

Air Emissions Factor Guide to Air Force Stationary Sources

Methods for Estimating Emissions
Of Air Pollutants
For Stationary Sources at
U.S. Air Force Installations

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ACRONYMS AND ABBREVIATIONS

µg	Microgram(s)
µm	Micrometer(s)
AAFES	Army & Air Force Exchange Service
AB	Afterburner
AEI	Air Emissions Inventory
AFB	Air Force Base
AFI	Air Force Instruction
AFCEE	Air Force Center for Engineering and the Environment
AFRL	Air Force Research Laboratory
AGE	Aerospace Ground Equipment
AGSE	Aerospace Ground Support Equipment
A-hr	Ampere-hours
ALAPCO	Association of Local Air Pollution Control Officials
AMX	Aircraft Maintenance Squadron
APU	Auxiliary Power Unit
AVGAS	Aviation Gasoline
BEE	Bioenvironmental Engineer
BMPs	Best Management Practices
BOOS	Burners Out Of Service
BSFC	Brake-Specific Fuel Consumption
Btu	British Thermal Unit
°C	Degrees Celsius
CAA	Clean Air Act
CAAA	Clean Air Act Amendments (of 1990)
CAIR	Clean Air Interstate Rule
CAS	Chemical Abstracts Service
CBPO	Consolidated Base Personnel Office
CE	Civil Engineering
CEMS	Continuous Emission Monitoring System
CEV	Civil Engineering Environmental
CFC	Chlorofluorocarbon
CFR	Code of Federal Regulations
CFRM	Continuous Flow Rate Monitor
CH ₄	Methane
CI	Compression Ignition
CNG	Compressed Natural Gas
CO	Carbon Monoxide
Co	Cobalt
Cr	Chromium
DAC	Defense Ammunition Center
DCA	Defense Commissary Agency
DESC	Defense Energy Support Center
DLA	Defense Logistics Agency
DNA	Defense Nuclear Agency
DoD	Department of Defense
DOE	Department of Energy
dscf	Dry Standard Cubic Feet
dscfm	Dry Standard Cubic Feet per Minute

EA	Environmental Assessment
EDMS	Emissions and Dispersion Modeling System
EDP	Electrodeposition
EF	Emission Factor
EGBE	Ethylene Glycol Monobutyl Ether
EIIP	Emissions Inventory Improvement Program
EIP	Emissions Inventory Plan
EIR	Emissions Inventory Report
EIS	Environmental Impact Statement
EtO	Ethylene Oxide
EOD	Explosive Ordnance Disposal
EPA	Environmental Protection Agency
EPAct	Energy Policy Act
EPCRA	Emergency Planning and Community Right-to-Know
ERC	Emission Reduction Credit
ESP	Electrostatic Precipitator
ESTCP	Environmental Security Technology Certification Program
°F	Degrees Fahrenheit
FAA	Federal Aviation Administration
FBC	Fluidized Bed Combustor
FCAW	Flux-Cored Arc Welding
FESOP	Federally Enforceable State Operating Permit
FF	Fabric Filter
FFV	Flexible Fuel Vehicles
FGD	Flue Gas Desulphurization
FGR	Flue Gas Recirculation
FIRE	Factor Information Retrieval System
FT	Fischer-Tropsch
ft	Foot (Feet)
g/L	Grams per Liter
gal	Gallon(s)
GHG	Greenhouse Gas
GMAW	Gas Metal Arc Welding
GOV	Government Owned Vehicles
GSA	General Services Administration
GSE	Ground Support Equipment
GVW	Gross Vehicle Weight
HAP	Hazardous Air Pollutant
HAZMAT	Hazardous Materials
HBFC	Hydrobromofluorocarbons
HC	Hydrocarbon
HCFC	Hydrochlorofluorocarbons
HCl	Hydrochloric Acid
HCP	Hard Chrome Plating
HEI	High Explosive Incendiary
HEPA	High Efficiency Particulate Air
HEV	Hybrid Electric Vehicles
HHV	High Heat Value
HMA	Hot Mix Asphalt
hp	Horse Power
hr	Hour(s)

HVAC	Heating, Ventilating, and Air Conditioning
HVLP	High Volume Low Pressure
HVOF	High Velocity Oxy-Fuel
IC	Internal Combustion
ICAO	International Civil Aviation Organization
IPCC	Intergovernmental Panel on Climate Change
IRP	Installation Restoration Program
kW	Kilowatt(s)
lb	Pound(s)
LDF	Liquid Drift Factors
LEL	Lower Explosive Limit
LFB	Low Flyby
LFG	Landfill Gas
LFP	Low Flight Pattern
LGRVM	Vehicle Management Flight Vehicle Maintenance
LNB	Low NO _x Burner
LPG	Liquid Petroleum Gas
LTO	Landing and Takeoff
MAJCOM	Major Command
MB	Material Burned
MC	Medium Cure
MEK	Methyl Ethyl Ketone
MEM	Mass of Energetic Material
Mg	Megagram(s) [i.e., metric ton]
mg	Milligram(s)
MIDAS	Munitions Items Disposition Action System
MM	Minutemen Missiles
MMBtu	Million British Thermal Units
Mn	Manganese
MPF	Military Personnel Flight
MPO	Metropolitan Planning Office
MSDS	Material Safety Data Sheet
MSW	Municipal Solid Waste
NAAQS	National Ambient Air Quality Standards
NACAA	National Association of Clean Air Agencies
NAICS	North American Industry Classification System
NASA	National Aeronautics and Space Administration
NDI	Non-destructive Inspection
NEI	National Emission Inventory
NEPA	National Environmental Policy Act
NESHAP	National Emission Standards for Hazardous Air Pollutants
NH ₃	Ammonia
Ni	Nickel
NMOC	Nonmethane Organic Compounds
N ₂ O	Nitrous Oxide
NO ₂	Nitrogen Dioxide
NO _x	Nitrogen Oxides
NSCR	Nonselective Catalytic Reduction
NSPS	New Source Performance Standard
NSR	New Source Review
OB/OD	Open Burning/Open Detonation

OBODM	Open Burning/Open Detonation Model
OCA	Off-Site Consequences Analysis
ODS	Ozone Depleting Substances
OIAI	Once In Always In
OLVIMS	On-line Vehicle Interactive Management System
OTAG	Office of Transportation Quality
P2	Pollution Prevention
PAH	Polycyclic Aromatic Hydrocarbon
Pb	Lead
PBT	Persistent Bioaccumulative Toxic
PEMS	Predictive Emission Monitoring System
PM	Particulate Matter – Aerodynamic diameter unspecified
PM ₁₀	Particulate Matter – Aerodynamic diameter < 10 micrometers
PM _{2.5}	Particulate Matter – Aerodynamic diameter < 2.5 micrometers
POM	Polycyclic Organic Matter
POTW	Publicly Owned Treatment Works
POV	Privately Owned Vehicles
ppm	Parts Per Million
ppmv	Parts Per Million By Volume
psi	Pounds per Square Inch
PTE	Potential-To-Emit
°R	Degrees Rankin
RAP	Reclaimed Asphalt Pavement
RC	Rapid Cure
REO	Regional Environmental Offices
REEDM	Rocket Exhaust Effluent Diffusion Model
RMP	Risk Management Plan
RVP	Reid Vapor Pressure
SAR	Second Assessment Report
SAW	Submerged Arc Welding
SC	Slow Cure
SCC	Source Classification Code
scf	Standard Cubic Foot
SCR	Selective Catalytic Reduction
SI	Spark Ignition
SIC	Standard Industrial Classification
SIP	State Implementation Plan
SMAW	Shielded Metal Arc Welding
SO ₂	Sulfur Dioxide
SOCMI	Synthetic Organic Chemical Manufacturing Industry
SO _x	Sulfur Oxides
STAPPA	State and Territorial Air Pollution Program Administrators
SVE	Soil Vapor Extraction
TAR	Third Assessment Report
TCLP	Toxicity Characteristics Leaching Procedure
TDS	Total Dissolved Solids
TGO	Touch-and-Go
THC	Total Hydrocarbons
TIM	Time In Mode
TLG	Total Landfill Gas
TNMOC	Total Nonmethane Organic Compounds

T.O.	Technical Order
TOC	Total Organic Compounds
tpy	Tons per Year
TRI	Toxic Release Inventory
TSD	Technical Data Sheets
TSP	Total Suspended Particulate
USAF	United States Air Force
ULSD	Ultra Low Sulfur Diesel
UST	Underground Storage Tanks
VIN	Vehicle Identification Number
VKT	Vehicle Kilometers Traveled
VMIF	Vehicle Maintenance Index File
VMT	Vehicle Miles Traveled
VOC	Volatile Organic Compound
yr	Year(s)

1 INTRODUCTION

1.1 Background and Purpose

The days when an installation only had to conduct a stack test once every five years and not worry about any other source of air pollution are ancient history. The Clean Air Act (CAA), with its subsequent amendments and 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. By and large, these programs make the same requirements of Department of Defense (DoD) installations. These rules require compliance assurance and self-reporting. Simply put, facility managers must know at all times if they are in compliance with air regulations.

The quantification of air pollutant emissions from a typical Air Force base is accomplished by conducting an air emissions inventory (AEI). An emission inventory is a compilation of all of the sources of air pollutant emissions and the emissions from these sources in a given area (installation) over a given period of time, typically one year. AEIs are the best estimates given available data. They are snapshots in time and subject to modification and improvement.

This document presents emissions estimation techniques and emission factors for preparation of an AEI, Federal Operating Permit (Title V) fee calculations, and annual/semi-annual demonstrations of compliance, federal/state/local air program applicability determinations, and general air quality planning. The methods described in this guidance are typically acceptable for these purposes but may be authorized for other reasons where higher cost methods for determining source emissions (stack/source testing, manufacturer's data, etc.) are not feasible or available. Federal, state, and local air pollution control agencies with jurisdiction should be consulted to determine which estimation method is most appropriate for a particular air quality concern.

This document was prepared by the Air Force Center for Engineering and the Environment (AFCEE) as a means of providing a uniform approach to estimating pollutant emissions from the most common types of stationary and mobile sources (emission units/processes) found at Air Force installations. This document describes recommended methodologies for calculating actual emissions from these sources. It includes most air emissions sources which might be found on an Air Force installation; however, it is not all-inclusive. If air emissions need to be calculated for a source which is not described in this document, use the most applicable state or federal (Environmental Protection Agency [EPA]) guidance for emissions calculations.

Any questions concerning this document, and/or requests for additional information pertaining to Air Force air emission inventories, should be directed to AFCEE, Technical Support Division, 485 Quentin Roosevelt Road, San Antonio, TX 78226-1845.

1.2 Emission Source Types

To those who are not familiar with CAA rule-making, determining the requirements for controlling or preventing emissions of air pollutants is neither a straight-forward nor simple process. This document addresses stationary and mobile emission sources typically found on Air Force installations. Only stationary (i.e., point and fugitive) and certain mobile source emissions are applicable to Air Force installations because of their direct bearing on the determination of "major source" status (para 1.5). Other than defining what they are, biogenic (or natural) sources and area sources are not addressed in any great detail within this document. Simply put, a biogenic source of air emissions is one that is not man-made. Biogenic sources include, but are not limited to, Volatile Organic Compound (VOC) emissions from vegetation and nitrous oxide (N₂O) emissions

from soil. Volcanoes and other geothermal emissions and even water vapor (by volume the largest category of “greenhouse gas”) are biogenic sources. The definition of an area source varies by pollutant group and regulation (i.e., criteria pollutants versus hazardous air pollutants [HAPs]). An area source is generally considered to be stationary and “nonroad” types of sources that are too small and too numerous to be individually included in a stationary source emissions inventory. These are sources for which emissions are estimated as a group rather than individually. Examples typically include residential wood heating and consumer solvent use.

1.2.1 Point Source and Fugitive Emissions

Emissions can be classified as point source or fugitive emissions. The EPA defines a point source as a “stationary location or fixed facility from which pollutants are discharged (e.g., a smokestack).” Point source emissions are those emissions that are captured and vented. Fugitive emission sources, on the other hand, are those that could not reasonably pass through a stack, chimney, or vent. They involve process emissions which exit the building through doors, windows, and other openings (e.g., VOC emissions from hand-wipe cleaning or architectural coating operations). Fugitive emissions may also be those emissions which are caused by equipment leaks in process appurtenances (e.g., piping flanges, valves, compressor/pump seals). In many cases fugitive emissions are not considered to be applicable to a particular air quality compliance concern or are explicitly excluded from the requirement to quantify and report emissions from a facility or process.

The exception to this generalization is HAPs and the 28 source categories identified in the law. All fugitive emissions of HAPs must be considered when making major source determinations. In addition to HAPs, fugitive emissions released from one of 28 specific source categories (Appendix B) or from a source category regulated on or before 7 August 1980 under CAA Section 111 or Section 112 must be included when making major source determinations for criteria pollutants. Although several of the 28 source categories may affect area sources, only two may apply to major sources found on a Air Force base: “Fossil-fuel boilers (or combinations thereof) totaling more than 250 MMBtu per hour heat input” and Aerospace Manufacturing and Rework Facilities. Fossil-fuel boilers (or combinations thereof) totaling more than 250 MMBtu per hour heat input is the source category that may typically be found on several Air Force installations. The “take-away” message from this section is the air pollution control agency with jurisdiction over a particular air quality concern or applicable regulations should be consulted prior to dedicating resources to the quantification of a base’s fugitive emissions. Not only does this practice foster good working relationships with local regulators, it will preclude the installation from expending resources where they were not needed or overlooking a source that should have been included.

1.2.2 Stationary Sources

A stationary source is any building, structure, facility, or installation that emits or may emit an air pollutant subject to regulation by the CAA. “Building, structure, facility, or installation means all of the pollutant-emitting activities which belong to the same industrial grouping and are located on one or more contiguous or adjacent properties, and are under the same the control of the same person.”¹ A stationary source can be an individual emissions unit, all emissions units in the same building, or all emissions units on an Air Force base, depending on the context in which it is used. In regards to air permits, “stationary source” typically refers to the collection of all emissions units within a contiguous area under common control (e.g., fence line to fence line on a typical base). Section I of this document addresses stationary sources at Air Force installations.

¹ (40 CFR 51.165)

1.2.3 Mobile Sources

A mobile source is a motor vehicle designed to transport people or property on a street or highway; a nonroad engine or a nonroad vehicle. Mobile sources do not have a fixed location point at a facility even though they have emissions of air contaminants which can be tied to specific processes or equipment. Typical mobile source types at an Air Force installation include aerospace ground support equipment (AGSE), privately owned vehicles, government owned vehicles, and nonroad vehicles/equipment. Examples of nonroad engines might include marine engines, aircraft engines, construction vehicles or equipment, and powered landscaping equipment (e.g., lawnmowers). Section II of this document addresses mobile sources at Air Force installations.

1.3 Actual Emissions

This document is concerned with “actual emissions.” This term is somewhat misleading as it may imply that the specific emissions values were specifically measured and can be quantified accurately. Rather, it refers to emissions based on actual operational parameters (e.g., hours of operation, operating conditions, or fuel usage). Actual emissions are typically quantified for sources at a site for submittal to state and local air pollution control agencies. These emissions may be required to fulfill a requirement for reporting for a certain period and frequency (e.g., reported for the previous calendar year on an annual basis). The emissions may be quantified to satisfy a permit condition which requires emissions reporting for specific permitted sources at intervals throughout the year or on a rolling basis (e.g., quarterly emissions or emissions on a rolling 12-month basis). Finally, actual emissions may be required as annual or semi-annual demonstration of compliance and emissions fee determination for holders of a Title V Permit.

1.4 Potential-to-Emit (PTE)

A source’s PTE is an essential part of an AEI. PTE is defined by the EPA (40 (Code of Federal Regulations (CFR) 70) as follows:

PTE means 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 Administrator.

In the past, there has been little flexibility in estimating PTE. One approach was to calculate the maximum capacity of the stationary source (i.e., the emission that would result if the source was operated 24 hours per day, 365 days per year—8,760 hours). The second was to calculate PTE based on enforceable limitations written into the permit’s language. Recently, however, some states (e.g., South Dakota, Texas, and Oklahoma) are accepting a more “real world” approach. Many support shops on a base are operational only during a “typical” work week (i.e., 40 hours per week/52 weeks per year) resulting in a work year of only 2,080 hours. In this example, the installation then uses 2,080 to determine its PTE.

Potential emissions are used to categorize a source as either “major” or “minor” for criteria air pollutants and either “major” or “area” for HAPs. Compliance costs may vary greatly depending on the source’s regulatory status. Under Titles III and V of CAA Amendments of 1990 (CAA-90), complex and lengthy requirements were established for any facility classified as a “major source,” as defined under 40 CFR 63 and 70, respectively. Both Titles III and V could conceivably

have tremendous economic and operational impacts at Air Force installations. Avoiding major source status can save a facility millions of dollars in manpower costs, equipment modifications, and fees. However, AEIs sometimes 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. Appendix H provides recommended methods for calculating PTE from typical Air Force processes in a manner which is both realistic and reasonably conservative.

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 listing the hours of operation as 8,760 hrs/yr. Each facility would do well to actively pursue negotiations with their state and local regulators on alternative PTE calculation methods.

1.5 Major Source Determination

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, Subject: Major Source Determinations for Military Installations under the Air Toxics, New Source Review (NSR), and Title V Operating Permit Programs of the CAA. This memo established several policies regarding major source determination at military installations. The following is a summary of these policies:

1.5.1 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:²

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

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 have to 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 based solely on emissions from National Guard activities.

² The 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.

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.³ 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, utilities, academic institutions, commercial space or flight 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 installation’s major source determination.

Since “common” control determinations tend to become complicated, the following rule-of-thumb is offered when applying the guidance: “Who has the power of authority to guide, manage, or regulate the pollutant-emitting activities for a particular activity on the base?” If the answer is the base commander, then these activities must be included in the major source determination.

1.5.2 Industrial Grouping and Support Facility Determinations⁴

As mentioned above, part of the criteria for making a major source determination under the provisions of 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 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.”⁵ Second, each activity is assigned the 2-digit SIC code that best describes it (e.g., 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 is important to note that when

³ The lessor refers to the military entity who owns the installation.

⁴ This subsection is applicable to major source determination under Title V of the CAAA-90 and under the NSR program, but is not applicable to major source determination under Title III of the CAAA-90.

⁵ At most Air Force installations, primary activities include activities like operation and maintenance of aircraft, training of military personnel, etc.

making a major source determination, each support activity is considered to be part of the same source as the primary activity it supports.

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, Army and Air Force Exchange Service (AAFES) gas stations, and dry cleaners. These activities are located on military installations for military personnel (both active duty and retired), their dependents, and DoD civilian employees working on the base, but they often do not represent essential activities related to the primary military activity of the base. Therefore, the EPA believes these types of activities may appropriately be considered not to be required support facilities (i.e., not essential to the primary military activities/mission 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. Many Air Force installations have been successful in “disaggregating” their AAFES gasoline stations resulting in a change to their major source status.

1.6 Emissions Inventory Methodologies

When conducting an AEI, the quantity of regulated pollutants emitted from all emission sources located on an Air Force installation (except those sources which are specifically exempt) must be determined. Several methods can be used to quantify air pollutants from emission sources. The methods listed below start at the most expensive, most reliable method for estimating emissions (i.e., monitoring/sampling) and progresses to the least expensive, least reliable method:

- emissions monitoring/sampling (e.g., continuous emissions monitoring and/or stack sampling),
- material balances,
- source category emissions model,
- state/industry factors,
- emission factors, and then
- engineering estimates.

Data from source-specific emission tests or continuous emission monitors are usually preferred for estimating a source’s emissions because those data provide the best representation of the tested source’s emissions. However, test data from individual sources are not always available and, even then, they may not reflect the variability of actual emissions over time. Thus, emission factors and/or material balance calculations are frequently the best or only method available for estimating emissions, in spite of their limitations. In all cases, managers must analyze the tradeoffs between the cost of the emissions estimates and the quality of the resulting estimates. Where risks of either adverse environmental effects or adverse regulatory outcomes are high, more sophisticated and more costly emission determination methods may be necessary. Though all emission calculation methods presented in this document use either emission factor estimates or material balance calculations they are not meant to suggest these are the only alternatives available.

An emission factor is a representative value that attempts to relate the quantity of a pollutant released with the activity associated with the release of that pollutant. These factors are usually expressed as the weight of pollutant released per a unit weight, volume, distance, or duration of the activity emitting the pollutant (e.g., pounds of particulate emitted per ton of coal burned). In most

cases, these factors are simply averages of all available data of acceptable quality, and are generally assumed to be representative of long-term averages for all facilities in the source category (i.e., a population average). EPA's AP-42 emission factors are given a rating from "A" through "E," with "A" being the best. The factor's rating is a general indication of the reliability of that factor. In all cases, however, the ratings are subjective and only indirectly consider the inherent scatter among the data used to develop factors, so the ratings should be seen as approximations. All emission factors provided in this document are supported by verifiable references listed in the Reference section of each chapter. Finally, the fact that an emission factor for a specific pollutant or process is not available does not imply that the EPA believes that the source should not be inventoried but only that the EPA does not have enough data to provide guidance.

The general equation for emission estimation using an emission factor is:

$$E = A \times EF \times \left(1 - \frac{ER}{100}\right) \quad \text{Equation 1-1}$$

Where

- E = emissions
- A = activity rate
- EF = emission factor
- ER = overall emission reduction efficiency,(%).

ER represents the overall control efficiency and is the product of the control device destruction or removal efficiency and the capture efficiency of the control system. When estimating emissions for a long time period (e.g., one year), an average efficiency is used to account for routine operations and upset periods as well.

For some sources, a material balance approach may provide a better estimate of emissions than emission tests would. In general, material balances are appropriate for use in situations where a high percentage of material is lost to the atmosphere (e.g., sulfur in fuel, solvent loss in an uncontrolled coating process). As the term implies, all the materials going into and coming out of the process must be accounted for such an emission estimation to be credible.

To ensure consistency of methods among the Air Force and agencies which regulate air pollution control at the federal, state, and local level, this document is based on emissions estimating methods found in the EPA document entitled, *Compilation of Air Pollutant Emission Factors, AP-42, Volume I: Stationary Point & Area Sources*⁶ and guidance documents prepared by the Emission Inventory Improvement Program (EIIP),⁷ which is jointly sponsored by the EPA and the National Association of Clean Air Agencies (NACAA).⁸

1.7 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 principal pollutant groups regulated under the CAA: criteria pollutants, HAPS, and ozone depleting substances (ODSs).

⁶ AP-42 is available from the EPA Website at <http://www.epa.gov/ttn/chief/ap42/>.

⁷ The EIIP Technical Report Series is available at <http://www.epa.gov/ttn/chief/eiip/techreport/>.

⁸ Formerly the State and Territorial Air Pollution Program Administrators/Association of Local Air Pollution Control Officials (STAPPA and ALAPCO).

1.7.1 Criteria Pollutants

In 1971, the EPA established National Ambient Air Quality Standards (NAAQS) for six pollutants which are termed criteria pollutants. There have been several changes since then but the current list remains at six. These include carbon monoxide (CO), nitrogen dioxide (NO₂), ozone, particulate matter (PM) with an equivalent aerodynamic diameter ≤ 10 microns (PM₁₀) which was later revised to include a separate standard for particulate with an equivalent aerodynamic diameter ≤ 2.5 microns (PM_{2.5}), sulfur dioxide (SO₂), and lead (Pb). The current NAAQS are provided in Appendix B. However, NO₂ in the ambient air is just one of several oxides of nitrogen that contribute to air quality issues. SO₂ is also just one of the oxides of sulfur contributing to air quality issues. Though there is a national standard, ozone is not emitted directly into the air. Ozone is created in the atmosphere (ambient air) through photochemical reactions involving the nitrogen oxides and VOCs. PM may be the result of the release of primary pollutants or the formation of secondary pollutants (e.g., SO₂ emitted during combustion is oxidized during transport to sulfur trioxide which reacts with water vapor to form sulfuric acid which reacts with numerous compounds to form sulfates/PM_{2.5}). As a result, the list of “criteria pollutants” for emissions inventory purposes is slightly different than the pollutants regulated by NAAQS and includes the following:

- CO
- Nitrogen Oxides (NO_x)
- PM₁₀
- PM_{2.5}
- Sulfur Oxides (SO_x)
- VOCs⁹
- Pb

Note that although Pb is a criteria pollutant, it is also a HAP. Therefore, to avoid duplication, this document addresses Pb as a HAP but not as a criteria pollutant.

