzofuran(s)
PCE	perchloroethylene (tetrachloroethylene)
PIC	products of incomplete combustion
PM	particulate matter
$PM_{2.5}$	particulate matter with an aerodynamic diameter less than 2.5 microns
PM_{10}	particulate matter with an aerodynamic diameter less than 10 microns
POL	Petroleum, Oils, and Lubricants
POM	polycyclic organic matter
POTW	Publicly Owned Treatment Works
POV	privately-owned vehicle(s)
ppb	parts per billion
ppm	parts per million
ppt	parts per trillion
PSD	Prevention of Significant Deterioration
psi	pounds per square inch
psia	pounds per square inch, absolute
psig	pressure per square inch, gauge
PSM	point source monitoring
PTE	Potential to Emit
PTO	Permit to Operate
°R	degrees Rankine
RACT	Reasonably Available Control Technology
RVP	Reid Vapor Pressure

SAW	submerged arc welding
SCC	Source Classification Code
scf	standard cubic feet
SCR	selective catalytic reduction
SDA	spray dryer adsorber
SI	spark ignition
SIC	Standard Industrial Classification
SMAW	shielded metal arc welding
SNAP	Significant New Alternatives Policy
SNCR	selective noncatalytic reduction
SO_2	sulfur dioxide
SO_x	oxides of sulfur (or sulfur oxides)
SVE	soil vapor extraction
SVOC	semivolatile organic compound(s)
TANKS	Storage Tank Emissions Calculation Software
TCDD	tetrachlorodibenzo-p-dioxin(s)
TCDF	tetrachlorodibenzofuran(s)
TDS	total dissolved solids
TNMOC	total nonmethane organic compound(s)
TOC	total organic compound(s)
tpy	ton(s) per year
TSP	total suspended particulate matter
μg	microgram
μl	microliter
USAF	United States Air Force
UST	underground storage tank
VOC	volatile organic compound(s)
wk	week(s)
yr	year(s)