1.7.2 Hazardous Air Pollutants (HAPs)

In contrast to criteria pollutants whose standards are based on ambient concentration values, the control of HAPs is based on an initial promulgation of emission standards and then a subsequent assessment of the risk that remains after implementation of the standards. (The CAA defines this remaining risk as the “residual” risk.) HAPs include the toxic compounds regulated under Section 112(b) of the CAA. EPA has been charged with continually analyzing available data on HAPs and revising the regulated list. There are established procedures for both “listing” and “delisting” compounds. In fact, when the amendments were originally promulgated in 1990, there were 189 chemical compounds listed as HAPs. Since then, three have been removed from this list: Caprolactam in June 1996 (61FR30816), Ethylene Glycol Monobutyl Ether (EGBE) in November 2004 (69FR69320), and Methyl Ethyl Ketone (MEK) in December 2005 (70FR75047). On the other side of the coin, EPA is considering adding “diesel exhaust” to the list of HAPs. Appendix A provides the current listing of HAPs in alphabetical order as well as by Chemical Abstracts Service (CAS) number order.

⁹ The EPA’s definition of VOCs is found in 40 CFR 51.100 and is provided in Appendix B of this document.

According to EPA, “Toxic air pollutants, also known as HAPs, are those pollutants that are known or suspected to cause cancer or other serious health effects, such as reproductive effects or birth defects, or adverse environmental effects.” Unlike criteria pollutants, HAPs are primarily chemical-specific pollutants (versus classes of pollutants) and many of the HAPs are actually constituent chemicals that are a subset of a criteria pollutant emission rate. This is found primarily with the VOCs (numerous constituent chemicals considered HAPs) and PM₁₀ (primarily heavy metals). Pb, which is both a criteria pollutant and a HAP, is addressed as a HAP throughout this document.

1.7.3 ODSs

ODSs may be found in air conditioning and refrigeration systems, fire suppression, medical waste sterilization (CFC-12 as a carrier gas for ethylene oxide) and maintenance activities (e.g., parts cleaning, dry cleaning). ODSs are regulated under the Montreal Protocol, European Union/Commission Regulations and CAAA-90. 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).

1.7.4 Greenhouse Gases (GHGs)

Global climate change is becoming one of the most important issues of the 21st century. Some GHGs such as carbon dioxide occur naturally and are emitted to the atmosphere through natural processes and human activities. Other GHGs (e.g., fluorinated gases) are created and emitted solely through human activities. The principal GHGs that enter the atmosphere because of human activities are carbon dioxide (CO₂), methane (CH₄), N₂O, and fluorinated gases.

CO₂ enters the atmosphere through the burning of fossil fuels (oil, natural gas, and coal), solid waste, trees and wood products, and also as a result of other chemical reactions (e.g., manufacture of cement). CO₂ is also removed from the atmosphere (or “sequestered”) when it is absorbed by plants as part of the biological carbon cycle. CH₄ is emitted during the production and transport of coal, natural gas, and oil. CH₄ emissions also result from livestock and other agricultural practices and by the decay of organic waste in municipal solid waste landfills. N₂O is emitted during agricultural and industrial activities, as well as during combustion of fossil fuels and solid waste.

As stated earlier, fluorinated gases are the result of human activities. Hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride are synthetic, powerful GHGs that are emitted from a variety of industrial processes. Fluorinated gases are sometimes used as substitutes for ozone-depleting substances discussed earlier (i.e., CFCs, HCFCs, and halons). These gases are typically emitted in smaller quantities, but because they are potent GHGs, they are sometimes referred to as High Global Warming Potential gases (“High GWP gases”).

States are developing climate change action plans to help each state identify and evaluate feasible and effective policies to reduce their GHG emissions through a combination of public and private sector policies and programs. As of July 2006, 29 states and Puerto Rico have completed, or are working on, action plans. By taking a proactive approach to planning GHG emissions reductions, states can lower their GHG, reduce their energy costs, protect air quality and public health, and improve the economy and environment (<http://epa.gov/climatechange/emissions/index.html>).

The EPA is slowly coming to grips with estimating and reporting GHG. The Emission Inventory Improvement Program, Technical Report Series Volume 8, “Estimating Greenhouse Gas

Emissions” is undergoing revision to (1) increase consistency with the national inventory of GHG emissions and sinks, (2) incorporate state-level data sources, methods, and emission factors where applicable, (3) update the text and examples for clarity, and (4) to include references to a MS Excel® based tool designed to assist states in the estimation of emissions. Substantive revisions include a number of methodological improvements and improved compatibility with international inventory guidelines and the Good Practice Guidance published by the Intergovernmental Panel on Climate Change (IPCC).

1.8 Inventory Data Elements and Format

The following section describes the types of input data necessary for preparing an AEI and presents suggestions for reporting the AEI results.

1.8.1 Inventory Data Elements

In order to calculate the emissions needed to compile an AEI, certain input information is required. For example, the emissions from external combustion units (e.g., boilers) depend on a variety of factors including the type/size of the combustor, firing configuration, fuel type and its constituents, control devices used and their respective efficiencies, operating capacity, and whether the system is properly operated/maintained.

Appendix D provides listings of the data elements required for each source type based on the calculation methodologies. A series of forms have been prepared by AFCEE to aid the field team in the collection of AEI data from selected sources. Copies of these forms are provided in Appendix J.

1.8.2 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 AEI 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. There are several advantages to having Air Force inventory reports prepared using a standard format. For example, having inventory reports in a similar format makes it easier to compare data, aggregate data, or perform trend analyses. Therefore, a recommended format for AEI inventory reports is provided in Appendix E of this document. The format is designed to assist air managers and state/local regulators in reviewing and/or completing 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),¹⁰ North American Industry Classification System (NAICS) codes,¹¹ qualifying assumptions, example calculations, and references.

¹⁰ A list of SCCs can be downloaded from the EPA at <http://www.epa.gov/ttn/chief/codes/index.html>. A detailed description of SCCs can be found at Appendix C.

¹¹ NAICS have replaced SIC codes. NAICS codes are available at <http://www.census.gov/epcd/www/naics.html>

1.9 Requirements and Uses for Emission Inventory

The following section describes the federal and Air Force requirements for AEIs. State and local requirements vary and are not discussed in this document. However, installation staff should ensure state and local requirements are identified and incorporated into their AEI process.

1.9.1 Regulatory Requirements

Ultimately, the requirement to conduct and maintain accurate records of sources of air pollutants can be traced back to the CAA and its subsequent amendments (e.g., CAAA-90). Generally speaking, these laws impose the same requirements on federal facilities as typical industrial facilities and include requirements for quantifying the amount of air pollutants being emitted to the local air-shed. AEIs are usually accomplished as a method for quantifying a facility's air emissions. The regulatory requirements for conducting an AEI are listed below:

1.9.1.1 Title I - Air Pollution Prevention and Control

The 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 emission inventories to the EPA and for sources to submit emission inventories to the state. The following is a summary of inventory requirements implemented by Title I of the CAAA-90:

- According to Section 172 of the CAA, a state must include a current inventory of each criteria pollutant whenever a 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.¹²
- Section 182(a)(1) of the CAA requires 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). Subsequent to the baseline inventory, states must submit periodic inventories every three years until the area reaches attainment.
- Section 182 of the CAA also requires 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 [tpy] of VOC or NO_x.)

1.9.1.2 Title III - General

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. The regulatory approach for HAPs is very different from criteria pollutants. Instead of regulating ambient air concentrations of HAPs, the CAA regulates individual pollutants and the sources that emit HAPs. Each NESHAP contains unique requirements, based on the source type. Each regulation contains specific monitoring, recordkeeping, and reporting requirements. Some examples of NESHAPs are the Municipal Solid Waste Landfills NESHAP, Engine Test Cell NESHAP, and Boilers and Process Heaters NESHAP. Each of these could affect sources on some Air Force installations. Some NESHAPs, such as the Aerospace Manufacturing and Rework NESHAP, only apply to sources which are considered a "major source" for HAPs. A

¹² In ozone nonattainment areas, this would include an inventory of ozone precursors: VOCs and NO_x.

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 PTE 10 or more tpy of any single HAP or 25 or more 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 (hence a requirement for conducting an AEI).

It is important to note that fugitive emissions must be included when determining if a source is a major source for HAPs. Additionally, a 16 May 1995, EPA policy memorandum titled “Potential to Emit for MACT Standards – Guidance on Timing Issues” 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 known as the “Once In, Always In” (OIAI) policy.

On 14 August 2000, EPA issued a memorandum, Subject: Guidance on the Major Source Determination for Certain HAPs. The memo was meant to address issues that have arisen as facilities that emit HAPs were trying to determine their major source applicability. Specifically, where a facility emits or has the PTE more than one chemical or substance in an aggregate group of HAPs it was not clear if the 10 tpy threshold value should apply to each chemical of the group individually or to the entire aggregate group of HAPs. This memo directs facilities to consider polycyclic organic matter (POM), xylene and creosol isomers, and the 16 “compounds” on the current HAP list (e.g., antimony compounds, arsenic compounds, beryllium compounds, chromium compounds, cadmium compounds, etc.) in aggregate when determining major source applicability (i.e., the total emissions of the individual chemicals in these aggregate groups must be less than 10 tpy or the source will be considered “major” for HAPs).

1.9.1.3 Title V - Permits

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

- A major source under Section 112 of the CAA (i.e., a major source for HAPs)
- 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 SIC code) which emits more than 100 tpy of any air pollutant (as defined under section 302(g) of the CAA). For some of the criteria pollutants, lower thresholds exist for certain nonattainment areas.¹³ These lower thresholds 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 PM₁₀ emissions in “serious” PM₁₀ nonattainment areas.

¹³ To determine if an Air Force facility is in a nonattainment area, staff may refer to EPA’s “Green Book” (<http://www.epa.gov/oar/oaqps/greenbk/index.html>) to view a list of areas designated as nonattainment by the respective pollutant.

In order for a source (e.g., an Air Force base) to determine if it is a major source under the provisions of Title V, an emissions inventory (of actual and potential emissions) must be accomplished. It is important to note that with the exemption of the HAPs regulated under Title III, when making a major source determination under Title V, fugitive emissions are not included in the emission inventory unless the source of emissions is from one of the 28 source categories listed in Appendix B.

1.9.1.4 General Conformity

The CAA, specifically section 176(c), prohibits federal activities from taking various actions in nonattainment or maintenance areas unless they first demonstrate conformance with the respective SIP. The general conformity rule does not specify a deadline for completing the conformity review and associated tasks. However, the rule states clearly that these tasks must be accomplished in a timely manner prior to initiating the proposed action. "A Federal Agency must make a determination that a Federal action conforms to the applicable implementation plan in accordance with the requirements of this subpart before the action is taken."¹⁴ A conformity review is a multi-step process used to determine and document whether a proposed action meets the conformity rule. There are two main components to this process: an **applicability analysis** to determine if a full-scale conformity determination is required and, if it is, a **conformity determination** to assess whether the action conforms to the SIP. The general conformity program (40 CFR 93) requires all federal actions in nonattainment and maintenance areas to comply with the appropriate SIP. An emissions inventory is usually required as part of the conformity determination to identify/quantify air emissions from the proposed federal actions.

The conformity process is separate from the National Environmental Policy Act (NEPA) analysis process. It is up to each federal agency to determine the best ways to integrate the conformity and NEPA processes. However, the conformity analysis can be completed concurrently with the NEPA analysis, and linkage between the two is allowed. This may be an efficient and convenient approach. There are certain requirements for NEPA that are not required under conformity. For example, NEPA requires the development of reasonable alternative actions, whereas conformity does not (conformity only requires analysis of the proposed alternative). In this case, it may be a more realistic approach to perform a conformity analysis for only the one alternative selected instead of for all alternatives. At a minimum, when the specific alternative is selected in the NEPA process, the conformity air quality analyses should be performed as appropriate. A joint notification and public participation process also is possible, as long as the requirements for each regulation are met.

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

In accordance with the provisions of Section 313 of the EPCRA, a facility that meets or exceeds annual reporting thresholds, including the manufacture or process of any listed toxic chemical in quantities equal to or greater than 25,000 pounds/year, or otherwise use of any listed toxic chemical in quantities equal to or greater than 10,000 pounds/year, must submit a "Form R" report. This section contains an ever changing list of more than 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.

In 2000, EPA lowered the reporting threshold for persistent bioaccumulative toxic (PBT) chemicals and added other PBT chemicals to the TRI list of toxic chemicals. PBTs are of

¹⁴ 40 CFR 93.150(b)

concern because they are toxic, remain in the environment for long periods of time, are not readily destroyed, and can accumulate in body tissue. The lowered thresholds require facilities, including DoD installations, to report the amount of PBT chemicals released into air, land, and water at much lower levels than previously reported. EPA finalized two thresholds based on the chemicals' potential to persist and bioaccumulate in the environment. The two levels include setting manufacture, process, and otherwise use thresholds to 100 pounds for PBT chemicals and to 10 pounds for a subset of PBT chemicals that are highly persistent and highly bioaccumulative. One exception is the dioxin and dioxin-like compounds category threshold which was set at 0.1 gram.

In 2001, EPA published the TRI Pb rule classifying Pb and Pb compounds as PBT chemicals and lowered their previously existing thresholds. Pb and Pb compounds were on the original TRI list of reportable chemicals, but with this ruling EPA reclassified these compounds as PBT chemicals due to their bioaccumulative properties. Facilities that manufacture, process, or otherwise use more than 100 pounds of Pb or Pb compounds must now report releases and off-site transfers. Previously, facilities were required to report Pb and Pb compound releases only if they manufactured or processed more than 25,000 pounds annually or otherwise used more than 10,000 pounds annually. Beginning in 2001, DoD reported releases and off-site transfers associated with operational range activities, including training, live fire, and clearance activities.

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 all of the TRI chemicals, most of the chemicals which are applicable to the Air Force are also identified as HAPs, which are addressed in this document (e.g., toluene, methyl chloroform, methylene chloride, phenol).

1.9.1.6 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 is 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 emission inventories can be used in EAs and EISs to help identify possible environmental consequences associated with air emissions from proposed federal actions. As stated earlier, a conformity analysis/determination may also be required.

1.9.1.7 State/Local Programs

Some state and local regulatory agencies have unique programs which require some sort of AEI. 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.

1.9.1.8 Air Force Instruction (AFI) 32-7040

“Air Quality Compliance,” states that installations shall prepare and periodically update an AEI of all installation stationary and Air Force owned or operated mobile sources at the frequency required by federal, state, and local regulations. It is recommended that AEIs be updated no less frequently than every three years, if no periodic emission inventory requirements apply, to accurately reflect current emissions. Overseas installations shall also conduct AEIs in accordance with final governing standards or host nation agreements. Required inventory data will be provided to federal, state, and local/regional regulatory agencies as required or upon request. Installations shall submit their most recent AEI in electronic format to AFCEE and their parent Command. AEIs may be submitted via email to afcee.aeicustodian@brooks.af.mil. They can also be mailed to AFCEE Technical Support Division, ATTN: Air Emissions Inventory Custodian, 485 Quentin Roosevelt Road, San Antonio, Texas 78226-1845.

1.9.2 Other Inventory Uses

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

1.9.2.1 Pollution Prevention (P2) Opportunities

An AEI 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. Armed with this information, installation management can develop strategies to identify opportunities for process changes or other methods for reducing the types and/or quantities of air pollutants emitted from their respective facilities.

1.9.2.2 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) or between different sources in order to meet applicable air pollution control requirements. Though the majority of states have emissions trading programs, programs vary from state to state, as well as regionally or locally. Some programs cover a specific region within a state or span several states. Certain general similarities were found in the different emissions averaging programs. These similarities include the fact that almost all programs allow emissions reduction credits to be generated, traded, transferred, or permanently retired. In most cases, though not all, emissions reductions must be permanent in order to generate credits. Also, emissions trading programs are more common in non-attainment areas, where the issue of emissions is a more pressing problem. The types of trading methods include emission bubbles, emission netting, emission offsets, and emission reduction banking. The following is a brief description of each:

- 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.

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

1.9.2.3 Risk Assessments

Section 112(r) of the CAA spells out requirements for a Risk Management Program which covers the accidental release prevention requirements. The rule regulates 77 toxic and 63 flammable substances which are stored or used in operational or manufacturing processes, and which exceed the threshold quantities listed in 40 CFR 68.130. The purpose of this program to inform local communities of processes in their area which have the potential to present a catastrophic release hazard, and to require responsible parties (i.e., the respective Air Force base) to develop a Risk Management Program which consists of four components:

- Management Program
- Hazard Assessment
- Accident Prevention Program
- Response Program

Assessments of Air Force facilities reveal that two of the regulated substances are found routinely in sufficient quantities to exceed the threshold quantities listed in 40 CFR 68.130. These substances include chlorine and SO₂ and are usually associated with the facilities water treatment operations.

Under the original rule, facilities were required to include a brief description of their “Off-Site Consequences Analysis” (OCA) in the executive summary of their Risk Management Plans (RMP). EPA and federal law enforcement agencies have become concerned that OCA descriptions in executive summaries may pose a security risk, so EPA revised the rule to remove this requirement. In view of security concerns, EPA expects that facilities will not include any OCA data in the executive summaries of their RMPs.

1.9.2.4 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 (e.g., ESOHCAMPS). Audits can be designed to verify compliance with environmental requirements, evaluate the effectiveness of environmental management systems, or assess risks from regulated and unregulated materials and practices. In addition, audits can be used by management to plan environmental activities for the future. Data from air emission 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.

1.10 Document Organization

This document is organized into chapters which are specifically related to facilities or processes typically found at Air Force installations. Chapter topics may or may not correspond directly to source types identified in EPA, state, or local guidance documents, but the intent is to consider sources usually associated with a particular facility/activity/process. This document addresses stationary sources of air emissions. Guidance for addressing mobile sources of air pollutants may be found in the "Air Emissions Inventory Guidance Document for Mobile Sources at Air Force Installations."

Information shared by multiple chapters as well as general reference information is provided in the Appendixes at the end of the document.

1.11 References

1. U.S. EPA, *Introduction to Air Pollutant Emission Estimation Techniques for Industry*, Draft Version, 30 November 1992.
2. U.S. EPA, *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 August 1996.
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.
18. U.S. EPA Policy Memorandum, *Guidance on the Major Source Determination for Certain Hazardous Air Pollutants*, 14 August 2000.

2 ABRASIVE BLASTING

2.1 Introduction

Abrasive blasting operations involve impacting particles of a hard material (e.g., sand, plastic beads, glass beads) on a surface to remove paint and/or corrosion from equipment. A high pressure pneumatic gun is used to blast the media at the equipment being stripped/cleaned. Depending on the size of the equipment, blasting is usually performed in a small enclosed cabinet, in a booth, or in a hangar. For example, an aircraft wheel is usually stripped in a cabinet, AGSE is usually stripped in a booth, and an aircraft is usually stripped in a hangar.

Typical Air Force shops which perform controlled abrasive blasting include Corrosion Control; Vehicle Maintenance, Repair and Reclamation (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.

Depending on the coatings (paint and primer) being stripped, the material exhausted from blasting operations is in the form of PM that may contain inorganic HAPs such as chromium, Pb, or cadmium. The exhaust from these blasting operations is usually vented to a control system consisting of a fabric filter (i.e., baghouse) to remove PM. A cyclone may precede the fabric filter in the collection system to separate the larger blast media from the smaller PM in the exhaust stream. The large beads are then recycled to the blasting system while the smaller PM, 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. Samples of the collected waste material are regularly collected for analysis to ensure the material is not hazardous waste. The waste material is periodically shipped off site for disposal at an appropriate landfill facility.

Emission factors for abrasive blasting operations are provided in Table 2-1 at the end of this chapter.

2.2 Emission Calculations

a. Emission Calculations Using Mass Balances

PM emissions from controlled blasting operations are based on the efficiency of the fabric filter control device and the amount of waste material captured/collected. 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.

$$WM_{\text{total}} = \frac{WM_{\text{col}}}{\frac{\text{eff}}{100}} \quad \text{Equation 2-1}$$

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.

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

$$E_{PM} = WM_{total} - WM_{col} \quad \text{Equation 2-2}$$

HAPs may be generated from abrasive blasting operations if the paint/coating being stripped contains an inorganic HAP such as chromium, Pb, or cadmium. Although HAP emissions from abrasive blasting are usually relatively low, they can be estimated by performing a chemical analysis of the waste material collected by the fabric filter. The chemical analysis of the waste material is typically by the Toxicity Characteristic Leaching Procedure (TCLP). The results of the total constituent analysis may be divided by twenty to convert the total results into an estimate of the total metal concentration in the waste.¹⁵ A total metal analysis will usually provide results in units of mg/kg (e.g., mg chromium/kg waste). The units can then be converted from mg/kg to lb/lb of waste. 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 using the following equation:

$$E_{HAP} = PM \times C_{HAP} \quad \text{Equation 2-3}$$

Where

$$\begin{aligned} E_{HAP} &= \text{Annual emission of a specific HAP (lb/yr)} \\ PM &= \text{Annual emission of PM (lb/yr)} \\ C_{HAP} &= \text{Fractional concentration of the HAP in the PM (lb/lb)}. \end{aligned}$$

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.

b. 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 exist for abrasive blasting. These factors are listed in Table 2-1. 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.

$$AE_i = EF_{PM} \times Q \times C_i \times [1 - (\frac{CE_i}{100})] \quad \text{Equation 2-4}$$

Where

$$\begin{aligned} AE_i &= \text{Annual emissions of chemical } i \text{ (lb/yr)} \\ EF_{PM} &= \text{PM emission factor (lb/lb of blast media used)}. \end{aligned}$$

¹⁵ The factor of twenty is the liquid-to-solid ratio in the TCLP (see "Total Constituent Analysis" at http://www.epa.gov/SW-846/faqs_tclp.htm).

Q	=	Annual blast media consumption (lb/yr) (maximum or actual)
C _i	=	Chemical <i>i</i> speciation (fraction) (C _i = 1.0 for PM)
CE _i	=	Chemical <i>i</i> emission control efficiency (%)
100	=	Factor to convert percent efficiency to fractional efficiency.

2.3 Information Resources

Information associated with abrasive blasting operations can be obtained from the specific shops/organizations performing the blasting operations (e.g., Corrosion Control, Wheel & Tire, AGSE, Civil Engineering). Information about the amount of abrasive blasting waste disposed off-site as hazardous waste, and the required chemical analysis of the waste for disposal, may be available from the hazardous waste section of the Civil Engineering Environmental Quality Flight (CEV).

2.4 Example Problems

a. Problem #1

The corrosion control shop on base performs abrasive bead blasting of the entire aircraft 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 PM (small beads, paint dust, etc.) is sent to a baghouse. Shop records show that 3,275 pounds of waste material were captured/collected by the baghouse and disposed. 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 (MSDS) for the primer and paint used on the aircraft reveals that the primer contains zinc chromate. Since chromium compounds are a HAP, a sample of the waste material was collected by the base Bioenvironmental Engineer (BEE) 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.

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

$$WM_{\text{total}} = \frac{WM_{\text{col}}}{\% \text{efficiency}}$$

$$WM_{\text{total}} = \frac{3,275 \text{ lb}}{0.96}$$

$$WM_{\text{total}} = \mathbf{3,411.46 \text{ lb/yr}}$$

Next calculate the PM emissions as follows:

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

$$E_{\text{PM}} = 3,411.46 \text{ lb/yr} - 3,275 \text{ lb/yr}$$

$$E_{\text{PM}} = \mathbf{136.46 \text{ lb/yr.}}$$

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

$$\left(\frac{940 \text{ mgCr}}{\text{kgwaste}} \right) \times \left(\frac{1 \text{ lb}}{453,590 \text{ mg}} \right) \times \left(\frac{1 \text{ kg}}{2.205 \text{ lb}} \right) = \mathbf{9.40 \times 10^{-4} \text{ lb Cr/lb waste}}$$

Finally calculate the chromium emissions as follows:

$$\begin{aligned} E_{Cr} &= E_{PM} \times (\text{lb Cr/lb waste}) \\ E_{Cr} &= (136 \text{ lb}) \times (9.40 \times 10^{-4} \text{ lb Cr/lb waste}) \\ E_{Cr} &= \mathbf{1.28 \times 10^{-1} \text{ lb.}} \end{aligned}$$

b. Problem #2

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 PM₁₀ emissions. (Using Table 2-1 below, the emission factor for PM₁₀ is determined to be 13 lb particulate/1000 lb blast media.)

$$\begin{aligned} AE_{PM10} &= EF_{PM} \times Q \times C_i \times [1 - (\frac{CE_i}{100})] \\ E_{PM10} &= (13 \text{ lb}/10^3 \text{ lb}) \times (6.5 \times 10^3 \text{ lb}) \\ E_{PM10} &= \mathbf{84.50 \text{ lb.}} \end{aligned}$$

2.5 References

1. Air Force Center for Environmental Excellence, "CAA Compliance Tool Box," 7 May 2006, available at <http://www.afcee.brooks.af.mil/products/air/federal/emisest/abrblast.html>.
2. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources (AP-42)*, Section 13.2.6, "Abrasive Blasting," October 1997.

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)	Total PM	
	- 5 mph wind speed	27
	- 10 mph wind speed	55
	- 15 mph wind speed	91
	PM ₁₀ ^a	13
	PM _{2.5} ^a	1.3
Abrasive (30/40 mesh garnet) blasting of unspecified metal parts, controlled with a fabric filter (SCC 3-09-002-04)	Total PM	0.69

^a Emissions of PM₁₀ and PM_{2.5} are not significantly dependent on wind speed.

3 AIRCRAFT ENGINE TESTING

3.1 Introduction

Aircraft engine testing is performed at many 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 flight, especially after any maintenance has been performed.

Testing of engines removed from aircraft is typically conducted in an enclosed test cell (called a hush house), though some installations perform limited engine testing on the aircraft or on test stands mounted in the open. Testing of engines removed from aircraft is generally considered a stationary source but some state/local regulatory agencies may have a different interpretation. Therefore, the appropriate state and/or local regulatory agencies should be contacted to ensure proper designation prior to performing an air emission inventory.

Emissions of concern from engine testing include criteria pollutants and HAPs. This guidance document contains criteria and HAP emission factors for 22 different engines in use on Air Force aircraft and auxiliary power units. 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.

Table F-1 in Appendix F lists the aircraft in use by the Air Force (and other services), their respective aircraft engines, the emission factors tables, and the reference where the emission factors were determined. Emission rates and emission factors are presented by mode of operation. For estimating SO₂ emissions, it can be assumed that all sulfur in the fuel undergoes complete oxidation to SO₂.

Emissions from aircraft engines and auxiliary power units not listed in this guide can be estimated by using the Federal Aviation Administration's (FAA) Emissions and Dispersion Modeling System (EDMS), a comprehensive emission factor database with information on both commercial and military aircraft (including many of the engines listed in this guide). The emission factors in EDMS come from the International Civil Aviation Organization (ICAO) Engine Exhaust Emissions Data Bank and government emission test reports for military aircraft engines. For engines not listed in this guide and not found in the EDMS database, emissions might possibly be estimated by using emission factors from similar engine designs.

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 by the actual fuel flow rate (used during testing) and then times the actual time spent testing the engine at that power setting. The following equation is used to estimate aircraft engine testing emissions:

$$E_{\text{pol}} = \text{EF} \times \text{FR} \times t \quad \text{Equation 3-1}$$

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 by the fuel density (e.g., density of JP-8 is 6.67 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 by the average time per test.]

Note that some installations keep records of the total quantity of fuel consumed during the year at each tested power setting. In this case, the “FR x t” portion of the equation should be replaced with the quantity of fuel consumed (1000 lb/yr) at the applicable power setting.

SO_x emission factors are derived by assuming all the sulfur in the fuel is converted to SO_x (as SO₂) during combustion. Based on this, SO_x emission factors are calculated using the following equation:

$$EF_{\text{SO}_2} = 20 \times S \quad \text{Equation 3-2}$$

Where

- EF_{SO_2} = 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 the ratio of the molecular weight of SO₂ by the molecular weight of sulfur
- S = Weight percent sulfur content of the fuel.

The weight percent sulfur content of the fuel (S) may vary depending on the supplier and the geographical location where the fuel is produced. Therefore, the typical sulfur content value should be obtained from the fuel supplier whenever possible. If this information is not available, then the average sulfur content values listed in Table G-1 in Appendix G can be used.¹⁶

3.3 Information Resources

The Aircraft Engine Maintenance organization should be contacted to obtain the information needed to calculate emissions from aircraft engine 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.

¹⁶ Defense Logistics Agency, Defense Energy Support Center, *Petroleum Quality Information System Fuels Data (2005)*, (April 2006).

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. 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 “actual” fuel flow rates for each power setting were approximately the same for each test, and are as follows:

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

Calculate the CO and SO₂ emissions associated with the testing of the TF33-P-7 engine.

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

$$\begin{aligned}
 \text{Total Time in Idle} &= 102 \text{ test/yr} \times 20 \text{ min/test} \times (1 \text{ hr}/60 \text{ min}) \\
 \text{Total Time in Idle} &= \mathbf{34.00 \text{ hr/yr}} \\
 \\
 \text{Total Time in Approach} &= 102 \text{ test/yr} \times 45 \text{ min/test} \times (1 \text{ hr}/60 \text{ min}) \\
 \text{Total Time in Approach} &= \mathbf{76.50 \text{ hr/yr}} \\
 \\
 \text{Total Time in Intermediate} &= 102 \text{ test/yr} \times 15 \text{ min/test} \times (1 \text{ hr}/60 \text{ min}) \\
 \text{Total Time in Intermediate} &= \mathbf{25.50 \text{ hr/yr}} \\
 \\
 \text{Total Time in Military} &= 102 \text{ test/yr} \times 15 \text{ min/test} \times (1 \text{ hr}/60 \text{ min}) \\
 \text{Total Time in Military} &= \mathbf{25.50 \text{ hr/yr}}
 \end{aligned}$$

Calculate the CO emissions from testing at each power setting and then summing these values to get the Total CO emissions. (The criteria pollutant emission factors for the TF33-P-7 engine are found in Appendix F, Table F-12.)

$$\begin{aligned}
 E_{\text{CO}} &= \text{EF} \times \text{FR} \times t \\
 E_{\text{CO-Idle}} &= (134.51 \text{ lb}/1000 \text{ lb}) \times (1.10/1000 \text{ lb/hr}) \times (34 \text{ hr/yr}) \\
 E_{\text{CO-Idle}} &= 5,030.67 \text{ lb/yr} \\
 E_{\text{CO-Approach}} &= (9.69 \text{ lb}/1000 \text{ lb}) \times (4.90/1000 \text{ lb/hr}) \times (76.5 \text{ hr/yr}) \\
 E_{\text{CO-Approach}} &= 3,632.30 \text{ lb/yr} \\
 E_{\text{CO-Intermediate}} &= (4.16 \text{ lb}/1000 \text{ lb}) \times (6.375/1000 \text{ lb/hr}) \times (25.5 \text{ hr/yr}) \\
 E_{\text{CO-Intermediate}} &= 676.26 \text{ lb/yr} \\
 E_{\text{CO-Military}} &= (1.49 \text{ lb}/1000 \text{ lb}) \times (8.28/1000 \text{ lb/hr}) \times (25.5 \text{ hr/yr}) \\
 E_{\text{CO-Military}} &= 314.60 \text{ lb/yr} \\
 E_{\text{CO-Total}} &= 5,030.67 \text{ lb/yr} + 3,632.30 \text{ lb/yr} + 676.26 \text{ lb/yr} + 314.60 \text{ lb/yr} \\
 E_{\text{CO-Total}} &= \mathbf{9,653.83 \text{ lb/yr.}}
 \end{aligned}$$

Calculate the SO₂ emission factor based on the sulfur content of the jet fuel/JP-8 (obtained from Appendix G, Table G-1).

$$\begin{aligned} EF_{SO_2} &= 20 \times S \\ EF_{SO_2} &= 20 \times 0.071 \\ EF_{SO_2} &= \mathbf{1.42 \text{ lb}/1000 \text{ lb}.} \end{aligned}$$

Calculate the SO₂ emissions.

$$\begin{aligned} E_{SO_2} &= EF \times FR \times t \\ E_{SO_2\text{-Idle}} &= (1.42 \text{ lb}/1000 \text{ lb}) \times (1.10/1000 \text{ lb/hr}) \times (34 \text{ hr/yr}) \\ E_{SO_2\text{-Idle}} &= 53.11 \text{ lb/yr} \\ E_{SO_2\text{-Approach}} &= (1.42 \text{ lb}/1000 \text{ lb}) \times (4.90/1000 \text{ lb/hr}) \times (76.5 \text{ hr/yr}) \\ E_{SO_2\text{-Approach}} &= 532.29 \text{ lb/yr} \\ E_{SO_2\text{-Intermediate}} &= (1.42 \text{ lb}/1000 \text{ lb}) \times (6.375/1000 \text{ lb/hr}) \times (25.5 \text{ hr/yr}) \\ E_{SO_2\text{-Intermediate}} &= 230.84 \text{ lb/yr} \\ E_{SO_2\text{-Military}} &= (1.42 \text{ lb}/1000 \text{ lb}) \times (8.28/1000 \text{ lb/hr}) \times (25.5 \text{ hr/yr}) \\ E_{SO_2\text{-Military}} &= 299.82 \text{ lb/yr} \\ E_{SO_2\text{-Total}} &= 53.11 \text{ lb/yr} + 532.29 \text{ lb/yr} + 230.84 \text{ lb/yr} + 299.82 \text{ lb/yr} \\ E_{SO_2\text{-Total}} &= \mathbf{1116.06 \text{ lb/yr}.} \end{aligned}$$

3.5 References

1. U.S. Air Force AFIERA/RSEQ, Environmental Quality Management, Inc., "Aircraft Engine and Auxiliary Power Unit Emissions Testing Final Report," Project No. 3414-08B-060, November 1998.
2. U.S. Air Force AFIERA/RSEQ, Environmental Quality Management, Inc., "Aircraft Engine and Auxiliary Power Unit Emissions Testing Final Report Addendum F119-PW-100 Engine," Project No. 030414.008C.5.060, June 2002.
3. Pratt & Whitney, "PT6A-68 Emissions Measurement Program Summary," September 2002.
4. Defense Logistics Agency, Defense Energy Support Center, *Petroleum Quality Information System Fuels Data (2005)*, April 2006.
5. U.S. Air Force AFIERA, Environmental Quality Management, Inc., "Clean Air Act Emissions Testing of the T-38 Aircraft Engines at Randolph Air Force Base, Texas," September 2002.
6. U.S. Air Force AFIERA/RSEQ, IERA-RS-BR-SR-2003-0002, "Aircraft/Auxiliary Power Units/Aerospace Ground Support Equipment Emission Factors," October 2002.

4 ASPHALT PAVING OPERATIONS

4.1 Introduction

Nearly 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 from the distillation of crude oils) or liquefied 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.

Liquefied 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 naphtha, kerosene, etc. Emulsified asphalt is a nonflammable liquid produced by combining asphalt and water with an emulsifying agent, such as soap. Liquefied asphalts are used in tack and seal operations, in priming roadbeds for hot mix application, and for paving operations up to several inches thick.

Emissions of pollutants from asphalt paving operations occur as the asphalt mixtures are being applied and then as they cure. The primary pollutants of concern from asphalts and asphalt paving operations are directly related to the diluents used and include VOCs and HAPs. 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 AEI. Because emissions result from the evaporation of the diluents used in the mix, factors such as temperature affect the rate of evaporation. Hot-mix asphalt results in the lowest emissions per ton followed by emulsified asphalts. Cutback asphalts result in the highest emissions.

VOC emissions from cutback asphalts result from the evaporation of the petroleum distillate solvent (diluent) used to liquefy 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 naphtha and gasoline solvents, kerosene-type solvents, or heavy residual oils, respectively. The proportions of solvent added generally range from 25 to 45 percent by volume, depending on the viscosity desired.

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 (i.e., over a period of 30 days or more) 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. Typical quantities of evaporative emissions from cutback asphalts are presented in Table 4-1.

Emissions of HAPs from asphalt paving operations are not as easily quantified. In fact, manufacturer technical data sheets (TSDs) or MSDSs or their equivalent will be required for each

type of asphalt used to identify the diluent composition (types and percentages of each constituent solvent).

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 by the weight percent of cutback asphalt which is expected to evaporate.

$$E_{\text{VOC}} = \text{QA} \times \left(\frac{\text{WP}_{\text{evap}}}{100} \right) \quad \text{Equation 4-1}$$

Where

$$\begin{aligned} E_{\text{VOC}} &= \text{Emissions of VOC (lb/yr)} \\ \text{QA} &= \text{Quantity of cutback asphalt used during the year for road pavement (lb/yr)} \\ \text{WP}_{\text{evap}} &= \text{Weight percent of cutback asphalt which evaporates (\%)} \\ 100 &= \text{Factor to convert weight percent to weight fraction.} \end{aligned}$$

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

Speciated HAP emissions are a function of the total VOCs emitted. To determine HAP emissions, first estimate the total VOC emissions. Then, multiply the VOC total by the ratio of the HAPs of interest. This is represented by:

$$E_{\text{HAP}} = E_{\text{VOC}} \times \text{WF}_{\text{HAP}} \quad \text{Equation 4-2}$$

Where

$$\begin{aligned} E_{\text{HAP}} &= \text{Mass emissions for each HAP} \\ E_{\text{VOC}} &= \text{VOC mass emissions} \\ \text{WF}_{\text{HAP}} &= \text{Weight Fraction of each HAP} \left(\frac{\text{Weight of each HAP}}{\text{Weight of VOC emitted}} \right) \end{aligned} \quad \text{Equation 4-3}$$

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. Ideally, TSDs and/or MSDSs may be requested from the manufacturer identifying the diluent constituents.

4.4 Example Problem

According to 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 RC type. Civil Engineering estimates the average solvent content in the cutback asphalt to be around 35%, by volume. Calculate the VOC emissions.

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

Calculate the VOC emissions as follows:

$$E_{\text{VOC}} = QA \times \left(\frac{WP_{\text{evap}}}{100} \right)$$

$$E_{\text{VOC}} = 3,500 \text{ lb/yr} \times (0.24)$$

$$E_{\text{VOC}} = \mathbf{840.00 \text{ lb/yr.}}$$

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, "Asphalt Paving Operation," July 1979 (Reformatted January 1995).
2. Emissions Inventory Improvement Program (EIIP), Volume III: Chapter 17, "Asphalt Paving," Draft Version, April 2001.

Table 4-1. Percent of Cutback Asphalts Evaporated

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

Note: The values shown represent the percent, by weight, of cutback asphalt evaporated (WP_{evap}).

^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 and 45%, by volume. Emissions may be linearly interpolated for any given volume of solvent between these values.

5 CORROSION CONTROL COATINGS

5.1 Chromium Electroplating

5.1.1 Introduction

Some Air Force installations (especially Logistics bases) perform chromium electroplating of various parts and materials. Chromium (Cr) 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.

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 foot (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.

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 a layer of hollow

plastic balls (polypropylene balls) to the surface of the plating bath. 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.

5.1.2 Emission Calculations

Emissions from chromium electroplating operations can be calculated as follows:

$$E_{\text{pol}} = EI \times 0.001 \times EF \quad \text{Equation 5-1}$$

Where

$$\begin{aligned} E_{\text{pol}} &= \text{Emissions of a pollutant (lb/yr)} \\ EI &= \text{Total Energy Input (Ampere-hours [A-hr])} \\ 0.001 &= \text{Factor for converting "A-hr" to "10}^3 \text{ A-hr"} \\ EF &= \text{Emission Factor (lb/10}^3 \text{ A-hr)}. \end{aligned}$$

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

5.1.3 Information Resources

All information needed to calculate emissions from chromium electroplating and/or chromic acid anodizing operations can be obtained from the base electroplating shop(s). Bioenvironmental Engineering should be able to provide a listing of the electroplating shops.

5.1.4 Example Problems

A shop operates two hard Cr electroplating tanks (Tank A and Tank B). Exhaust from each tank is vented to a packed-bed scrubber. No other controls are used. 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.

$$\begin{aligned} E_{\text{pol}} &= EI \times 0.001 \times EF \\ E_{\text{Cr}} &= (667,000 \text{ A-hr/yr} + 532,000 \text{ A-hr/yr}) \times 0.001 \times (3.0 \times 10^{-4} \text{ lb/10}^3 \text{ A-hr}) \\ E_{\text{Cr}} &= \mathbf{0.36 \text{ lb/yr.}} \\ E_{\text{PM}} &= (667,000 \text{ A-hr/yr} + 532,000 \text{ A-hr/yr}) \times 0.001 \times (6.3 \times 10^{-4} \text{ lb/10}^3 \text{ A-hr}) \\ E_{\text{PM}} &= \mathbf{0.76 \text{ lb/yr.}} \end{aligned}$$

5.2 Chromium 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 equipment used for chromic acid anodizing. These differences include the following: the rectifier must 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/ft². The chromium acid anodizing process produces PM emissions made up entirely of chromic acid mist.

Emissions from a chromic acid anodizing tank can be calculated as follows:

$$E_{\text{pol}} = \text{OT} \times 0.001 \times \text{SA} \times \text{EF} \quad \text{Equation 5-2}$$

Where

E_{pol}	= Emissions of a pollutant (lb/yr)
OT	= Tank operating time (hr/yr)
0.001	= Factor for converting “hours” to “10 ³ 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.

5.3 Replacement of Chromium Electroplating Using High Velocity Oxy-Fuel (HVOF) Thermal Spray Coatings

Due to both environmental and life-cycle-cost issues, the DoD has established a program to qualify HVOF thermal spray coatings as viable alternatives to hard chrome plating (HCP) in aircraft maintenance. HCP is a technique that has been in commercial production for over 50 years and which is a critical process associated with maintenance activities at all DoD depots and shipyards. In the aviation sector, it is used both for applying hard coatings to aircraft landing gear components and/or aircraft actuator parts, and for general re-build of worn or corroded components that have been removed from aircraft during overhaul. HCP uses chromium in the hexavalent state (hex-Cr or CR⁺⁶), which is a known carcinogen.

HVOF thermal spray process is a dry process that produces a dense metallic coating whose desired physical properties are equal to or surpass those of HCP. These properties include wear resistance, corrosion resistance, low oxide content, low stress, low porosity, and high bonding strength to the base metal.

HVOF thermal spray uses a fuel (i.e., propylene, hydrogen, kerosene)/oxygen mixture in a combustion chamber. This combustion process melts a metal-containing powder that is continually fed into a gun using a carrier gas (argon) and propels it at high speeds (3,000 - 4,000 ft/sec) towards the surface of the part to be coated. The high speeds of the spray coating produce a coating that can be used as an alternative to the HCP process. The metal powder is available in many compositions, including nickel, nichrome, chrome carbide, and tungsten carbide.

The waste stream produced by HVOF is from the capture of the overspray. Current users either use a water curtain filter system or a dry high efficiency particulate air (HEPA) filter. Since the overspray contains only the pure metal or alloy, it is feasible to recycle or reclaim this waste stream.

5.4 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, "Electroplating," July 1996.
2. U.S. Environmental Protection Agency, Factor Information Retrieval System (FIRE), December 2005.
3. Sartwell, B.D., Natishan, P.M., Singer, I.L., et al, "Replacement of Chromium Electroplating Using HVOF Thermal Spray Coatings," Naval Research Laboratory, Washington, D.C.

Table 5-1. Emission Factors for Hard Chromium Electroplating Operations

Control Type	PM ₁₀ ^a (lb/10 ³ A-hr) ^b	Chromium Compounds (lb/10 ³ A-hr) ^b
Uncontrolled	3.57 x 10 ⁻²	1.71E-02
With moisture extractor	4.00 x 10 ⁻³	2.00E-03
With polypropylene balls	1.26 x 10 ⁻²	6.00E-03
With fume suppressant	4.86 x 10 ⁻³	2.29E-03
With fume suppressant and polypropylene balls	9.00 x 10 ⁻⁴	4.29E-04
With packed-bed scrubber	6.29 x 10 ⁻⁴	3.00E-04
With packed-bed scrubber, fume suppressant, and polypropylene balls	7.86 x 10 ⁻⁵	3.71E-05
With chevron-blade mist eliminator	2.57 x 10 ⁻³	1.26E-03
With mesh-pad mist eliminator	3.71 x 10 ⁻⁴	1.71E-04
With packed-bed scrubber and mesh-pad eliminator	9.57 x 10 ⁻⁷	4.57E-07
With composite mesh-pad mist eliminator	1.14 x 10 ⁻⁴	5.43E-05

^a. According to both FIRE and AP-42, all PM from chromium electroplating is likely to be emitted as PM₁₀.

^b. Emission factors in AP-42 and FIRE, listed in units of grains/dscf, were converted into units of lb/10³ A-hr. These emission factors were first converted to grains/A-hr by multiplying by 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

Control Type	PM ₁₀ ^a (lb/10 ³ A-hr) ^b	Chromium Compounds (lb/10 ³ A-hr) ^b
Uncontrolled	9.86 x 10 ⁻³	4.71E-03
With fume suppressant	3.57 x 10 ⁻⁵	1.71E-05

^a. According to both FIRE and AP-42, all PM from chromium electroplating is likely to be emitted as PM₁₀.

^b. Emission factors in AP-42 and FIRE, listed in units of grains/dscf, were converted into units of lb/10³ A-hr. These emission factors were first converted to grains/A-hr by multiplying by 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 5-3. Emission Factors for Chromic Acid Anodizing Operations

Control Type	Chromium Compounds (lb/10³ hr-ft²)	PM₁₀^a (lb/10³ hr-ft²)
Uncontrolled	2.86 x 10 ⁻¹	6.00 x 10 ⁻¹
With polypropylene balls	2.43 x 10 ⁻¹	5.14 x 10 ⁻¹
With fume suppressant	9.14 x 10 ⁻³	1.86 x 10 ⁻²
With fume suppressant and polypropylene balls	3.57 x 10 ⁻³	7.57 x 10 ⁻³
With packed-bed scrubber	1.37 x 10 ⁻³	2.86 x 10 ⁻³
With packed-bed scrubber and fume suppressant	1.07 x 10 ⁻⁴	2.29 x 10 ⁻⁴
With mesh-pad mist eliminator	7.29 x 10 ⁻⁴	1.57 x 10 ⁻³
With packed-bed scrubber and mesh pad mist eliminator	7.71 x 10 ⁻⁵	1.57 x 10 ⁻⁴
With wet scrubber, moisture extractor, and HEPA filter	6.86 x 10 ⁻⁵	1.43 x 10 ⁻⁴

^a According to AP-42, all PM from chromium electroplating is likely to be emitted as PM₁₀.

6 DRY CLEANING OPERATIONS

6.1 Introduction

Although most Air Force installations offer some sort of dry cleaning service, in many cases the actual dry cleaning is performed by contractors 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 may be included in an AEI.

Dry cleaning involves the cleaning of fabrics (e.g., garments, draperies, leather goods) 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 referred to as "PERC" (use estimated at 82% of all dry cleaning facilities). Depending on the type of solvent used, the emissions of concern from dry cleaning operations are VOCs (i.e., from petroleum solvents) and/or organic HAPs (e.g., perchloroethylene).

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 older technologies 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 NESHAP program and those regulated under state/local programs. NESHAP requirements can require the use of refrigerated condensers, leak detection and seal inspection programs, and monitoring and reporting requirements.

Most facilities using perchloroethylene use dry-to-dry machines. 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. It is 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. 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, or large businesses that provides 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. Emissions control is also achieved through changes in operational practices to reduce fugitive emissions best management practices (BMPs). Examples of BMPs include prompt detection and repair of any leaky valves, hose connections, or gaskets; storage of solvents and

wastewater in tightly sealed containers; and minimizing the length of time the door on any given dry cleaning machine is left open.

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.

6.2 Emission Calculations

The primary method of calculating emissions from dry cleaning operations is to use a mass balance approach.

6.2.1 Mass Balance Method

Calculate as follows:

$$E_{\text{solvent}} = [(V_{\text{FS}} - V_{\text{WS}}) \times D] - V_{\text{CS}} \quad \text{Equation 6-1}$$

Where

- E_{solvent} = Emissions of solvent (lb/yr)
- V_{FS} = Volume of fresh solvent added to the dry cleaning process (gal/yr)
- V_{WS} = Volume of waste solvent removed from the process (gal/yr)
- D = Density of solvent (lb/gal)
- V_{CS} = Mass of solvent which is captured via carbon adsorption and not reintroduced back into the process (lb/yr) (Note: May be a VOC or HAP depending on the solvent used).

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 (i.e., V_{CS} is the total mass of solvent captured by the carbon adsorber).

6.2.2 Emission Factor Method

Calculate as follows:

$$E_{\text{solvent}} = MC \times EF \quad \text{Equation 6-2}$$

Where

- E_{solvent} = Emissions of solvent (lb/yr)
- MC = Mass of clothes cleaned (100 lb/yr) [Note: The annual amount (mass) of others cleaned in each machine can be estimated by multiplying the machine's capacity by the number of loads washed in the machine during the year.]
- EF = Emission factor (lb/100 lb).

6.3 Information Resources

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

6.4 Example Problems

Problem # 1

A dry cleaning facility has a single dry-to-dry machine which uses perchloroethylene/PERC. Two hundred and fifty gallons of fresh perchloroethylene were added to the process during the year while approximately 200 gallons of waste solvent were removed from the process for off-site recycling. Emissions 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. The carbon adsorption material is shipped off base for regeneration and solvent recovery. 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. [Note: Density of perchloroethylene is 13.5 lb/gal]

Calculate using the mass balance method described above.

$$\begin{aligned} E_{\text{solvent}} &= [(V_{\text{FS}} - V_{\text{WS}}) \times D] - V_{\text{CS}} \\ E_{\text{perc}} &= [(250 \text{ gal/yr} - 200 \text{ gal/yr}) \times 13.5 \text{ lb/gal}] - 400 \text{ lb/yr} \\ E_{\text{perc}} &= \mathbf{275.00 \text{ lb/yr.}} \end{aligned}$$

Problem # 2

A dry cleaning facility has a single transfer machine which uses perchloroethylene. No emission controls are associated with the transfer machine. Seventy five loads of laundry were cleaned in the transfer machine throughout the year. The typical size of each load was approximately 40 pounds. Calculate the perchloroethylene emissions using the emission factor method.

Calculate using the emission factor method.

- (1) Calculate the mass of clothes (in hundreds of pounds) cleaned in the machine throughout the year.

$$\begin{aligned} \text{MC} &= 75 \text{ loads/yr} \times 40 \text{ lb/load} \\ \text{MC} &= \mathbf{3000.00 \text{ lb/yr.}} \end{aligned}$$

- (2) Calculate the emissions using the mass of clothes cleaned and the appropriate emission factor.

$$\begin{aligned} E_{\text{solvent}} &= \text{MC} \times \text{EF} \\ E_{\text{perc}} &= (3000 \text{ lb clothes/yr}) \times 27.5 \text{ lb perc/100 lb clothes} \\ E_{\text{perc}} &= \mathbf{825.00 \text{ lb/yr.}} \end{aligned}$$

6.4 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, "Dry Cleaning," April 1981 (Reformatted January 1995).
2. Emission Inventory Improvement Program (EIIP), *Volume III, Chapter 4, "Dry Cleaning,"* Final Report, May 1996.

Table 6-1. Liquid-Phase and Vapor-Phase HAP Speciation of Petroleum Dry Cleaning Solvents

Solvent Type (Process Used)	Source	Emission Rate	
		Typical System (lb/100 lb) ^a	Well-Controlled System (lb/100 lb) ^a
Petroleum (transfer process)	Washer/dryer	18	2
	Filter disposal		
	Uncooked (drained)	8	
	Centrifuged		0.5-1
	Still residue disposal	1	0.75 (avg.)
	Miscellaneous	1	1
	Total for process	28	4-5
Perchloroethylene (transfer process)	Washer/dryer/still/muck cooker	8	0.3
	Filter disposal		
	Uncooked muck	14	
	Cooked muck	1.3	0.5-1.3
	Cartridge filter	1.1	0.5-1.1
	Still residue disposal	1.6	0.5-1.6
	Miscellaneous	1.5	1
		Total for process	27.5
Trichlorotrifluoroethane (dry-to-dry process)	Washer/dryer/still	0	0
	Cartridge filter disposal	1	1
	Still residue disposal	0.5	0.5
	Miscellaneous	1-3	1-3
		Total for process	2.5-4.5

^a All values are in units of lb solvent emitted per 100 lb clothes cleaned.

7 EQUIPMENT LEAKS

7.1 Introduction

Most Air Force installations have fuel transfer systems consisting of pumps, pipelines, fill stands, hydrants, loading and unloading racks, etc. Over time, various components (e.g., valves, pump seals, connectors, flanges, compressor seals, pressure relief valves) may develop leaks and release fugitive emissions. The primary emissions associated with equipment leaks are total VOC and organic HAP emissions.

VOC emission factors for equipment leaks can be found in the EPA document “Protocol for Equipment Leak Emission Estimates” (Ref. #1). The 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 Table 7-1 are based on the emission factors for marketing terminals because this operation most closely resembles fueling 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 are as follows:

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 these definitions, gasoline would be considered a light liquid 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

Calculate VOC emissions from each specific type of component as follows:

$$E_{\text{VOC}} = EF_{\text{TOC}} \times WF_{\text{VOC}} \times t \times NC \times \left[1 - \left(\frac{CE}{100}\right)\right] \quad \text{Equation 7-1}$$

Where

- E_{VOC} = Total VOC emission (lb/yr)
- EF_{VOC} = Emission Factor (lb/hr/source)
- WF_{VOC} = Average weight fraction VOC in the stream
- t = Time during the year similar components were in operation (hr/yr)
- NC = Number of similar components located on base (# of similar emission sources)
- CE = Approximate control efficiency.

Calculate HAP emissions using the following equation:

$$E_{\text{HAP}} = E_{\text{VOC}} \times \frac{\text{VWP}_{\text{HAP}}}{100} \quad \text{Equation 7-2}$$

Where

$$\begin{aligned} E_{\text{HAP}} &= \text{Emissions of a specific HAP (lb/yr)} \\ E_{\text{VOC}} &= \text{VOC Emissions (lb/yr)} \\ \text{VWP}_{\text{HAP}} &= \text{Weight percent of the HAP in the VOC emission} \\ 100 &= \text{Factor to convert weight percent to weight fraction} \end{aligned}$$

7.3 Equipment Modifications

Some facilities may utilize equipment modifications to reduce the emission leaks from transfer equipment. Table 7-2 lists the approximate control efficiency for the most common equipment modifications that may be utilized.

Vapor-phase speciation of gasoline can be found in the “Gasoline Service Stations” section (Table 15-2) of this report while vapor-phase speciation of JP-8 and diesel can be found in the “Fuel Storage” section (Tables 13-1 and 13-2).

7.4 Information Resources

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

7.5 Example Problem

The following type and number of components are associated with 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.

For JP-8 assume that all of the total organic compounds (TOC) are VOC, the weight fraction of VOCs is one, and there are no control devices installed.

$$\begin{aligned} E_{\text{VOC}} &= E_{\text{F}_{\text{TOC}}} \times \text{WF}_{\text{TOC}} \times t \times \text{NC} \times \left[1 - \left(\frac{\text{CE}}{100}\right)\right] \\ E_{\text{VOC-Valves}} &= E_{\text{F}_{\text{TOC}}} \times \text{WF}_{\text{TOC}} \times t \times \text{NC} \times \left[1 - \left(\frac{\text{CE}}{100}\right)\right] \\ E_{\text{VOC-Valves}} &= 9.5 \times 10^{-5} \times 1.00 \times 8,760 \text{ hr} \times 325 \times \left[1 - \left(\frac{0}{100}\right)\right] \\ E_{\text{VOC-Valves}} &= \mathbf{270.47 \text{ lb/yr.}} \\ E_{\text{VOC-Seals}} &= 1.2 \times 10^{-3} \times 1.00 \times 8,760 \text{ hr} \times 28 \times \left[1 - \left(\frac{0}{100}\right)\right] \\ E_{\text{VOC-Seals}} &= \mathbf{294.34 \text{ lb/yr.}} \end{aligned}$$

(Sample equation continued)

$$E_{\text{VOC-Fittings}} = 1.8 \times 10^{-5} \times 1.00 \times 8,760 \text{ hr} \times (590+460) \times \left[1 - \left(\frac{0}{100}\right)\right]$$

$$E_{\text{VOC-Fittings}} = \mathbf{165.56 \text{ lb/yr.}}$$

$$E_{\text{VOC-Other}} = 2.9 \times 10^{-4} \times 1.00 \times 8,760 \text{ hr} \times (42 + 35) \times \left[1 - \left(\frac{0}{100}\right)\right]$$

$$E_{\text{VOC-Other}} = \mathbf{196.61 \text{ lb/yr.}}$$

$$E_{\text{VOC-Total}} = 270.47 \text{ lb/yr} + 294.34 + 165.56 + 196.61$$

$$E_{\text{VOC-Total}} = \mathbf{925.98 \text{ lb/yr.}}$$

7.6 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. Southwest Research Institute, “*JP-8 Volatility Study*”, March 2003.

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

Component Type	Service^a	VOC Emission factor (lb/hr/source)
Valves (except pressure relief valves)	Gas/Vapor	2.86×10^{-5}
	Liquid	9.46×10^{-5}
Pump seals	Gas/Vapor	1.43×10^{-4}
	Liquid	1.19×10^{-3}
Fittings (connectors and flanges)	Gas/Vapor	9.24×10^{-5}
	Liquid	1.76×10^{-5}
Other (compressor seals, open-ended lines, pressure relief valves, sampling connections, and any other potential release point) ^b	Gas/Vapor	2.64×10^{-4}
	Liquid	2.86×10^{-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.

Table 7-2. Control Efficiencies for Equipment Modification

Equipment Type	Modification	Approximate Control Efficiency (%)
Pumps	Sealless design	100 ^a
	Closed-vent system	90 ^b
	Dual mechanical seal with barrier fluid maintained at a higher pressure than the pumped fluid	100
Valves	Sealless design	100 ^a
Compressors	Closed-vent system	90 ^b
	Dual mechanical seal with barrier fluid maintained at a higher pressure than the pumped fluid	100
Pressure relief devices	Closed-vent system	c
	Rupture disk assembly	100
Connectors	Weld together	100
Open-ended lines	Blind, cap, plug, or second valve	100
Sampling connections	Closed-loop sampling	100

^a. Sealless equipment can be a large source of emission in the event of equipment failure.

^b. Actual efficiency of a closed-vent system depends on percentage of vapors collected and efficiency of control device to which the vapors are routed.

^c. Control efficiency of closed vent-systems installed on a pressure relief device may be lower than other closed-vent system, because they must be designed to handle both potentially large and small volumes of vapor.

8 ETHYLENE OXIDE (EtO) STERILIZERS

8.1 Introduction

EtO is commonly used (either in pure form or in a mixture) as a sterilant. EtO sterilization of medical equipment and surgical materials is performed at many hospitals/clinics in the Air Force. EtO 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.

- Contaminated material is loaded into the chamber.
- The chamber door is closed and hermetically sealed.
- Air is vacuumed from the chamber.
- The sterilant (either 100% EtO, 12% EtO with 88% Freon, or 10% EtO with 90% CO₂) is introduced into the chamber to a set pressure or concentration and for a specified time period. (Note: 100% EtO is used with a negative pressure while EtO mixtures are used with positive pressure.)
- An exhaust vacuum removes the sterilant from the chamber.
- The sterilant is exhausted through a vent line either directly to the atmosphere, or through a control device and then to the atmosphere.
- Fresh air is drawn into the chamber until atmospheric pressure is reached.
- The chamber door is opened and the treated material removed.
- The treated material may be transferred to an aeration cabinet which circulates heated air around the material in order to drive-off any residual EtO.

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 EtO mixture into the chamber under pressure, and then (after treatment) flush out the EtO 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.

U.S. EPA proposed a new rule entitled *National Emission Standards for Hospital EtO Sterilizers* on November 6, 2006. The final rule was issued on December 28, 2007 and applies to any existing or new hospital ethylene oxide sterilization facility that is an area source of HAPs. The owner or operator of an existing area source was required to comply with this area source NESHAP by December 29, 2008. The owner or operator of a new area source was to comply with this area source NESHAP by December 28, 2007 or upon initial startup, whichever was later.

EtO is both a VOC and a HAP. Emissions from EtO sterilizers may be passed through a control device prior to being vented into the atmosphere. Possible control techniques include thermal oxidation (incineration), catalytic oxidation, wet scrubbing, charcoal adsorption, and refrigeration/reclamation.

8.2 Emission Calculations

Emissions from EtO sterilizers can be estimated using a mass balance approach. Using this approach, the entire amount of EtO used for sterilization is assumed to be emitted, with the exception of emissions captured by a control device.

$$E_{\text{EtO}} = \text{QS} \times \frac{\text{WP}_{\text{EtO}}}{100} \times \left[1 - \left(\frac{\text{Eff}}{100}\right)\right] \quad \text{Equation 8-1}$$

Where

E_{EtO}	=	Emissions of EtO (lb/yr)
QS	=	Quantity (mass) of sterilant used (lb/yr)
WP_{EtO}	=	Weight percent or ethylene oxide in sterilant (%)
Eff	=	Efficiency of control device (%) [Note: Eff is zero if no control device is used]
100	=	Factor to convert weight percent or percent efficiency to a decimal fraction.

8.3 Information Resources

Hospitals and/or clinics which use EtO 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 10% EtO and 90% CO₂ 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 EtO.

$$E_{\text{EtO}} = \text{QS} \times \frac{\text{WP}_{\text{EtO}}}{100} \times \left[1 - \left(\frac{\text{Eff}}{100}\right)\right]$$

$$E_{\text{EtO}} = 185 \text{ lb/yr} \times \left(\frac{10}{100}\right) \times \left[1 - \left(\frac{0}{100}\right)\right]$$

$$E_{\text{EtO}} = \mathbf{18.50 \text{ lb/yr.}}$$

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.
2. U.S. Environmental Protection Agency, *Ethylene Oxide Emissions Standards for Sterilization Facilities*, Federal Register, V. 66, No. 213, November 2, 2001.

9 EXTERNAL COMBUSTION SOURCES

9.1 Introduction

External combustion sources include boilers, furnaces, and heaters used for heating and/or power production 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. 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.

9.1.1 Size and Classification

External combustion sources are typically classified according to fuel type, size, and/or function. In regards to size, boilers are categorized according to their heat input capacities. The most common fuel types used in external combustion sources at Air Force installations, in order of predominance, are as follows:

- Natural gas
- Fuel Oil
- Coal
- Liquefied petroleum gas (LPG)
- Waste or residual oil

The boiler source category comprises sources that combust fuels to produce hot water and/or steam. Utility boilers utilize steam to generate electricity. Industrial boilers often generate steam for electrical power, as well as process steam. Space heaters use the hot water for heating commercial and residential building space. In general, boilers are categorized as follows:

Type of Boilers	Size
Utility	>100 MMBtu/hr ^a
Industrial	10 – 250 MMBtu/hr
Commercial/Institutional	0.3 – 10 MMBtu/hr
Residential	<0.3 MMBtu/hr

^a MMBtu: million British Thermal units

9.1.2 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 are 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.

9.1.3 Fuel and Combustor Types

9.1.3.1 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 CH₄ (generally above 85 percent) and varying amounts of ethane, propane, butane, and inerts (typically nitrogen, CO₂, and helium).

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 which the natural gas and air are combined in a burner and mixed to promote efficient combustion. Hot combustion gases exchange heat with circulating air before being exhausted from a vent or chimney.

Natural gas boilers are considered clean relative to coal- or oil-fired boilers, but improper operating conditions (such as poor air-fuel mixing) may still result in smoke (unburned carbon) in the exhaust, as well as CO and perhaps small amounts of unburned hydrocarbons. NO_x emissions are usually the major pollutants of concern in a well-operated natural gas boiler. NO_x emissions are primarily a function of the combustion chamber temperature.

Due to its characteristically low fuel nitrogen content, nearly all NO_x emissions from natural gas combustion are thermal NO_x. 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). Several modifications can be made to natural gas boilers to reduce NO_x emissions. Staged combustion can reduce NO_x emissions by 5 to 20 percent (EPA, January 1995). Low excess air levels and flue gas recirculation (FGR) also often lower NO_x emissions.

9.1.3.2 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. Residual No. 4 is occasionally classified as distillate while No. 5 and No. 6 fuel oils are considered residual oils. (No. 6 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.

Residual oils, produced from the residue remaining after the lighter fractions (gasoline, kerosene, and distillate oils) have been removed from the crude oil, contain significant quantities of ash, nitrogen, and sulfur. 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.

9.1.3.3 *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.

Lignite is characterized by a high moisture content and low heating value. These properties make shipping and use of lignite unfeasible. Emission factors for lignite are not included in this document.

Bituminous coal is by far the largest group of coal and is characterized as having higher fixed carbon and lower volatile matter than lignite. 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.

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 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 United States .

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. 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.

Emissions from coal combustion depend on the rank and composition of the fuel, the type and size of the boiler, firing conditions, load, type of control technologies, and the level of equipment maintenance. The major pollutants of concern from bituminous and subbituminous coal combustion are PM, SO_x, and NO_x. Some unburned combustibles, including CO and numerous organic compounds, are generally emitted even under proper boiler operating conditions.

Emissions from anthracite coal firing primarily include PM, SO_x, NO_x, and CO; and trace amounts of organic compounds and trace elements.

9.1.3.4 LPG

LPG usually consists of butane, propane, or a mixture of the two. The product used for domestic heating is composed primarily of propane (approximately 90%). LPG 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.

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. The EPA lists no emission factors for HAPs from LPG.

9.1.3.5 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.

It is important to note that the activities listed above use waste oil in such a way that regulators may interpret as the incineration of waste, which may trigger the need for regulatory action (i.e., obtaining a new or modifying an existing permit). Check with base command before proceeding with using waste oil or retrofitting combustors to use waste oil.

9.1.4 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 post combustion control. A listing of the most common types of control techniques for external combustion is provided in Table 9-1.

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

Fuel	Pollutant	Control Device Type	Average Control Efficiency ^a (%)	Control Efficiency Range ^a (%)	
				Minimum Value	Maximum Value
Coal	NO _x	FGR		5	45
		Low Excess Air		5	30
		Low NO _x Burners (LNBs)		35	55
		Natural Gas Burners/Reburn		50	70
		Overfire Air		5	30
		Selective Catalytic Reduction		63	94
		Selective Non-catalytic Reduction		30	60
		LNB w/ Selective Non-catalytic Reduction		50	80
		LNB w/ Overfire Air and Selective Catalytic Reduction		85	95
		LNB with Overfire Air		40	60
	SO ₂ ^b	Wet Acid Gas Scrubber		80	99
		Spray Dryer Absorber		70	90
	PM	Electrostatic Precipitator (ESP)	99	90	99.9
		Fabric Filter	99	99	
Mechanical Collector		65	90	95	
Wet PM Scrubber			50	99	
Coal (Anthracite)	PM	ESP	98.4		
		Fabric Filter		98.4	99.4
Coal (Bituminous)	PM	ESP		96	99.4
		Fabric Filter		98.3	99.9
	PM ₁₀	Fuel Switching to Sub-bituminous Coal (Industrial Sources) ^c	21.4		
		Fuel Switching to Residual Oil (Industrial Sources) ^c	62.9		
		Fuel Switching to Natural Gas (Industrial Sources) ^c	98.2		
		Fuel Switching to Sub-bituminous Coal (Utility Sources) ^c	21.4		
		Fuel Switching to Residual Oil (Utility Sources) ^c	69.5		
		Fuel Switching to Natural Gas (Utility Sources) ^c	99.3		
	PM _{2.5}	Fuel Switching to Sub-bituminous Coal (Industrial Sources) ^c	21.4		
		Fuel Switching to Residual Oil (Industrial Sources) ^c	7.4		
		Fuel Switching to Natural Gas (Industrial Sources) ^c	93.1		
		Fuel Switching to Sub-bituminous Coal (Utility Sources) ^c	21.4		
		Fuel Switching to Natural Gas (Utility Sources) ^c	97.5		

Fuel	Pollutant	Control Device Type	Average Control Efficiency ^a (%)	Control Efficiency Range ^a (%)	
				Minimum Value	Maximum Value
Coal Sub-bituminous	PM ₁₀	Fuel Switching to Residual Oil (Industrial Sources) ^c	52.8		
		Fuel Switching to Natural Gas (Industrial Sources) ^c	97.7		
		Fuel Switching to Residual Oil (Utility Sources) ^c	61.2		
		Fuel Switching to Natural Gas (Utility Sources) ^c	99.2		
	PM _{2.5}	Fuel Switching to Natural Gas (Industrial Sources) ^c	91.2		
		Fuel Switching to Natural Gas (Utility Sources) ^c	96.8		
Lignite	SO ₂ ^b	Wet Acid Gas Scrubber		90	
	PM	ESP		95	99.5
		Mechanical Collector		60	80
Oil, Distillate, No. 2	NO _x	FGR		45	55
		Low Excess Air		2	19
		Overfire Air		20	45
		Selective Catalytic Reduction			90
Oil, Residual, Nos. 4, 5, & 6	NO _x	FGR	21	2	31
		Low Excess Air		5	31
		Overfire Air		24	47
		Selective Catalytic Reduction		70	80
		Selective Non-catalytic Reduction		35	70
	PM ₁₀	Fuel Switching to Natural Gas (Industrial Sources) ^c	95.1		
		Fuel Switching to Natural Gas (Utility Sources) ^c	97.9		
	PM _{2.5}	Fuel Switching to Natural Gas (Industrial Sources) ^c	92.5		
		Fuel Switching to Natural Gas (Utility Sources) ^c	97.0		
Utility Oil or Natural Gas	NO _x	FGR		40	65
Municipal Waste	NO _x	Selective Catalytic Reduction	69		80
Natural Gas	NO _x	Flue Gas Recirculation		49	68
		Low Excess Air		0	31
		LNBs		40	85
		Overfire Air	60	13	73
		Selective Catalytic Reduction		80	90
		Selective Non-catalytic Reduction		35	80
Natural Boiler Gas	NO _x	LNBs with Overfire Air		40	50
Sewage Sludge	PM	Wet PM Scrubber		60	99
“Not Identified”	SO ₂ ^b	Wet Acid Scrubber (Chemical Manufacturing) _b		90	99

^a A blank field indicates that no data was available for this pollutant, fuel type, and control device.

^b Control device controls SO_x.

^c These are the potential emission reductions from fuel switching. Source: EPA. 1998. *Stationary Source Control Techniques Document for Fine PM*. U.S. Environmental Protection Agency. EPA 452/R-97-001.

^d Control efficiency is applicable to general fuel combustion operations.

9.2 Emission Calculations

Table 9-2 identifies the preferred and alternative emission estimation approach for selected pollutants. For many of the pollutants emitted from boilers, several of the previously defined emission estimation methodologies can be used.

Table 9-2. Preferred and Alternative Emission Estimation Methods

Parameter	Preferred Emission Estimation Approach	Alternative Emission Estimation Approach ^a
SO ₂	CEMS ^b /PEM ^c data	1. Fuel Analysis ^d 2. Stack sampling data 3. EPA/state published emission factors
NO _x	CEMS/PEM data	1. Stack sampling data 2. EPA/state published emission factors
CO	CEMS/PEM data	1. Stack sampling data 2. EPA/state published emission factors
CO ₂	CEMS/PEM data	1. Stack sampling data 2. Fuel analysis 3. EPA/state published emission factors
VOC ^e	Stack Sampling Data	EPA/state published emission factors
THC	CEMS/PEM data	1. Stack sampling data 2. EPA/state published emission factors
Heavy Metals	Fuel Analysis ^f	1. Stack sampling data 2. EPA/state published emission factors
Speciated Organics	Stack Sampling Data	EPA/state published emission factors
Sulfuric Acid Mist	Stack Sampling Data	EPA/state published emission factors
Flow Rate	CFRM ^g data/Stack Sampling Data	1. Stack sampling data 2. EPA/state published emission factors

^a. CEMS=Continuous Emission Monitoring System.

^b. PEMS= Predictive Emission Monitoring System.

^c. In most cases, there are several alternative emission estimation approaches.

^d. May be used when no SO₂ control device is present.

^e. There is no direct measurement method for VOC. VOC is defined by EPA as those VOCs that are photo reactive and contribute to ozone formation. There are two common ways for determining VOC. The first is to measure as many of the individual organic compounds as possible and add those that are considered VOC. The second is to measure total hydrocarbons, subtract CH₄ and ethane, and add formaldehyde. The second procedure is more of an estimate of VOC, but is considered acceptable. When using emission factors for VOC and speciated organics it should be noted that the sum of individual organic compounds may exceed the VOC emission factor due to the differences in test methods and the availability of test data for each pollutant.

^f. Preferred for oil combustion only when no particulate control device is present; otherwise use stack sampling data.

^g. CFRM = Continuous flow rate monitor.

Emissions from external combustion units can be calculated as follows:

$$E_{\text{pol}} = \text{FC} \times \text{EF}_u \times \left[1 - \left(\frac{\text{CE}}{100}\right)\right] \quad \text{Equation 9-1}$$

Where

- E_{pol} = Emissions of a particular pollutant (lb/yr)
 FC = Quantity of fuel consumed per year (“tons/yr” for coal; “10³ gal/yr” for fuel oils and LPG; “10⁶ ft³/yr” for natural gas)
 EF_u = Uncontrolled emission factor in units of pounds pollutant per quantity of fuel burned (“lb/ton” for coal; “lb/10³ gal” for fuel oils and LPG; “lb/10⁶ ft³” for natural gas)
 CE = Efficiency of the control device (%)
 100 = Factor for converting percent efficiency to fractional efficiency.

9.3 Emission Calculations from CEMS

A CEMS provides a continuous record of emissions over an extended and uninterrupted period of time. Various principles are employed to measure the concentration of pollutants in the gas stream; they are usually based on photometric measurements. Once the pollutant concentration is known, emission rates are obtained by multiplying the pollutant concentration by the volumetric stack gas flow rate. The accuracy of this method may be problematic at low pollutant concentrations.

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. 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/10³ gal, or lb/10⁶ ft³. The conversion was accomplished by multiplying the lb/MMBtu emission factor by the applicable fuel heating value. Typical fuel heating values used in the conversion calculations are listed in Table 9-3 below.

Table 9-3. 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 9-4 through 9-26 below. Emissions of some pollutants (especially NO_x and CO) are 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 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, the emissions can still be estimated by using the uncontrolled emission factor and the efficiency of the control device.

9.4 Information Resources

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

9.5 Example Problem

A 12 MMBtu/hr commercial boiler is fueled with No 2. distillate oil. FGR is used to control NO_x emissions from the boiler. The estimated NO_x reduction efficiency of the FGR system is 60%. Approximately 18,200 gallons of fuel oil was combusted in the boiler during the year. The distillate oil has a maximum sulfur content of 0.05%. Calculate the emissions of NO_x as well as the uncontrolled VOC and SO₂ emissions from the boiler.

- a. Calculate the emissions of NO_x (the only controlled pollutant).

$$E_{\text{pol}} = \text{FC} \times \text{EF}_u \times \left[1 - \left(\frac{\text{CE}}{100}\right)\right]$$

$$E_{\text{NO}_x} = (18.2 \times 10^3 \text{ gal/yr}) \times 20 \text{ lb}/10^3 \text{ gal} \times \left[1 - \left(\frac{60}{100}\right)\right]$$

$$E_{\text{NO}_x} = \mathbf{145.60 \text{ lb/yr.}}$$

- b. Calculate emissions of the uncontrolled pollutants.

$$E_{\text{pol}} = \text{FC} \times \text{EF}_u$$

Pollutant	Fuel Consumed (10 ³ gal/yr)		Emission Factor (lb/10 ³ gal)		Emissions (lb/yr)
Criteria Pollutants					
VOC	18.2	x	0.34	=	6.2
CO	18.2	x	5	=	91
SO _x	18.2	x	142(0.05)	=	129.2
HAPs					
Beryllium	18.2	x	4.2 x 10 ⁻⁴	=	7.6 x 10 ⁻³

Table 9-4. Criteria Pollutant Emission Factors for Uncontrolled Bituminous and Subbituminous Coal Combustion

Firing Configuration	SCC ^a	Emission Factor (lb/ton)						
		CO	SO _x ^b	VOC ^c	NO _x ^h	PM ^{d,e}	PM ₁₀ ^{d,e}	PM _{2.5} ^{d,e}
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	22 (12)	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	15 (8.4)	10A	2.3A	0.6A
Pulverized coal, wet bottom, wall fired	1-01-002-01/21 1-02-002-01/21 1-03-002-05/21	0.5	38S (35S)	0.04	31 (24)	7A	2.6A	1.48A
Pulverized coal, dry bottom, cell burner fired	1-01-002-15/35	0.5	38S (35S)	ND	31/14	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	33 (17)	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	11 (8.8)	66	13.2	4.6
Overfeed Stoker ^f	1-01-002-05/25 1-02-002-05/25 1-03-002-07/25	6	38S (35S)	0.05	7.5	16	6	2.2
Underfeed stoker	1-02-002-06 1-03-002-08	11	31S	1.3	9.5	15	6.2	3.8
Hand-fed units	1-03-002-14	275	31S	10	9.1	15	6.2	ND
Fluidized bed combustor, circulating bed	1-01-002-18 1-02-002-18 1-03-002-18	18	C ^g	0.05	5.0	17	12.4	ND
Fluidized bed combustor, bubbling bed	1-01-002-17 1-02-002-17 1-03-002-17	18	C ^g	0.05	15.2	17	12.4	ND

Note: ND = No Data.

^a SCC = Source Classification Code (See Appendix C).

^b 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.

^c VOC values are based on the emission factors for Total Nonmethane Organic Compounds (TNMOC).

^d Emission factors are for filterable PM (i.e., particulate collected on, or prior to, the filter of an EPA Method 5 [or equivalent] sampling train).

^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.

^f Includes traveling grate, vibrating grate, and chain grate stokers.

^g 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 $\text{lb SO}_x/\text{ton coal} = 39.6(S)(\text{Ca}/S) - 1.9$. 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.

^h Emission Factors with without parentheses are for conventional burners and emission factors in parentheses are for LNBs.

Table 9-5. PM Emission Factors for Controlled Bituminous and Subbituminous Coal Combustion

Firing Configuration	Emission Factor (lb/ton) ^a											
	Multiple Cyclone			Scrubber			ESP			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	1.2A	0.30A	0.05A	0.7A	0.46A	0.3A	0.07A	0.04A	0.021A	0.02A	0.02A	0.01A
Pulverized coal, wet bottom	1.4A	1.3A	1.0A	ND	ND	ND	0.054A	0.052A	0.041A	ND	ND	ND
Cyclone Furnace	ND	ND	ND	0.13A	0.011A	0.10A	0.012A	0.010A	0.006A	ND	ND	ND
Spreader Stoker	18.8 (10.0) ^b	16.2 (8.6) ^b	1.66 (3.2) ^b	ND	ND	ND	0.50	0.46	0.32	0.10	0.086	0.030
Overfeed Stoker	5.0	4.6	3.9	ND	ND	ND	ND	ND	ND	ND	ND	ND
Underfeed Stoker	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Note: Data from AP-42, Section 1.1, Figures 1.1-1 to 1.1-5; Emission factors are for filterable PM [i.e., particulate collected on or prior to the filter of an EPA Method 5 (or equivalent) sampling train]; ND = No Data.

a. 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 factors are calculated by multiplying the weight percent ash in the coal by the numerical value preceding A.

b. The first number is for systems with flyash reinjection and the number in parentheses is for systems without flyash reinjection.

Table 9-6. Emission Factors for Metals, POM, and Formaldehyde from Uncontrolled Bituminous and Subbituminous Coal Combustion

Firing Configuration	Emission Factor (lb/ton) ^a									
	Arsenic	Beryllium	Cadmium	Chromium	Pb	Manganese	Mercury	Nickel	POM	HCOH
Pulverized coal, wet bottom	1.40E-02 (1.08E-02)	2.11E-03 (1.62E-03)	1.48E-03 (1.14E-03)	3.37E-02 (2.59E-02)	1.32E-02 (1.01E-02)	4.92E-02 (3.79E-02)	4.16E-04 (3.20E-04)	2.77E-02 (2.13E-02)	ND	ND
Pulverized coal, dry bottom	1.78E-02 (1.37E-02)	2.11E-03 (1.62E-03)	1.15E-03 (8.88E-04)	3.67E-02 (2.82E-02)	1.32E-02 (1.01E-02)	4.17E-02 (3.21E-02)	4.16E-04 (3.20E-04)	3.02E-02 (2.32E-02)	5.41E-05 (4.16E-05)	ND
Pulverized coal, dry bottom, tangential	ND	ND	ND	ND	ND	ND	ND	ND	6.24E-05 (4.80E-05)	ND
Cyclone Furnace	2.99E-03 (2.30E-03)	2.11E-03 (1.62E-03)	7.28E-04 (5.60E-04)	2.23E-02 (1.71E-02)	1.32E-02 (1.01E-02)	1.99E-02 (1.53E-02)	4.16E-04 (3.20E-04)	1.90E-02 (1.46E-02)	ND	ND
Spreader Stoker	1.05E-02 (8.06E-03)	ND	8.32E-04 (6.40E-04)	3.27E-02 (2.51E-02)	1.32E-02 (1.01E-02)	ND	ND	ND	ND	5.75E-03 (4.42E-03)
Overfeed Stoker, traveling grate	2.04E-02 (1.57E-02)	ND	1.63E-03 (1.25E-03)	ND	1.32E-02 (1.01E-02)	ND	ND	ND	ND	3.64E-03 (2.80E-03)
Underfeed Stoker	2.05E-01 (1.58E-01)	ND	1.20E-03 (9.20E-03)	ND	ND	ND	ND	ND	5.10E-03 (3.92E-03)	ND

Note: Emission factors without parenthesis are for combustion of bituminous coal while values in parenthesis are for subbituminous coal; ND = No Data.

^a Emission factors listed in AP-42 were converted from "lb/MMBtu" to "lb/ton" by multiplying by the applicable fuel heating value listed in Table 9-3.

Table 9-7. HAP Emission Factors for Controlled Bituminous and Subbituminous Coal Combustion

Pollutant	Emission Factor (lb/ton) ^a
Acetaldehyde	5.7E-04 ^a
Acetophenone	1.5E-05 ^a
Acrolein	2.9E-04 ^a
Antimony	1.8E-05 ^b
Arsenic	4.1E-04 ^b
Benzene	1.3E-03 ^a
Benzyl chloride	7.0E-04 ^a
Beryllium	2.1E-05 ^b
Bis(2-ethylhexyl)phthalate (DEHP)	7.3E-05 ^a
Bromoform	3.9E-05 ^a
Carbon disulfide	1.3E-04 ^a
Cadmium	5.1E-05 ^b
2-Chloroacetophenone	7.0E-06 ^a
Chlorobenzene	2.2E-06 ^a
Chloroform	5.9E-05 ^a
Chromium	2.6E-04 ^b
Chromium - Hexavalent	7.9E-05 ^b
Cobalt	1.0E-04 ^b
Cumene	5.3E-06 ^a
Cyanide	2.5E-03 ^a
2,4-Dinitrotoluene	2.8E-07 ^a
Dimethyl sulfate	4.8E-05 ^a
Ethyl benzene	9.4E-05 ^a
Ethyl chloride	4.2E-05 ^a
Ethylene dichloride	4.0E-05 ^a
Ethylene dibromide	1.2E-06 ^a
Formaldehyde	2.4E-04 ^a
Hexane	6.7E-05 ^a
Isophorone	5.8E-04 ^a
Pb	4.2E-04 ^b
Magnesium	1.1E-02 ^b
Manganese	4.9E-04 ^b
Mercury	8.3E-05 ^b
Methyl bromide	1.6E-04 ^a
Methyl chloride	5.3E-04 ^a
Methyl ethyl ketone	3.9E-04 ^a
Methyl hydrazine	1.7E-04 ^a
Methyl methacrylate	2.0E-05 ^a
Methyl tert butyl ether	3.5E-05 ^a
Methylene chloride	2.9E-04 ^a
Nickel	2.8E-05 ^b
Phenol	1.6E-05 ^a
Propionaldehyde	3.8E-04 ^a
Tetrachloroethylene	4.3E-05 ^a
Toluene	2.4E-04 ^a
1,1,1-Trichloroethane	2.0E-05 ^a

Table 9-7. [Con't] HAP Emission Factors for Controlled Bituminous and Subbituminous Coal Combustion

Pollutant	Emission Factor (lb/ton) ^a
Selenium	1.3E-03 ^b
Styrene	2.5E-05 ^a
Xylenes	3.7E-05 ^a
Vinyl acetate	7.6E-06 ^a

^a Emission factors are applicable to boilers using both wet limestone scrubbers or spray dryers and an ESP or fabric filter (FF). In addition, the factors apply to boilers using only an ESP or FF.

^b Emission factors apply to boilers utilizing either venturi scrubbers, spray dryer absorbers, or wet limestone scrubbers with an ESP or FF.

^c Data from AP-24, Section 1.1

Table 9-8 Emission Factors for Dioxins and Furans from Controlled Bituminous and Subbituminous Coal Combustion

Pollutant	Emission Factor (lb/ton)	
	FGD-SDA with FF ^a	ESP or FF ^b
2,3,7,8-Tetrachlorodibenzo-p-dioxin	No Data	1.43E-11
Dibenzofurans	2.01E-07	1.09E-09

^a Factors apply to boilers equipped with both flue gas desulphurization spray dryer adsorber (FGD-SDA) and a FF.

^b Factors apply to boilers equipped with an ESP or a FF.

Table 9-9. Emission Factors for Hydrogen Chloride and Hydrogen Fluoride from Bituminous and Subbituminous Coal Combustion

Firing Configuration	Emission Factor (lb/ton) ^a	
	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 apply to both controlled and uncontrolled sources.

Table 9-10. Emission Factors for POM from Controlled Bituminous and Subbituminous Coal Combustion

Firing Configuration	Control Device	Emission Factor ^a (lb/ton) ^b
Pulverized coal, dry bottom, wall fired	Wet Scrubber	2.22E-04 (1.71E-04)
	Multiple Cyclones and ESP	4.81E-04 (3.70E-04)
Pulverized coal, wet bottom	Wet Scrubber	1.47E-02 (1.13E-02)
	ESP	2.31E-04 (1.78E-04)
Pulverized coal, dry bottom, tangentially fired	Multiple Cyclones and ESP	5.72E-05 (4.40E-05)
Cyclone furnace	Wet Scrubber	4.21E-04 (3.24E-04)
	ESP	5.30E-05 (4.08E-05)
Overfeed Stoker	Multiple Cyclones	7.64E-06 (5.88E-06)

^a. Emission factors values not in parenthesis are for bituminous coal and values in parenthesis are for subbituminous coal.

^b. Emission factors listed in FIRE were converted from "lb/MMBtu" to "lb/ton" by multiplying by the applicable fuel heating value listed in Table 9-3.

Table 9-11. Criteria Pollutant Emission Factors for Uncontrolled Anthracite Coal Combustion

Firing Configuration	SCC ^a	Emission Factor (lb/ton)						
		CO	NO _x	SO _x ^b	VOC	PM ^c	PM ₁₀ ^c	PM _{2.5} ^c
Stoker-fired	1-01-001-02 1-02-001-04 1-03-001-02	0.6	9.0	39S	ND	0.8A	0.08A	0.08A
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	ND	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	ND	ND	ND	ND	10.0	ND	ND

Note: ND = No Data.

^a. SCC = Source Classification Code (See Appendix C).

^b. S is the weight percent 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.

^c. A is a weight percent ash content of coal as fired. Emission factor is calculated by multiplying the weight percent ash in the coal by the numerical value preceding A.

Table 9-12. PM Emissions from Controlled Pulverized Coal Boilers Burning Anthracite Coal

Control Device	Emission Factor (lb/ton) ^a		
	PM	PM ₁₀	PM _{2.5}
Multiple Cyclones	2A	1.10A	0.48A
Baghouse	0.02A	0.013A	0.006A

^a A is weight percent ash content of the coal as fired. The emission factor is 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 9-13. HAP Emission Factors for Uncontrolled Anthracite Coal Combustion

Pollutant	Emission Factors per Type of Firing Configuration (lb/ton)			
	Stoker-fired	Pulverized Coal	Residential Space Heaters	Hand-fired
<i>Inorganic HAPs</i>				
Arsenic	1.9E-04	ND	ND	ND
Beryllium	3.1E-04	ND	ND	ND
Cadmium	7.1E-05	ND	ND	ND
Chromium	2.8E-02	ND	ND	ND
Pb	8.9E-03	8.9E-03	ND	8.9E-03
Manganese	3.6E-03	ND	ND	ND
Mercury	1.3E-04	ND	ND	ND
Nickel	2.6E-02	ND	ND	ND
Selenium	1.3E-03	ND	ND	ND
<i>Organic HAPs</i>				
Biphenyl	2.5E-02	ND	ND	ND
Fluoranthrene	ND	ND	1.7E-04	ND
Naphthalene	1.3E-01	ND	2.2E-04	ND
Phenanthrene	6.8E-03	ND	2.4E-04	ND
POM	ND	ND	ND	1.44E-03 ^a
2,3,7,8-TCDD ^c	ND	ND	3.2E-09	ND

Note: ND = No Data.

^a This emission factor was obtained by multiplying the "lb/MMBtu" emission factor listed in the FIRE program by the typical heating value of anthracite coal (25 MMBtu/ton).

^b 2,3,7,8-Tetrachlorodibenzo-p-dioxin.

Table 9-14. CO, SO₂, and PM Emission Factors for Uncontrolled Fuel Oil Combustion

Firing Configuration	SCC ^a	Emission Factor (lb/10 ³ gal)		
		CO	SO ₂ ^b	PM ^{c,d}
Boilers > 100 MMBtu/hr				
No. 6 oil, normal firing	1-01-004-01 1-02-004-01 1-03-004-01	5	157S	9.19(S) + 3.22
No. 6 oil, tangential firing	1-01-004-04	5	157S	9.19(S) + 3.22
No. 5 oil, normal firing	1-01-004-05 1-02-004-04	5	157S	10
No. 5 oil, tangential firing	1-01-004-06	5	157S	10
No. 4 oil, normal firing	1-01-005-04 1-02-005-04	5	150S	7
No. 4 oil, tangential firing	1-01-005-05	5	150S	7
No. 2 oil fired	1-01-005-01 1-02-005-01 1-03-005-01	5	157S	2
Boilers < 100 MMBtu/hr				
No. 6 oil fired	1-02-004-02/03 1-03-004-02/03	5	157S	10
No. 5 oil fired	1-03-004-04	5	157S	9.19(S) + 3.22
No. 4 oil fired	1-03-005-04	5	150S	7
Distillate oil fired ^e	1-02-005-02/03 1-03-005-02/03	5	142S	2
Residential furnace ^f	A2104004/A2104011	5	142S	0.4

^a SCC = Source Classification Code (See Appendix C).

^b Includes both SO₂ and SO₃ (reported as SO₂). 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.

^c Each PM emission factor was derived by adding together the applicable filterable PM emission factor and the applicable condensable particulate emission factor found in Section 1.3 of AP-42.

^d 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.

^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 9-15. VOC, PM₁₀, and PM_{2.5} Emission Factors for Uncontrolled Fuel Oil Combustion

Firing Configuration	SCC	Emission Factor (lb/10 ³ gal)		
		VOC ^a	PM ₁₀ ^b	PM _{2.5} ^b
<i>Utility Boilers</i>				
No. 6, normal firing	1-01-004-01	0.76	5.9A	4.3A
No. 6, tangential firing	1-01-004-04	0.76	5.9A	4.3A
No. 5, normal firing	1-01-004-05	0.76	5.9A	4.3A
No. 5, tangential firing	1-01-004-06	0.76	5.9A	4.3A
No. 4, normal firing	1-01-005-04	0.76	5.9A	4.3A
No. 4, tangential firing	1-01-005-05	0.76	5.9A	4.3A
<i>Industrial Boilers</i>				
No. 6 oil fired	1-02-004-01/02/03	0.28	7.17A	4.67A
No. 5 oil fired	1-02-004-04	0.28	7.17A	4.67A
No. 4 oil fired	1-02-005-04	0.2	7.17A	4.67A
Distillate oil fired ^c	1-02-005-01/02/03	0.2	1.00	0.25
<i>Commercial/Institutional Boilers</i>				
No. 6 oil fired	1-03-004-01/02/03	1.13	0.59A	0.22A
No. 5 oil fired	1-03-004-04	1.13	0.59A	0.22A
No. 4 oil fired	1-03-005-04	0.34	0.59A	0.22A
Distillate oil fired ^c	1-03-005-01/02/03	0.34	1.08	0.83
Residential furnace ^d	A2104004/A2104011	0.713	ND	ND

Note: ND = No Data; SCC = Source Classification Code (See Appendix C).

^a. VOC values are for TNMOC

^b. A = ash content of the fuel:

No. 6 oil: $A = 1.12(S) + 0.37$ where S = weight percent sulfur in the oil

No. 5 oil: $A = 1.2$

No. 4 oil: $A = 0.84$

^c. Distillate oil includes both No. 1 and No. 2 fuel oils.

^d. Residential furnaces are typically considered to be units < 0.3 MMBtu/hr.

Table 9-16. NO_x Emission Factors for Fuel Oil Combustion

Firing Configuration	SCC ^a	NO _x Emission Factor (lb/10 ³ gal)
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, LNB	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, LNB	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	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 ^b	1-02-005-02/03, 1-03-005-02/03	20
Residential furnaces	A2104004/A2104011	18

^a. SCC = Source Classification Code (See Appendix C).

^b. Distillate oil includes both No. 1 and No. 2 fuel oils.

Table 9-17. HAP Emission Factors for Uncontrolled Fuel Oil Combustion (lb/10³ gal)

Pollutant	Utility Boilers			Industrial Boilers				Commercial/Institutional		
	No. 6 Oil	No. 5 Oil, Normal Firing	Distillate Oil	No. 6 Oil	No. 5 Oil	Distillate Oil	Distillate Oil	No. 6 Oil	Distillate Oil	Distillate Oil
SCCs	1-01-004-01 1-01-004-04	1-01-004-05	1-01-005-01	1-02-004-01	1-02-004-04	1-02-005-01	1-02-005-02 1-02-005-03	1-03-004-01	1-03-005-01	1-03-005-02 1-03-005-03
Antimony	5.25E-03	ND	ND	5.25E-03	ND	ND	ND	5.25E-03	ND	ND
Arsenic	1.32E-03	1.01E-03	5.6E-04	1.01E-02	ND	5.6E-04	ND	1.01E-02	5.6E-04	ND
Beryllium	2.78E-05	3.21E-05	4.2E-04	6.30E-04	ND	4.2E-04	ND	6.30E-04	4.2E-04	ND
Cadmium	3.98E-04	1.04E-04	4.2E-04	1.71E-02	ND	4.2E-04	ND	1.71E-02	4.2E-04	ND
Chromium	8.45E-04	6.06E-04	4.2E-04	1.12E-02	ND	4.2E-04	ND	1.12E-02	4.2E-04	ND
Cobalt	6.02E-03	ND	ND	1.49E-02	ND	ND	ND	1.49E-02	ND	ND
Pb	1.51E-03	2.4E-03	1.26E-03	ND	ND	1.26E-03	1.25E-03	ND	1.26E-03	1.25E-03
Manganese	3.0E-03	2.61E-03	8.4E-04	7.28E-03	ND	8.4E-04	ND	7.28E-03	8.4E-04	ND
Mercury	1.13E-04	ND	4.2E-04	2.51E-03	ND	4.2E-04	ND	2.51E-03	4.2E-04	ND
Nickel	8.45E-02	5.55E-02	4.2E-04	2.38E-01	ND	4.2E-04	ND	2.38E-01	4.2E-04	ND
Selenium	6.83E-04	5.67E-04	2.1E-03	5.70E-03	ND	2.1E-03	ND	5.70E-03	2.1E-03	ND
Benzene	2.14E-04	ND	ND	1.1E-03	ND	ND	ND	1.1E-03	2.75E-03	ND
Ethylbenzene	6.36E-05	ND	ND	ND	ND	ND	ND	ND	ND	ND
Formaldehyde	3.30E-02	7.05E-03	4.8E-02	4.25E-02	7.05E-03	4.8E-02	ND	4.25E-02	4.8E-02	ND
Naphthalene	1.13E-03	6.27E-04	4.66E-02	6.45E-02	5.04E-05	ND	ND	6.45E-02	ND	ND
POM	1.2E-03	ND	3.3E-03	1.2E-03	ND	3.3E-03	ND	1.2E-03	3.3E-03	ND
Toluene	6.20E-03	ND	ND	8.8E-03	ND	ND	ND	8.8E-03	ND	ND
o-Xylene	1.09E-04	ND	ND	ND	ND	ND	ND	ND	ND	ND
Xylene, mixed isomers	ND	ND	ND	7.5E-03	ND	ND	ND	7.5E-03	ND	ND

Note: EPA emission factors listed in units of “lb/MMBtu” were converted into units of “lb/10³ gal” by multiplying by the applicable fuel heating value listed in Table 9-3.

ND = No Data.

Table 9-18. PM Emission Factors for Controlled Residual Fuel Oil Combustion

Firing Configuration	Emission Factor (lb/10 ³ gal)								
	ESP			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 ^a (SCCs 1-01-004-01/04)	0.0093(S) + 0.0031	0.0083(S) + 0.0027	0.0045(S) + 0.0015	0.0683(S) + 0.0226	0.0672(S) + 0.0222	0.0650(S) + 0.0215	ND	ND	ND
No. 5 fuel oil fired (SCCs 1-01-004-05/06)	0.0108	0.0089	0.0048	0.0732	0.0720	0.0696	ND	ND	ND
No. 4 fuel oil fired (SCCs 1-01-005-04/05)	0.0070	0.0062	0.0034	0.0512	0.0504	0.0487	ND	ND	ND
Industrial Boilers									
No. 6 fuel oil, normal firing ^a (SCCs 1-02-004-01/02/03)	ND	ND	ND	ND	ND	ND	0.224(S) + 0.074	0.202(S) + 0.067	0.045(S) + 0.015
No. 5 fuel oil, normal firing (SCC 1-02-004-04)	ND	ND	ND	ND	ND	ND	0.240	0.216	0.048
No. 4 fuel oil, normal firing (SCC 1-02-005-04)	ND	ND	ND	ND	ND	ND	0.168	0.151	0.034

Note: Data from AP-42 Figures 1.3-1 and 1.3-2; ND = No Data.

^a. 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 9-19. HAP Emission Factors for Controlled Fuel Oil Combustion (lb/10³ gal)

Pollutant	Utility Boilers				Industrial Boilers
	No. 6 Fuel Oil – Normal Firing, Controlled with FGR	No. 6 Fuel Oil - Tangential Firing, Controlled with FGR	No. 5 Fuel Oil – Normal Firing, Controlled with FGR	No. 5 Fuel Oil - Normal Firing, Controlled with Multiple Cyclones	No. 6 Fuel Oil, Controlled with LNB and FGR
Cadmium	ND	ND	4.31E-04	ND	ND
Chromium	9.63E-04	ND	1.51E-03	1.51E-03	ND
Pb	ND	ND	ND	ND	ND
Manganese	3.84E-03	ND	8.08E-03	8.08E-03	ND
Nickel	4.52E-02	ND	3.3E-02	3.30E-02	ND
Ethylbenzene	ND	ND	ND	ND	1.4E-02
Formaldehyde	ND	ND	5.16E-02	5.17E-02	ND
Naphthalene	4.01E-04	ND	7.18E-03	7.18E-03	ND
POM	ND	8.69E-04	1.41E-02	1.41E-02	ND

Note: EPA emission factors listed in units of “lb/MMBtu” were converted into units of “lb/10³ gal” by multiplying by the typical heating value of residual fuel (150 MMBtu/10³ gal).

ND = No Data.

Table 9-20. NO_x and CO Emission Factors from Natural Gas Combustion

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

^a. SCC = Source Classification Code (See Appendix C).

^b. 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.

^c. 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.

Table 9-21. SO₂, VOC, and PM Emission Factors from Natural Gas Combustion

Pollutant	Emission Factor (lb/10 ⁶ scf)
SO ₂ ^a	0.6
VOC	5.5
PM ^b	7.6

^a. Based on 100% conversion of fuel sulfur to SO₂ and a fuel sulfur content of 2,000 grains/10⁶ scf. If the site-specific sulfur content is known, the SO_x emission factor in this table may be adjusted by multiplying it by the ratio of the site-specific sulfur content (grains/10⁶ scf) to 2,000 grains/10⁶ scf.

^b. Combination of both filterable and condensable PM. All PM is assumed to be less than 1.0 micrometer in diameter (i.e., the emission factor applies to Total PM, PM₁₀, and PM_{2.5}).

Table 9-22. HAP Emission Factors from Natural Gas Combustion

Pollutant	Emission Factor (lb/10 ⁶ scf)
<i>Inorganic HAPs</i>	
Arsenic	2.0E-04
Beryllium	1.2E-05
Cadmium	1.1E-03
Chromium	1.4E-03
Cobalt	8.4E-05
Pb	5.0E-04
Manganese	3.8E-04
Mercury	2.6E-04
Nickel	2.1E-03
Selenium	2.4E-05
<i>Organic HAPs</i>	
Benzene	2.1E-03
Dichlorobenzene	1.2E-03
Formaldehyde	7.5E-02
Hexane	1.8
Naphthalene	6.1E-04
Polycyclic Organic Matter (POM)	8.8E-05
Toluene	3.4E-03

Table 9-23. Criteria Pollutant Emission Factors for Uncontrolled Liquid Petroleum Gas Combustion

Pollutant	Butane Emission Factor (lb/10 ³ gal)		Propane Emission Factor (lb/10 ³ gal)	
	Industrial Boilers ^a	Commercial Boilers ^b	Industrial Boilers ^a	Commercial Boilers ^b
SCC	1-02-010-01	1-03-010-01	1-02-010-02	1-03-010-02
PM / PM ₁₀ ^c	0.6	0.5	0.6	0.4
SO _x ^d	2.2	2.2	1.4	1.4
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. Heat input capacities generally between 10 and 100 million Btu per hour (10 to 100 MMBtu/hr).

^b. Heat input capacities generally between 0.3 and 10 million Btu per hour (0.3 to < 10 MMBtu/hr).

^c. Based on filterable PM. All PM is assumed to be less than 10 μm in size (i.e., PM = PM10).

^d. Based on an average of emission factors published by DOE (Reference 9).

Table 9-24. Criteria Pollutant Emission Factors for Uncontrolled Waste Oil Combustion

Pollutant	Emission Factor (lb/10 ³ gal)		
	Small Boilers	Space Heaters, Vaporizing Burner	Space Heaters, Atomizing Burner
SCCs ^a	1-03-013-02	1-05-001-14, 1-05-002-14	1-05-001-13, 1-05-002-13
CO	5	1.7	2.1
NO _x	19	11	16
SO _x ^b	147S	100S	107S
PM ^c	64A	2.8A	66A
PM ₁₀ ^c	51A	ND	57A
VOC ^d	1.0	1.0	1.0

ND = No Data.

^a SCC: Source Classification Codes (See Appendix C).

^b S is the weight % sulfur content of the fuel. For example, if the fuel contains 0.5% sulfur, S = 0.5. The emission factor is calculated by multiplying the weight percent sulfur in the fuel by the numerical value preceding S.

^c A is the weight % ash content of the fuel. For example, if the fuel contains 0.1% ash, A = 0.1. The emission factor is calculated by multiplying the weight percent ash in the fuel by the numerical value preceding A.

^d VOC emission factor is based on the value for TOC.

Table 9-25. HAP Emission Factors for Uncontrolled Waste Oil Combustion

Pollutant	Emission Factor (lb/10 ³ gal)		
	Small Boilers	Space Heaters, Vaporizing Burner	Space Heaters, Atomizing Burner
SCCs ^a	1-03-013-02	1-05-001-14, 1-05-002-14	1-05-001-13, 1-05-002-13
<i>Inorganic HAPs</i>			
Antimony	BDL	3.4E-04	4.5E-04
Arsenic	1.1E-01	2.5E-03	6.0E-02
Beryllium	BDL	BDL	1.8E-03
Cadmium	9.3E-03	1.5E-04	1.2E-02
Chromium	2.0E-02	1.9E-01	1.8E-01
Cobalt	2.1E-04	5.7E-03	5.2E-03
Hydrogen Chloride (HCl)	66Cl ^b	ND	ND
Pb ^c	55L	0.41L	50L
Manganese	6.8E-02	2.2E-03	5.0E-02
Nickel	1.1E-02	5.0E-02	1.6E-01
Selenium	BDL	BDL	BDL
Phosphorous	ND	3.6E-02	ND
<i>Organic HAPs</i>			
Bis(2-ethylhexyl)phthalate	ND	2.2E-03	ND
Dibutylphthalate	ND	ND	3.4E-05
Dichlorobenzene	ND	8.0E-07	ND
Naphthalene	ND	1.3E-02	9.2E-05
Phenol	ND	2.4E-03	2.8E-05
POM ^d	ND	2.6E-02	1.1E-04

Note: ND = No Data. BDL = Below Detection Limit.

^a SCC: Source Classification Codes (See Appendix C).

^b 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.

^c L = weight % Pb in the fuel. The emission factor is calculated by multiplying the weight percent Pb in the fuel by the numerical value preceding L.

^d The emission factor for POM was derived by adding together the emission factors for the following pollutants: phenanthrene/anthracene, pyrene, benz(a)anthracene/chrysene, and benzo(a)pyrene.

9.6 References

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U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources* (AP-42), Section 1.11, "Waste Oil Conversion," October 1996.

U.S. Environmental Protection Agency, Factor Information Retrieval System (WebFIRE), <http://cfpub.epa.gov/oarweb/index.cfm?action=fire.main>, December 2005.

U.S. Department of Energy, *Technical Support Document: Energy Efficiency Standards for Consumer Products: Residential Water Heaters*, Appendix K-2, December 2000.

10 FIRE FIGHTER TRAINING

10.1 Introduction

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 DoD Louis F. Garfield Fire Training Academy 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. JP-8 is also used as fuel for aircraft and vehicle 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. Criteria pollutant emissions from training fires include PM, CO, NO_x, SO₂, and VOC. Emission indices for these pollutants are dependent upon the type of fuel burned and are estimated based on measured emissions from the uncontrolled burning of each fuel.

10.2 Emission Calculations

Emissions from fire fighter training operations using propane and/or JP-8 fuel can be calculated as follows:

$$E_{\text{pol}} = QF \times EF \quad \text{Equation 10-1}$$

Where

$$\begin{aligned} E_{\text{pol}} &= \text{Emissions of a particular pollutant (lb/yr)} \\ QF &= \text{Quantity of fuel burned (gal/yr)} \\ EF &= \text{Emission factor (lb/gal)}. \end{aligned}$$

Emission factors for fire training using LPG and JP-8 are provided in Table 10-1.

Table 10-1. Emission Factors for Fire Fighter Training

Pollutant	Liquid Propane Fuel Emission Factors (lb/gal) ^a	JP-8 Fuel Emission Factors (lb/gal) ^a
Criteria Pollutants		
CO	0.0154	0.2961
NO _x	0.0557	0.0100
PM ^b	0.0095	0.1939
VOC ^c	0.0240	0.5845
SO ₂ ^d	0.00002	0.0068
HAPs^e		
Formaldehyde	0.0007	0.0070

^a. Except for SO₂, which is based on the FAA, Air Quality Procedures For Civilian Airports and Air Force Bases, April, 1997.

^b. Based on sampling results for total PM.

^c. Based on sampling results for THC.

^d. Based on FAA emissions index.

^e. Formaldehyde was the only HAP sampled for.

10.3 Information Resources

The quantity of each fuel type burned during fire fighter training operations should be available from the base fire department. For Goodfellow AFB, this information can be obtained from the DoD Louis F. Garfield Fire Training Academy.

10.4 Example Problem

Approximately 24,000 gallons of liquid propane and approximately 800 gallons of JP-8 were used during the year for two fire training pits. Calculate the emission of both criteria pollutants and HAPs.

- a. Calculate the emissions associated with the propane fires:

$$E_{\text{pol}} = \text{QF} \times \text{EF}$$

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
SO ₂	24,000	x	0.00002	=	0.48
Formaldehyde	24,000	x	0.0007	=	17

- b. Calculate the emissions associated with the JP-8 fires:

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
SO ₂	800	x	.0068	=	5.44
Formaldehyde	800	x	0.0070	=	6

- c. 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
SO ₂	0.48	+	5.44	=	5.92
Formaldehyde	17	+	6	=	23

10.5 References

Federal Aviation Agency, *Air Quality Procedures for Civilian Airports and Air Force bases*, Appendix H: Stationary Emission Methodology, June 2005.

U.S. Air Force, *Environmental Quality Management, Emissions Testing of Fire Fighter Training Facility - Goodfellow AFB TX*, January 1998.

11 FUEL CELL MAINTENANCE

11.1 Introduction

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 steps.

- The fuel cell is defueled and the fuel loaded into bowsers and/or approved containers.
- The fuel cell is purged with either fresh air or an approved fluid. (Note: Fluid purging is usually only performed at Depots.)
- Oxygen and lower explosive limit (LEL) readings are taken and the tank is repurged if oxygen/LEL levels are not within acceptable limits.
- The explosion suppression foam (if applicable) is removed from the fuel cell.
- The fuel cell is depuddled to remove any remaining liquid fuel.
- The fuel cell is purged again with fresh air.
- The fuel cell is entered and maintenance performed.

Note that mechanical ventilation is performed constantly during all fuel cell entries.

The emissions of concern from fuel cell maintenance include VOCs and HAP constituents found in the fuel. 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 or tank trucks, air purging of the fuel vapors from the tank, and removal and subsequent air 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 (T.O.) 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

The following equations can be used for estimating VOC and HAP emissions associated with maintenance of fuel cells:

In order to dilute flammable vapor concentrations below safety limits, purging of the fuel cells is necessary to remove VOC vapors from either an empty fuel cell, or from the vapor space of a partially filled cell.

1. Empty fuel cells may be purged using a displacement gas to remove accumulated vapors. VOC emissions are estimated by calculating the amount of VOC removed during the purge assuming that the initial VOC concentration of an empty vessel's vapor space before the purge is equivalent to vapor in equilibrium with the removed liquid. The following equation is used to calculate the VOC emissions generated during the purge of a fuel cell:

$$E_{voc} = V \times (C_i - C_f)$$

Equation 11-1

Where,

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

V = vessel volume (ft³)

C_f = final VOC concentration in vessel (lb/ft³)

C_i = initial VOC concentration in vessel (lb/ft³).

This equation does not account for evaporation of any residual liquid in the vessel, and no free liquid, however it is assumed the vapor in the vessel is initially saturated.

Before E_{voc} can be determined, the initial VOC concentration, C_i , in the fuel cell is calculated using Equation 11-2.

$$C_i = M_v P_{VA} / R T_{LA}$$

Equation 11-2

Where,

M_v = vapor molecular weight

P_{VA} = vapor pressure at the daily average liquid surface temperature in psia

R = ideal gas constant (10.731 psia*ft³/lb-mole*R)

T_{LA} = daily average liquid surface temperature °R (°F+460).

The final VOC concentration, C_f , is a function of the number of purge gas volumes used. This relation can be expressed as a power law:

$$\frac{C_f}{C_i} = x^n$$

Where:

n = the number of purge gas volumes used

x = the fractional dilution per volume change, assuming perfect mixing, the fractional dilution per volume change has been shown to be 37 percent.¹⁷

C_f = final concentration in vessel

C_i = initial concentration in vessel.

¹⁷ U.S. Environmental Protection Agency. *Control of Volatile Organic Compound Emissions from Batch Processes*, EPA-453/R-93-017, November 1993.

The equation for determining final VOC concentration can now be expressed as:

$$C_f = C_i * (0.37)^n$$

Equation 11-3

For maintenance operations that are conducted using continual purge (i.e., exhaust fans operating during the entire maintenance process), assume C_f is equal to 0.

The following steps show how equation 11-6 for estimating VOC purge emissions was derived:

$$\frac{d(VCa)}{dt} = -qCa$$

Where:

V = vessel volume

Ca = concentration of VOC species

q = volumetric purge rate

t = time

if: $q = 1 \text{ ft}^3/\text{min}$ and $V = 1 \text{ ft}^3$, then the equation reduces to:

$$\frac{dCa}{Ca} = -dt$$

By integrating and setting the following boundary limits:

t = 0 Ca = Ci (Ci = initial concentration in vessel)

t = 1 Ca = Cf, (Cf = final concentration in vessel)

The equation reduces to $\ln(C_f/C_i) = -1$, therefore, $C_f = 0.37C_i$

2. Calculate VOC emissions associated with the air drying of the fire-suppressant foam as follows:

$$E_{\text{VOC(foam)}} = [\text{WFB}_{(\text{sat})} - \text{WFB}_{(\text{dried})}] \times \text{NFB} \times \text{NFC}_{(\text{foam})} \quad \text{Equation 11-4}$$

Where,

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

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

$\text{WFB}_{(\text{dried})}$ = 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 per fuel cell (blocks/cell)

$\text{NFC}_{(\text{foam})}$ = Number of fuel cells from which foam blocks were removed during the year (cells/yr).

3. Calculate HAP emissions associated with evaporative losses from fuel cell purging or the air drying of the fire-suppressant foam as follows:

$$E_{\text{HAP}} = E_{\text{VOC}} \times \left(\frac{\text{VWP}_{\text{HAP}}}{100} \right) \quad \text{Equation 11-5}$$

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 to convert weight percent to weight fraction.

Both vapor-phase and liquid-phase HAP speciations of JP-8 can be found in the *Fuel Storage* chapter (Chapter 13) of this guide.

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 fire-suppressant 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. Calculate the annual VOC and organic HAP emissions associated with the maintenance of the C-17 fuel cells.

Calculate VOC emissions from the outboard fuel cells:

1. Determine initial concentration of VOC using Equation 11-2. Vapor molecular weight and vapor pressure at the daily average liquid surface temperature is found in Table 14-2.

$$C_i = \frac{130 \frac{\text{lb}}{\text{lb-mole}} * 0.011 \text{ psi}}{\frac{10.731 \text{ psi ft}^3}{\text{lb mol R}} * 530^\circ \text{ R}}$$

$$C_i = \frac{1.43 \frac{\text{lb}}{\text{lb-mol}} \text{ psi ft}^3}{\left(\frac{5,687.43 \text{ psi ft}^3}{\text{lb mol}} \right)}$$

$$C_i = 2.51 \times 10^{-4} \frac{\text{lb}}{\text{ft}^3}$$

2. Determine C_f by using Equation 11-3.

$$C_f = 2.51 \times 10^{-4} \frac{\text{lb}}{\text{ft}^3} * (0.37)^2$$

$$C_f = 3.43 \times 10^{-5} \frac{\text{lb}}{\text{ft}^3}$$

3. Calculate VOC emissions by subtracting the final VOC concentration from the initial concentration and multiplying by the capacity of the outboard cells. This step will need to be repeated in order to account for the emissions from the inboard cells. Note in the following equation, 0.134 ft³/ gal is used to convert gallons to cubic feet.

$$E_{\text{voc}} = V * (C_i - C_f)$$

$$E_{\text{voc}} = 5,637 \text{ gal} * 0.134 \frac{\text{ft}^3}{\text{gal}} * (2.51 \times 10^{-4} \frac{\text{lb}}{\text{ft}^3} - 3.43 \times 10^{-5} \frac{\text{lb}}{\text{ft}^3})$$

$$E_{\text{voc}} = 0.164 \text{ lb per tank}$$

Multiply by the number of cells since each are of equal capacity (e.g., 43 5,637 gal cells).

$$E_{\text{voc}} = (0.164 \text{ lb}) * 43$$

$$E_{\text{voc}} = 7.052 \text{ lb (outboard fuel cells)}$$

4. Calculate VOC emissions from the inboard fuel cells by repeating Step 3 using the fuel capacity for inboard tanks (7,857 gal). The total VOC emissions associated with the purging of the C-17 fuel cells.

$$\text{Total } E_{\text{VOC(purge)}} = 7.05 \text{ lb} + 11.18 \text{ lb}$$

$$\text{Total } E_{\text{VOC(purge)}} = \mathbf{18.23 \text{ lb.}}$$

Calculate the organic HAP emissions using the vapor-phase speciation found in Chapter 13 of this document.

11.5 References

U.S. Air Force, *Inspection and Repair of Aircraft Integral Tanks and Fuel Cells*, Technical Order 1-1-3, 31 August 2006 (Change 1 – 1 Feb 2007).

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

U.S. Environmental Protection Agency. *Control of Volatile Organic Compound Emissions from Batch Processes*, EPA-453/R-93-017, November 1993.

12 FUEL SPILLS

12.1 Introduction

Fuel spills most often occur during fuel transfer activities. When spills occur, most of the fuel is recovered during the clean-up effort. The quantity which is not recovered is assumed to evaporate into the atmosphere. The emissions of concern from fuel spills include VOCs and organic HAPs.

12.2 Emission Calculations

VOC Emissions from fuel spills are calculated as follows:

$$E_{\text{VOC}} = (QS - QR) \times D \quad \text{Equation 12-1}$$

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 6.67 for JP-8, 7.28 for diesel, and 6.11 for gasoline. Refer to the MSDS for the product being used on your facility for specifics.]

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.

$$E_{\text{HAP}} = E_{\text{VOC}} \times \left(\frac{\text{LWP}_{\text{HAP}}}{100} \right) \quad \text{Equation 12-2}$$

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, diesel fuels, and gasoline are found in Chapter 13, *Fuel Storage*.

12.3 Information Resources

Information pertaining to fuel spills (e.g., type and quantity of fuel spilled, quantity of fuel recovered) are usually kept by the base Environmental Management (or the CEV) 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

Approximately 625 gallons of JP-8 were spilled during the year and approximately 450 gallons were recovered. The specific gravity for JP-8 is 6.67lb/gal. Calculate the VOC and the organic HAP emissions.

a. Calculate VOC emissions.

$$\begin{aligned} E_{\text{VOC}} &= (QS - QR) \times D \\ E_{\text{VOC}} &= (625 \text{ gal/yr} - 450 \text{ gal/yr}) \times 6.67 \text{ lb/gal} \\ E_{\text{VOC}} &= \mathbf{1,167.25 \text{ lb/yr.}} \end{aligned}$$

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.

$$\begin{aligned} E_{\text{HAP}} &= E_{\text{VOC}} \times \left(\frac{\text{LWP}_{\text{HAP}}}{100} \right) \\ E_{\text{benzene}} &= 1,167.25 \text{ lb/yr} \times \left(\frac{0.033}{100} \right) \\ E_{\text{benzene}} &= \mathbf{3.85 \times 10^{-1} \text{ lb/yr}} \\ E_{\text{cumene}} &= 1,167.25 \text{ lb/yr} \times \left(\frac{0.179}{100} \right) \\ E_{\text{cumene}} &= \mathbf{2.09 \text{ lb/yr}} \\ E_{\text{ethylbenzene}} &= 1,167.25 \text{ lb/yr} \times \left(\frac{0.157}{100} \right) \\ E_{\text{ethylbenzene}} &= \mathbf{1.83 \text{ lb/yr}} \\ E_{\text{naphthalene}} &= 1,167.25 \text{ lb/yr} \times \left(\frac{0.264}{100} \right) \\ E_{\text{naphthalene}} &= \mathbf{3.08 \text{ lb/yr}} \\ E_{\text{toluene}} &= 1,167.25 \text{ lb/yr} \times \left(\frac{0.216}{100} \right) \\ E_{\text{toluene}} &= \mathbf{2.52 \text{ lb/yr}} \\ E_{\text{2,2,4-trimethylpentane}} &= 1,167.25 \text{ lb/yr} \times \left(\frac{0.001}{100} \right) \\ E_{\text{2,2,4-trimethylpentane}} &= \mathbf{1.17 \times 10^{-2} \text{ lb/yr}} \\ E_{\text{xylenes (mixed isomers)}} &= 1,167.25 \text{ lb/yr} \times \left(\frac{1.173}{100} \right) \\ E_{\text{xylenes (mixed isomers)}} &= \mathbf{13.69 \text{ lb/yr}} \end{aligned}$$

12.5 References

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

13 FUEL STORAGE

13.1 Introduction

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), Jet A (aviation 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. The three major types of storage tanks are fixed roof tanks, external floating roof tanks, and internal floating roof tanks. The following is a summary of each tank type.

13.1.1 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.

13.1.2 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, guide poles and wells, vacuum breakers, etc.

13.1.3 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:

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

For 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 recommended that the EPA’s TANKS program be used to calculate emissions from liquid storage tanks.¹⁸

¹⁸ The EPA’s TANKS program can be obtained at: <http://www.epa.gov/ttn/chief/software/tanks/>.

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:

$$E_{\text{HAP}} = E_{\text{VOC}} \times \left(\frac{\text{VWP}_{\text{HAP}}}{100} \right) \quad \text{Equation 13-1}$$

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 to weight fraction.

Table 13-1 provides a typical liquid- and vapor-phase HAP speciation of JP-8, Jet A, and diesel fuel respectively.¹⁹

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), and for the physical information required on each tank (e.g., tank type, volume, dimensions, color/shade, condition). The Civil Engineering Liquid Fuels shop should be contacted for physical tank information not available from Fuels Management.

13.4 Example Problems

a. VOC Emissions

The EPA's TANKS emissions estimation program includes an example for each type of storage tank addressed by the program. The following is an example utilizing the TANKS 4.0.9d modeling program.

Assume that a facility in Wilmington, Delaware stores kerosene jet fuel (JP-8) in a fixed dome roof tank. The tank has a diameter of 20 feet, a height of 10 feet, and dome height of 1.37 feet with a liquid capacity of 10,000 gallons. Assume an average liquid height of 4 (ft), a maximum liquid height of 4.5 feet, and a tank color of white.

Select	<i>Vertical Fixed Roof Tank</i>
Identification No:	<i>Example Storage Tank</i>
Description	Use the example problem stated above
State	<i>Delaware</i>
City	<i>Wilmington</i>
Company	<i>Example AFB</i>
Shell Height (ft):	<i>10</i>
Shell Diameter (ft):	<i>20</i>
Maximum Liquid Height (ft):	<i>4.5</i>

¹⁹ Specific tank types and related emissions components are discussed in Chapter 7.1 of AP-42, available at <http://www.epa.gov/ttn/chief/ap42/ch07/final/c07s01.pdf>.

Average Liquid Height (ft): 4
Working Volume (gal): 10,000
Turnovers per Year: (may be left blank; it will be calculated by inputting the Net Throughput)
Net Throughput (gal/yr): 25,0000
Is Tank Heated? No
Shell Color/Shade: White/White (D)
Shell Condition: Good (D)
Color/Shade: White/White (D)
Condition: Good (D)
Type: Dome
Height (ft): 1.37
Radius (ft) (Dome Roof): (accept the default value of 20)
Breather Vent Settings (accept the default values)

Nearest Major City: *Wilmington, Delaware*

Chemical Category of Liquid: *Petroleum Distillates*
Single or Multi-Component Liquid: *Single*
Chemical Name: *Jet Kerosene.*

Select the **Monthly Calculations** tab and click Run Report.

Report Type *Summary*
Time Basis *Annual*, and select **OK**.

Select **Windows/Printer** and click **OK**. Microsoft Internet Explorer will open. (It may attempt to block the content, just click **OK** and click on the Information Bar in Internet Explorer select to Allow **Blocked Content**, then click yes at the follow up warning message.)

The summary report, presented on at the end of this chapter, provides an overview of the inputs into the Tanks program and the total VOC annual emissions for Working and Breathing loss.

b. HAP Emissions

Eight above ground tanks and six underground tanks are used for the storage of JP-8 fuel. After running the EPA's TANKS 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 benzene 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	0.002	x	1,475	=	2.95

*Weight fraction equals weight percent divided by 100.

13.5 References

U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources* (AP-42), Section 7.1, "Organic Liquid Storage Tanks," November 2006.

U.S. Environmental Protection Agency, *TANKS Program* (Storage Tank Emissions Calculation Software), Version 4.0.9d, October 2005.

U.S. Air Force Institute of Environmental Safety and Occupational Health (AFIERA), *JP-8 Volatility Study*, Report # IERA-RS-BR-SR-2001-0002, March 2001.

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

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

Table 13-1. Fuels Data Used for Vapor-Phase Speciation

Compound	Liquid Molecular Weight ^a	Vapor Molecular Weight	Vapor Pressure at 60 (psia) ^a	Weight % in Liquid Diesel ^a	Weight % in Liquid Gasoline ^a	Weight % in Liquid JP-8 ^b	Weight % in Vapor JP-8 ^c	Weight % in Liquid Jet A
Benzene	78.11	N/A	1.16	0.0008	1.80	0.0034	0.20	0.00
Cumene (Isopropyl benzene)	120.2	N/A	0.051	ND	0.50	0.1111	0.29	N/A
Ethylbenzene	106.17	N/A	0.108	0.013	1.40	0.1552	0.86	0.13
Hexane	86.17	N/A	1.876	0.001	1.00	0.0088	0.84	0.01
Naphthalene	128.2	N/A	0.0024	ND	ND	0.0039	0.38	N/A
Toluene	92.13	N/A	0.309	0.032	7.00	0.1046	1.65	0.13
2,2,4-Trimethylpentane (Isooctane)	114.23	N/A	0.598	ND	4.00	0.0007	0.02	N/A
Xylenes	106.17	N/A	0.129	0.29	7.00	0.7176	4.74	0.31
Diesel Fuel ^a	188	130	0.009	N/A	N/A	N/A	N/A	N/A
Gasoline ^a (RVP 10)	92	66	5.2	N/A	N/A	N/A	N/A	N/A
JP-8	162	130	0.0244 ³	N/A	N/A	N/A	N/A	N/A

^a. Data obtained from chemical database in EPA Tanks, version 4.09d

^b. Values for weight percent in liquid phase back-calculated from values for weight percent in vapor phase in report cited in reference 3 below, using procedures consistent with Section 7.1.4 of AP-42.

^c. Vapor pressure and vapor phase weight percent values obtained from USAF IERA Report *IERA-RS-BR-SR-2001-002, JP-8 Volatility Study*, March 2001.

N/A = Not applicable.

ND = No data available.

TANKS 4.0.9d
Emissions Report - Summary Format
Tank Identification and Physical Characteristics

Identification

User Identification: Example Storage Tank
 City: Wilmington
 State: Delaware
 Company: Example AFB
 Type of Tank: Vertical Fixed Roof Tank
 Description: Assume that a facility in Delaware stores JP-8 Fuel in a fixed roof tank with a dome roof. The tank diameter is 20 feet, with a liquid capacity of 10,000 gallons.

Tank Dimensions

Shell Height (ft): 10.00
 Diameter (ft): 20.00
 Liquid Height (ft): 4.26
 Avg. Liquid Height (ft): 4.00
 Volume (gallons): 10,000.00
 Turnovers: 25.00
 Net Throughput(gal/yr): 250,000.00
 Is Tank Heated (y/n): N

Paint Characteristics

Shell Color/Shade: White/White
 Shell Condition: Good
 Roof Color/Shade: White/White
 Roof Condition: Good

Roof Characteristics

Type: Dome
 Height (ft): 1.37
 Radius (ft) (Dome Roof): 20.00

Breather Vent Settings

Vacuum Settings (psig): -0.03
 Pressure Settings (psig): 0.03

Meteorological Data used in Emissions Calculations: Wilmington, Delaware (Avg Atmospheric Pressure = 14.72 psia)

TANKS 4.0.9d
Emissions Report - Summary Format
Liquid Contents of Storage Tank

Example Storage Tank - Vertical Fixed Roof Tank
Wilmington, Delaware

Mixture Component	Mol Wt	Daily Liquid Surf. Temperature (deg F)			Liquid Bulk Temp (deg F)	Vapor Pressure (psia)			Vapor Mol. Weight	Liquid Mass Fract.	Vapor Mass Fract.	Mol. Weight	Basis for Vapor Pressure Calculations
		Avg.	Min.	Max.		Avg.	Min.	Max.					
Jet kerosene	All	55.92	51.01	60.84	54.20	0.0075	0.0063	0.0087	130.0000			162.00	Option 1: VP90 = .006 VP60 = .0085

TANKS 4.0.9d
Emissions Report - Summary Format
Individual Tank Emission Totals

Emissions Report for: Annual

Example Storage Tank - Vertical Fixed Roof Tank
Wilmington, Delaware

Components	Losses(lbs)		
	Working Loss	Breathing Loss	Total Emissions
Jet kerosene	5.79	4.60	10.39

14 FUEL TRANSFER

14.1 Introduction

Generally speaking, fuel distribution activities are area sources of air pollution: 1) fuel trucks in transit; 2) fuel delivery to out lets (Stage I) (e.g., the AAFES gas station); 3) vehicle refueling (Stage II); and 4) storage tank “breathing.”

Fuel transfer operations involve the loading of fuel into tanker trucks, aircraft, vehicles/equipment, and into bowsers. It is 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, 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 on 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.

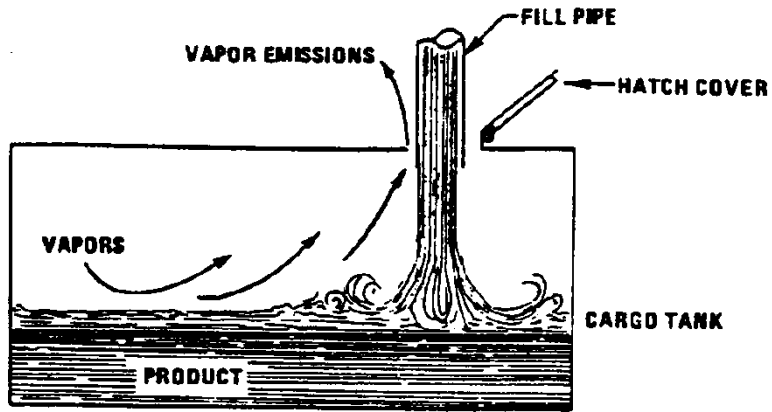


Figure 14-1. Tank Filling Using Splash Loading Method

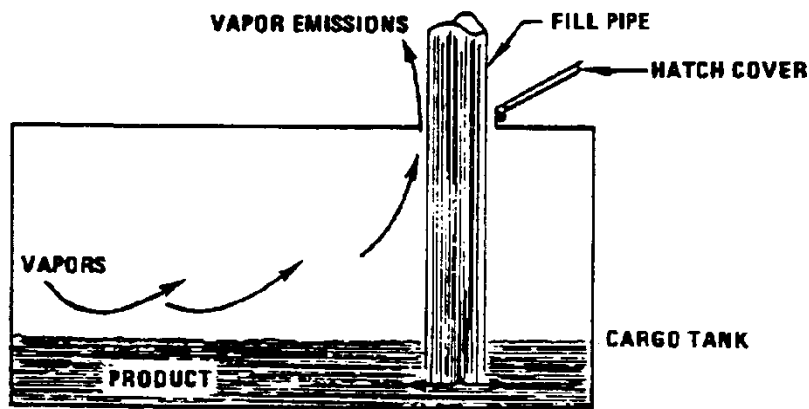


Figure 14-2. Tank Filling Using Submerged Fill Pipe Method

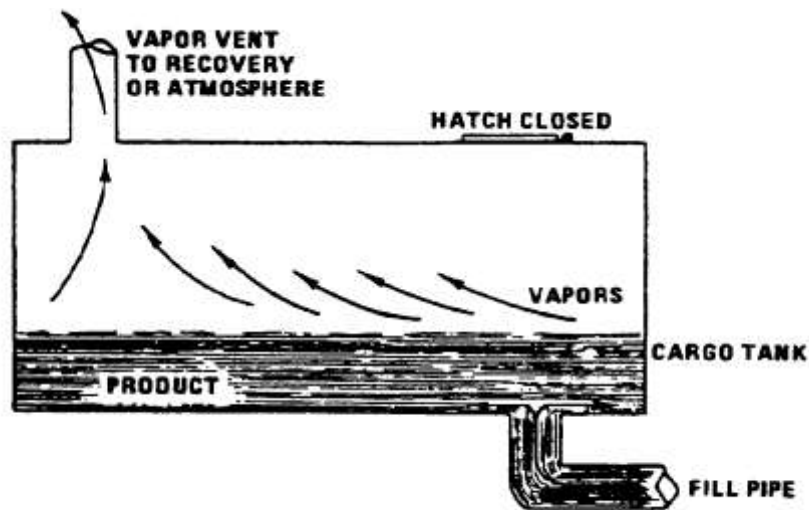


Figure 14-3. Tank Filling Using Bottom Loading Method

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.

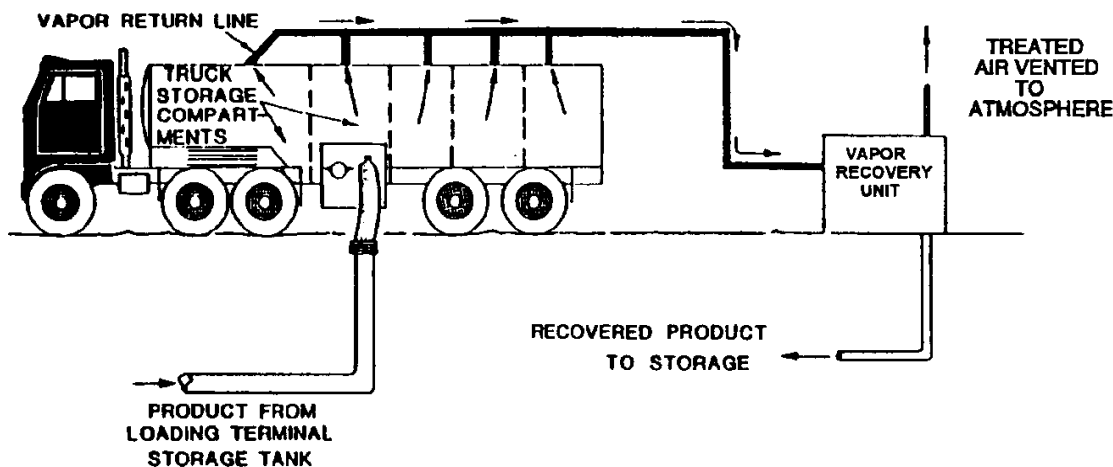


Figure 14-4. Tank Truck Loading with Vapor Recovery

14.2 Emission Calculations

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

$$E_{\text{VOC}} = F_T \times L_L \quad \text{Equation 14-1}$$

Where

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

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

$$L_L = 12.46 \times \left[\frac{(S \times P \times M)}{T} \right] \times \left[1 - \left(\frac{C_{\text{ap}}^{\text{eff}}}{100} \right) \times \left(\frac{C_{\text{on}}^{\text{eff}}}{100} \right) \right] \quad \text{Equation 14-2}$$

(Equation 14-2 continued)

Where

- 12.46 = constant
 S = Saturation Factor [see Table 14-1 below]
 P = True vapor pressure of liquid loaded (psi) [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 (90-99% eff).]

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 ^b 15	60	5.6	5.58	6.77	8.16	9.77	11.61	13.71	16.10
Gasoline RVP 13.5	62	5.6	4.93	6.01	7.26	8.71	10.38	12.29	14.46
Gasoline RVP 13	62	5.6	4.70	5.70	6.90	8.30	9.90	11.70	13.80
Gasoline RVP 11.5	65	5.6	4.089	4.99	6.067	7.31	8.75	10.41	12.295
Gasoline RVP 10	66	5.6	3.4	4.2	5.2	6.2	7.4	8.8	10.5
Gasoline RVP 8.3	68	5.6	2.79	3.40	4.20	5.10	6.20	7.40	8.80
Gasoline RVP 7.8	68	5.6	2.59	3.21	3.94	4.79	5.79	6.96	8.30
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 ^c	130	6.7	0.0041	0.0060	0.0085	0.011	0.015	0.021	0.029
Distillate oil No. 2	130	7.1	0.0031	0.0045	0.0065	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 RVP=Reid Vapor Pressure.^c The values for Jet kerosene may be used for JP-8.

HAP emissions associated with evaporative losses from fuel transfer operations are calculated as follows:

$$E_{\text{HAP}} = E_{\text{VOC}} \times \left(\frac{\text{VWP}_{\text{HAP}}}{100} \right) \quad \text{Equation 14-3}$$

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 Table 13-1 of this report.

14.3 Information Resources

Information concerning fuel transfer operations should be gathered from the same sources identified in Chapter 13, Fuel Storage. The primary points of contact for fuel transfer operations are POL; Power Pro and/or Heating, Ventilating, and Air Conditioning (HVAC); AGE Flight; AAFES; golf courses; and any additional fuel storage locations (e.g., marinas or freight transport units). Additionally, for operations involving the transfer of fuel into vehicles/equipment, the shops responsible for the vehicles/equipment may also need to be contacted (e.g., Vehicle Management Flight Vehicle Maintenance [LGRVM]). Similarly, the aircraft maintenance squadron(s) (AMXS) 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, the responsible shop, CE, or the applicable manufacturer will need to be contacted to obtain the control efficiency.

14.4 Example Problem

Calculate the annual VOC emissions associated with aircraft fueling and defueling operations. 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. 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. Calculate the VOC emissions associated with loading fuel into the fuel trucks as follows:

$$L_L = 12.46 \times \left[\frac{(S \times P \times M)}{T} \right] \times \left[1 - \left(\frac{\text{Cap}_{\text{eff}}}{100} \right) \times \left(\frac{\text{Con}_{\text{eff}}}{100} \right) \right]$$

(VOC equation continued)

$$L_{L(\text{trucks})} = 12.46 \times \left[\frac{(1.00 \times 0.0085 \times 130)}{520} \right] \times \left[1 - \left(\frac{70}{100} \right) \times \left(\frac{95}{100} \right) \right]$$

$$L_{L(\text{trucks})} = \mathbf{0.0089 \text{ lb}/10^3 \text{ gal}}$$

$$E_{\text{VOC}} = F_T \times L_L$$

$$E_{\text{VOC}(\text{trucks})} = (4,450 \times 10^3 \text{ gal/yr}) \times (0.0089 \text{ lb}/10^3 \text{ gal})$$

$$E_{\text{VOC}(\text{trucks})} = \mathbf{39.61 \text{ lb/yr}}$$

b. Calculate the VOC emissions associated with loading fuel into the aircraft tanks as follows:

$$L_{L(\text{aircraft})} = 12.46 \times \left[\frac{(0.60 \times 0.0085 \times 130)}{520} \right] \times \left[1 - \left(\frac{0}{100} \right) \times \left(\frac{0}{100} \right) \right]$$

$$L_{L(\text{aircraft})} = \mathbf{0.016 \text{ lb}/10^3 \text{ gal}}$$

$$E_{\text{VOC}(\text{aircraft})} = (4,450 \times 10^3 \text{ gal/yr}) \times (0.016 \text{ lb}/10^3 \text{ gal})$$

$$E_{\text{VOC}(\text{aircraft})} = \mathbf{71.20 \text{ lb/yr}}$$

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

$$L_{L(\text{bowsers})} = 12.46 \times \left[\frac{(1.45 \times 0.0085 \times 130)}{520} \right] \times \left[1 - \left(\frac{0}{100} \right) \times \left(\frac{0}{100} \right) \right]$$

$$L_{L(\text{bowsers})} = \mathbf{0.038 \text{ lb}/10^3 \text{ gal}}$$

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

$$E_{\text{VOC}(\text{bowsers})} = \mathbf{6.65 \text{ lb/yr}}$$

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

$$E_{\text{VOC}(\text{total JP-8})} = E_{\text{VOC}(\text{trucks})} + E_{\text{VOC}(\text{aircraft})} + E_{\text{VOC}(\text{bowsers})}$$

$$E_{\text{VOC}(\text{total JP-8})} = 39.61 \text{ lb/yr} + 71.20 \text{ lb/yr} + 6.65 \text{ lb/yr}$$

$$E_{\text{VOC}(\text{total JP-8})} = \mathbf{117.46 \text{ lb/yr.}}$$

14.5 References

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

U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources* (AP-42), Section 7.1, "Organic Liquid Storage Tanks," November 2006.

15 GASOLINE SERVICE STATIONS

15.1 Introduction

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 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. Below is a description of each of these emission sources.

15.1.1 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 a 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 filling, 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 shown in Figure 15-1.

15.1.2 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 USTs 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.

15.1.3 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 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 UST 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 UST is assisted by a vacuum pump. Tests on Stage 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.

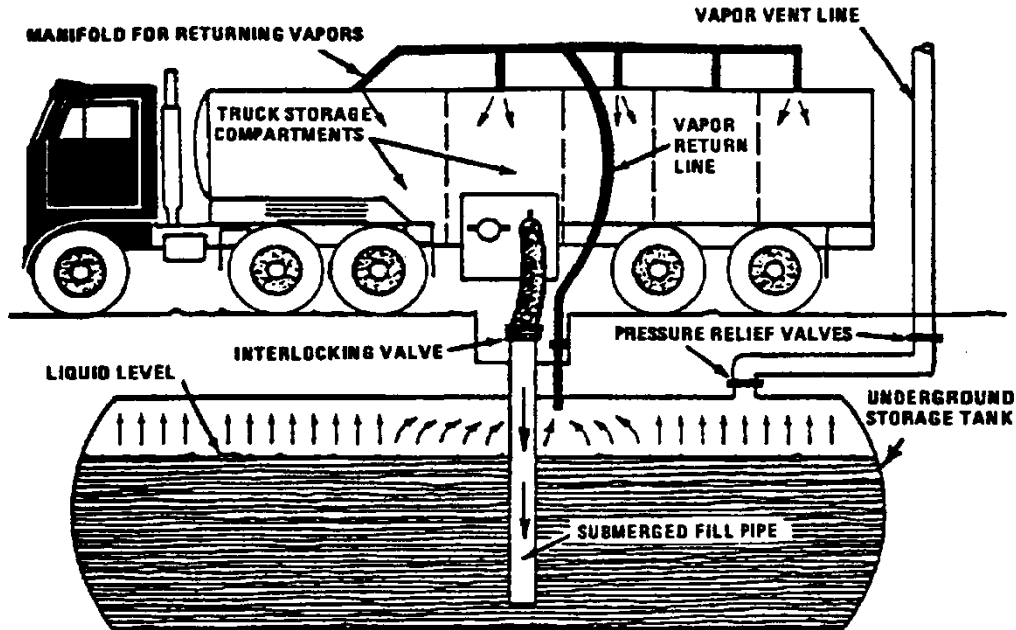


Figure 15-1. Schematic of Stage I Vapor Control

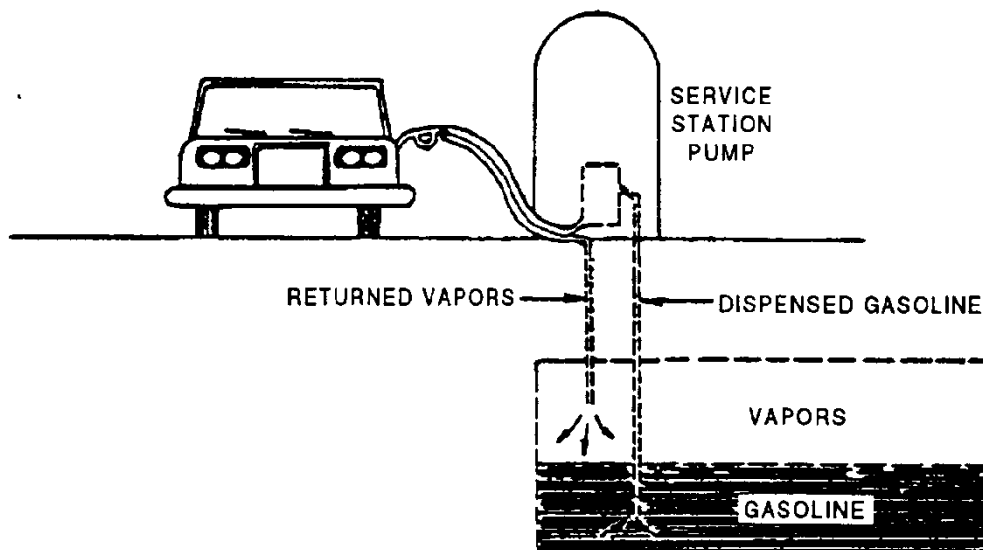


Figure 15-2. Schematic of Stage II Vapor Control

The data elements needed to calculate emissions from a gasoline distribution system are directly dependent on the methodology used to collect the data. Each type of methodology requires some

measure of activity (or surrogate for the activity) and an emission factor. The data elements required for each estimation technique are identified in Table 15-1.

Table 15-1. Required Data Elements

Subcategory	Data Element	Preferred Method	Alternate Method 1	Alternate Method 2
Gasoline Trucks in Transit	County-level fuel sales tax/survey data	X	X	
	Highway/weigh station data	X		
	State fuel sales			X
	Gasoline station sales			X
Fuel Delivery to Outlets	County-level fuel sales tax/survey data	X		
	Filling technology survey data	X	X	
	Filling technology summary from local/state regulators or trade groups			X
	State fuel sales		X	X
	Gasoline station sales		X	X
Vehicle Refueling	MOBILE model inputs ^a	X	X	X
	County-level fuel sales tax/survey data	X		
	State fuel sales		X	
	Gasoline station sales		X	
	VMT data			X
Tank Breathing	County-level fuel sales tax/survey data	X		
	State fuel sales		X	
	Gasoline station sales		X	

^a: EPA. 1994, *User's Guide to MOBILEXX*. U.S. EPA, Office of Mobile Sources, Ann Arbor, Michigan.

15.2 Emission Calculations

VOC emissions from gasoline service stations are calculated as follows:

$$E_{\text{VOC-Total}} = E_{\text{VOC-Fill}} + E_{\text{VOC-B\&E}} + E_{\text{VOC-VD}} + E_{\text{VOC-S}} \quad \text{Equation 15-1}$$

Where

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

The emissions from each source type are calculated as follows:

$$E_{\text{VOC-Total}} = [\text{GT} \times \text{EF}_{\text{VOC-Fill}}] + [\text{GT} \times \text{EF}_{\text{VOC-B\&E}}] + [\text{GT} \times \text{EF}_{\text{VOC-VD}}] + [\text{GT} \times \text{EF}_{\text{VOC-S}}] \quad \text{Equation 15.2}$$

Where

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

VOC emission factors associated with gasoline service stations are listed in Table 15-2. 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. 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 multiplying the spillage VOC emissions by the liquid-phase weight percent of each HAP in gasoline. The table below provides both a typical liquid-phase and a typical vapor-phase HAP speciation of gasoline.

Table 15-2. Evaporative 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). Actual emissions will vary. Additionally, EPA's webFIRE has emission factors from gasoline service stations (SCC 40600306) that may be helpful for an installation's specific requirements.

^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 TANKS program (see the "Fuel Storage" section of this document). Also, the TANKS 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.

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 gasoline storage tanks, in some cases the gasoline supplier(s) will need to be contacted. The required storage tank information includes the method in which the tanks are filled (submerged filling or splash spilling) and whether or not Stage I vapor recovery controls are being used.

15.4 Example Problem

A total of 172,000 gallons of gasoline was dispensed at the service station during the year and no Stage II vapor recovery controls were used. Only one fuel supplier was used during the year. The USTs were filled using the submerged filling technique and no Stage I vapor controls were used. Calculate the VOC emissions.

a. Calculate VOC emissions as follows:

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

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

$$+ [(172 \times 10^3 \text{ gal/yr}) \times 11.0 \text{ lb}/10^3 \text{ gal}] + [(172 \times 10^3 \text{ gal/yr}) \times 0.7 \text{ lb}/10^3 \text{ gal}]$$

$$E_{\text{VOC-Total}} = 1,255.60 \text{ lb/yr} + 172.00 \text{ lb/yr} + 1,892.00 \text{ lb/yr} + 120.40 \text{ lb/yr}$$

$$E_{\text{VOC-Total}} = \mathbf{3,440.00 \text{ lb/yr.}}$$

b. Calculate the Benzene emissions associated with the evaporative losses from the USTs and automobile tanks. Multiply 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:

$$E_{\text{VOC-Evap}} = 1,255.60 \text{ lb/yr} + 172.00 \text{ lb/yr} + 1,892.00 \text{ lb/yr}$$

$$E_{\text{VOC-Evap}} = \mathbf{3,319.60 \text{ lb/yr.}}$$

(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

*Weight fraction equals weight percent divided by 100.

c. Calculate the benzene emissions associated with the gasoline spillage during automobile refueling. Multiply 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

*Weight fraction equals weight percent divided by 100.

d. Calculate total benzene 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

Table 15-3. Fuels Data Used for Vapor-Phase Speciation

Compound	Liquid Molecular Weight ^a	Vapor Molecular Weight	Vapor Pressure at 60 (psia) ^a	Weight % in Liquid Diesel ^a	Weight % in Liquid Gasoline ^a	Weight % in Liquid JP-8 ^b	Weight % in Vapor JP-8 ^c
Benzene	78.11	N/A	1.16	0.0008	1.80	0.0034	0.20
Cumene (Isopropyl benzene)	120.2	N/A	0.051	ND	0.50	0.1111	0.29
Ethylbenzene	106.17	N/A	0.108	0.013	1.40	0.1552	0.86
Hexane	86.17	N/A	1.876	0.001	1.00	0.0088	0.84
Naphthalene	128.2	N/A	0.0024	ND	ND	0.0039	0.38
Toluene	92.13	N/A	0.309	0.032	7.00	0.1046	1.65
2,2,4-Trimethylpentane (Isooctane)	114.23	N/A	0.598	ND	4.00	0.0007	0.02
Xylenes	106.17	N/A	0.129	0.29	7.00	0.7176	4.74
Diesel Fuel ^a	188	130	0.009	N/A	N/A	N/A	N/A
Gasoline ^a (RVP 10)	92	66	5.2	N/A	N/A	N/A	N/A
JP-8	162	130	0.0244 ³	N/A	N/A	N/A	N/A

^a Data obtained from chemical database in EPA Tanks, version 4.09d.

^b Values for weight percent in liquid phase back-calculated from values for weight percent in vapor phase in report cited in reference 3 below, using procedures consistent with Section 7.1.4 of AP-42.

^c Vapor pressure and vapor phase weight percent values obtained from USAF IERA Report IERA-RS-BR-SR-2001-002, JP-8 Volatility Study, March 2001.

N/A = Not applicable.

ND = No data available.

15.5 References

Emissions Inventory Improvement Program (EIIP), *Volume III: Chapter 11, Gasoline Marketing (Stage I and Stage II)*, September 1997.

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

U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources* (AP-42), Section 7.1, "Organic Liquid Storage tanks," November 2006.

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

U.S. Environmental Protection Agency, TANKS Program (Storage Tank Emissions Calculation Software), Version 4.0.9d, October 2005.

16 HEAVY CONSTRUCTION OPERATIONS

16.1 Introduction

Heavy construction is a source of dust emissions that may have substantial temporary impact on local air quality. Building and road construction are two examples of construction activities with high emissions potential. Emissions during the construction of a building or road can be associated with land clearing, drilling and blasting, ground excavation, cut and fill operations (i.e., earth moving), and construction of a particular facility itself. Dust emissions often vary substantially from day to day, depending on the level of activity, the specific operations, and the prevailing meteorological conditions. A large portion of the emissions results from equipment traffic over temporary roads at the construction site.

Although much of the emissions from heavy construction operations are generated by exhaust of motorized equipment/vehicles, these emissions are considered “mobile source emissions” and are addressed in the chapters on non-road vehicles and on-road vehicles, Chapters 43 and 44 of the Air Emissions Inventory Guidance, Volume II, Mobile Sources. Only those emissions which fall under the definition of “stationary source emissions” are addressed in this chapter. The pollutant of concern from the stationary source portion of heavy construction operations is fugitive dust (PM).

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 are the only ones addressed in this document. These two phases can be further broken down into more specific activities, some of which are listed in Table 16-1.

In addition to the on-site activities, substantial emissions may be generated from material tracked out from the site and deposited on adjacent paved streets. Because all traffic passing the site (i.e., not just that associated with the construction) can resuspend the deposited material, this “secondary” source of emissions may be far more important than all the dust sources actually within the construction site. Furthermore, this secondary source will be present during all phases of the construction project. Persons developing construction site emission estimates must consider the potential for increased adjacent emissions from off-site paved roadways (see AP-42, Section 13.2.1, “Paved Roads”). High wind events also can lead to emissions from cleared land and material stockpiles. Section 13.2.5 of AP-42, “Industrial Wind Erosion”, presents an estimation methodology that can be used for such sources at construction sites.

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

Construction Phase	Dust-generating Activities
I. Demolition and debris removal	<ol style="list-style-type: none"> 1. Demolition of buildings or other obstacles such as trees, boulders, etc. <ol style="list-style-type: none"> 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

Table 16-1. [Con't] Specific Activities Associated with Typical Heavy Construction Operations

Construction Phase	Dust-generating Activities
II. Site Preparation (earth moving)	<ol style="list-style-type: none"> 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, 1.2 tons/acre/month of activity, 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 by 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 during a typical day. It is 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.

$$E_{TSP} = 80 \times D \times A \quad \text{Equation 16-1}$$

Where

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

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 PM₁₀. Since the majority of emissions from construction operations come from soil emitted during site preparation activities, a review of AP-42 was performed to determine if there was a typical PM₁₀ to TSP ratio for fugitive soil emissions. A PM₁₀ to PM₃₀ ratio was found in AP-42 Section 13.2.2 for dust emissions from unpaved roads. This ratio equates to 0.45 (i.e., 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 PM₁₀ emissions from construction operations (Note: Section 11.9 of AP-42 does consider TSP from fugitive dust emissions to be the same as \leq PM₃₀).

$$E_{PM10} = E_{TSP} \times 0.45 \quad \text{Equation 16-2}$$

Where

$$\begin{aligned} E_{PM10} &= \text{Emissions of PM}_{10} \text{ (lb/yr)} \\ E_{TSP} &= \text{Emissions of TSP (lb/yr)} \\ 0.45 &= \text{Estimated ratio of PM}_{10} \text{ to TSP.} \end{aligned}$$

Because the above emission factor (80 lb/acre/day) is referenced to TSP, use of this factor to estimate PM₁₀ emissions may result in conservatively high estimates.

Note that the procedures described 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 sum them to get the total emissions. That approach is much more comprehensive, however, it requires information about a variety of data elements, some of which are typically not known for heavy construction at Air Force installations.

16.3 Information Resources

Heavy construction operations on base are performed either by Civil Engineering or by a contractor. Base Civil Engineering, however, 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 on which typical daily construction operations were performed.

16.4 Example Problem

Within the past year, 35 full working days of construction operations were performed. On a typical workday, construction operations were performed on an area of approximately ½ acre. Calculate the estimated TSP (i.e., PM) and PM₁₀ emissions.

$$\begin{aligned} E_{TSP} &= 80 \times D \times A \\ E_{TSP} &= 80 \times 35 \times 0.5 \\ E_{TSP} &= \mathbf{1,400.0 \text{ lb/yr}} \\ \\ E_{PM10} &= E_{TSP} \times 0.45 \\ E_{PM10} &= 1,400 \text{ lb/yr} \times 0.45 \\ E_{PM10} &= \mathbf{630.0 \text{ lb/yr}} \end{aligned}$$

16.5 References

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

17 HOT MIX ASPHALT PLANTS

17.1 Introduction

The preparation of hot mix asphalt (HMA) paving materials on an Air Force installation is typically associated with large-scale paving projects, and is not common. However, a HMA plant setup on site at an Air Force installation might produce substantial emissions during a particular year.

HMA paving materials are a mixture of size-graded, high quality aggregate (which can include reclaimed asphalt pavement [RAP]), and liquid asphalt cement, which is heated and mixed in measured quantities to produce HMA. HMA paving materials can be manufactured by: (1) batch mix plants, (2) continuous mix (mix outside dryer drum) plants, (3) parallel flow drum-mix plants, and (4) counterflow drum-mix plants. Emissions of concern from HMA activities include PM, VOCs, criteria pollutants, and HAPs.

An HMA plant can be constructed as a permanent plant, a skid-mounted (easily relocated) plant, or a portable plant. All plants can have RAP processing capabilities. Virtually all plants being manufactured today have RAP processing capability. Most plants have the capability to use either gaseous fuels (natural gas) or fuel oil. However, based upon DOE and limited state inventory information, between 70 and 90 percent of the HMA is produced using natural gas as the fuel to dry and heat the aggregate.

Emissions from HMA plants may be divided into ducted production emissions, pre-production fugitive dust emissions, and other production-related fugitive emissions. Pre-production fugitive dust sources associated with HMA plants include vehicular traffic generating fugitive dust on paved and unpaved roads, aggregate material handling, and other aggregate processing operations. Fugitive dust may range from 0.1 μm to more than 300 μm in aerodynamic diameter. On average, 5 percent of cold aggregate feed is less than 74 μm (minus 200 mesh). Fugitive dust that may escape collection before primary control generally consists of PM with 50 to 70 percent of the total mass less than 74 μm .

17.2 Emission Calculations

Without considering cost, stack sampling is the preferred emission estimation methodology for process NO_x , CO, VOC, THC, PM, metals, and speciated organics. In addition, emission factors are commonly used to prepare emission inventories. However, the emission estimate obtained from using emission factors is based upon emissions testing performed at similar facilities and may not accurately reflect emissions at a single source. Emission factors are the preferred technique for estimating fugitive dust emissions for aggregate stockpiles and driving surfaces, as well as process fugitives. Each state may have a different preference or requirement, so contact the nearest state or local air pollution agency before deciding which emission estimation methodology to use.

17.2.1 Emissions Calculations Using Stack Sampling Data

If the stack sampling method is used to calculate emissions, the required information should be obtained from stack sampling test reports. Use the following equations to calculate the PM emissions based on stack sampling data utilizing EPA Method 5:

$$C_{\text{PM}} = \left[\frac{C_f}{V_{\text{m,STP}}} \right] \times 15.43 \quad \text{Equation 17-1}$$

(Equation 17-1 Continued)

Where

$$\begin{aligned}
 C_{PM} &= \text{concentration of PM or grain loading (grain/dscf)} \\
 C_f &= \text{filter catch (g)} \\
 V_{m,STP} &= \text{metered volume of sample at STP (dscf)} \\
 15.43 &= 15.43 \text{ grains per gram}
 \end{aligned}$$

And

$$E_{PM} = C_{PM} \times Q_d \times \left(\frac{60}{7000} \right) \quad \text{Equation 17-2}$$

Where

$$\begin{aligned}
 E_{PM} &= \text{PM emission (lb/hr)} \\
 Q_d &= \text{stack gas volumetric flow rate (dscfm)} \\
 60 &= 60 \text{ min/hr} \\
 7000 &= 7000 \text{ grains per pound.}
 \end{aligned}$$

17.2.2 Emissions Calculations Using Emission Factors

Criteria pollutant and HAPs emission factors for the various types of HMA plants and fuels are presented in Tables 17-1 and 17-2 respectively. A supplementary source for toxic air pollutant and criteria pollutants emission factors is the EPA's WebFIRE data system. An emission factor should be reviewed and approved by state/local agencies or the EPA prior to use. Use the following equation to calculate emissions of a particular pollutant:

$$E_x = EF_x \times \text{Activity of Production Rate} \quad \text{Equation 17-3}$$

Where

$$\begin{aligned}
 E_x &= \text{emissions of pollutant "x"} \\
 EF_x &= \text{emission factor of pollutant "x"}.
 \end{aligned}$$

17.3 Information Resources

Asphalt paving operations on base are performed either by Civil Engineering or by a commercial contractor. Base Civil Engineering, however, should have, or be able to obtain, the information necessary to calculate emissions from on-base HMA plant operations.

17.4 Example Problems

1. Calculate the PM emissions based on the stack sampling data presented below.

Parameter	Measurement
Total sampling time (minutes)	120
Moisture collected (grams)	395.6
Filter catch - C_f (grams)	0.0851
Average sampling rate (dscfm)	0.34
Standard metered volume - $V_{m,STP}$ (dscf)	41.83
Volumetric flow rate - Q_d (dscfm)	17,972

Calculate the concentration of PM:

$$C_{PM} = \left(\frac{C_f}{V_{m,STP}} \right) \times 15.43$$

$$C_{PM} = \left(\frac{0.085}{41.83} \right) \times 15.43$$

$$C_{PM} = \mathbf{0.03 \text{ grains/dscf.}}$$

Table 17-1. Criteria Pollutant Emission Factors from Hot Mix Asphalt Plants

Hot Mix Asphalt Process	CO ^b	NO _x	SO ₂ ^c	VOC	PM	PM ₁₀	PM _{2.5}
<i>Batch Mix HMA Plants</i>							
Dryer, screens, mixer ^a							
- Uncontrolled					32	4.5	0.27
- Venturi or Wet scrubber					0.14	ND	ND
- Fabric Filter					0.042	0.027	ND
Natural Gas-Fired	0.4	0.025	0.0046	0.0082			
No. 2 Fuel Oil	0.4	0.12	0.088	0.0082			
Waste Oil-/No. 6 Oil-Fired	0.4	0.12	0.088	0.036			
Coal-Fired	ND	ND	0.043	ND			
<i>Drum Mix HMA Plants</i>							
Dryer, screens, mixer ^a							
- Uncontrolled					28	6.5	1.5
- Venturi or Wet scrubber					0.045	ND	ND
- Fabric Filter					0.033	0.023	ND
Natural Gas-Fired	0.13	0.026	0.0034	0.032			
No. 2 Fuel Oil	0.13	0.055	0.011	0.032			
Waste Oil-/No. 6 Oil-Fired	0.13	0.055	0.058	0.032			
Coal-Fired	ND	ND	0.19	ND			

Note: All values reported in units of pounds per ton of product; Data rounded to two significant figures; ND = No data

^a Fuel type does not significantly effect PM emissions.

^b CO emission factors represent normal plant operations without scrutiny of burner design, operation, and maintenance.

^c Data shows that 50 percent of the fuel-bound sulfur, up to a maximum of 0.1 lb/ton of product, is expected to be retained in the product with the remainder emitted as SO₂.

Calculate the particulate emission rate:

$$E_{PM} = C_{PM} \times Q_d \times \left(\frac{60}{7000} \right)$$

$$E_{PM} = 0.03 \times 17,972 \times \left(\frac{60}{7000} \right)$$

$$E_{PM} = \mathbf{4.62 \text{ lb/hr.}}$$

2. Calculate the xylene emissions for a batch mix HMA plant with a natural gas-fired dryer. The HMA plant is assumed to operate 1,200 hours per year and have a maximum asphalt production rate of 350 ton/hr.

$$E_{\text{xylene}} = EF_{\text{xylene}} \times \text{Activity of Production Rate}$$

$$E_{\text{xylene}} = (0.0027 \text{ lb/ton}) \times 350 \text{ ton/hr}$$

$$E_{\text{xylene}} = 0.95 \text{ lb/hr} \times 1 \text{ ton}/2000 \text{ lb} \times 1200 \text{ hr/yr}$$

$$E_{\text{xylene}} = \mathbf{0.57 \text{ ton/yr.}}$$

The xylene emission factor was obtained from AP-42, Table 11.1-9.

17.5 References

U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources* (AP-42), Section 11.1, "Hot Mix Asphalt Plants," March 2004.

Table 17-2. HAPs Emission Factors from Hot Mix Asphalt Plants

Pollutant	Batch Dryer: Nat.Gas or No.2 Oil Fired	Batch Dryer: Wst.Oil or No.6 Oil Fired	Drum Dryer: Nat.Gas Fired	Drum Dryer: No.2 Oil Fired	Drum Dryer: Wst.Oil Fired
Acetaldehyde	3.2E-04	3.2E-04	ND	ND	1.3E-03
Benzene	2.8E-04	2.8E-04	3.9E-04	3.9E-04	3.9E-04
Ethylbenzene	2.2E-03	2.2E-03	2.4E-04	2.4E-04	2.4E-04
Formaldehyde	7.4E-04	7.4E-04	3.1E-03	3.1E-03	3.1E-03
Hexane	ND	ND	9.2E-04	9.2E-04	9.2E-04
Methyl Ethyl Ketone	ND	ND	ND	ND	2.0E-05
Propionaldehyde	ND	ND	ND	ND	1.3E-04
Quinone	2.7E-04	2.7E-04	ND	ND	1.6E-04
2,2,4- Trimethylpentane	ND	ND	4.0E-05	4.0E-05	4.0E-05
Methyl chloroform	ND	ND	4.8E-05	4.8E-05	4.8E-05
Toluene	1.0E-03	1.0E-03	1.5E-04	2.9E-03	2.9E-03
Xylene	2.7E-03	2.7E-03	2.0E-04	2.0E-04	2.0E-04
2-Methylnaphalene	7.1E-05	7.1E-05	7.4E-05	1.7E-04	1.7E-04
Acenaphthene	9.0E-07	9.0E-07	1.4E-06	1.4E-06	1.4E-06
Acenaphthelene	5.8E-07	5.8E-07	8.6E-06	2.2E-05	2.2E-05
Anthracene	2.1E-07	2.1E-07	2.2E-07	3.1E-06	3.1E-06
Fluoranthene	1.6E-07	2.4E-05	6.1E-07	6.1E-07	6.1E-07
Fluorene	1.6E-06	1.6E-06	3.8E-06	1.1E-05	1.1E-05
Naphthalene	3.6E-05	3.6E-05	9.0E-05	6.5E-04	6.5E-04
Phenanthrene	2.6E-06	3.7E-05	7.6E-06	2.3E-05	2.3E-05
Pyrene	6.2E-08	5.5E-05	5.4E-07	3.0E-06	3.0E-06

Note: All values in units of pounds per ton of product; ND = No data.

18 INCINERATORS

18.1 Introduction

There are two types of incinerators typically found on Air Force installations: classified waste incinerators and medical (hospital) waste incinerators. Emissions include PM₁₀, SO₂, CO, and NO_x. 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.

18.1.1 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 "Institutional/Commercial Incinerator." Specifically, a classified waste incinerator is in the same category as a municipal waste incinerator burning other than refuse.

18.1.2 Medical Waste Incinerators

Medical waste incinerators are used to burn wastes produced by hospitals, clinics, and veterinary facilities. The wastes burned in medical waste 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 rotary kiln medical waste incinerators are currently being used in the Air Force.

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 where the combustion air is regulated to provide an excess-air combustion condition. The combustion gasses are 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.

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.

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 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.

18.2 Emission Calculations

Pollutant emissions from incinerators are calculated by multiplying the mass of waste burned by the emission factor for each specific pollutant.

$$E_{\text{pol}} = \text{WC} \times \text{EF} \quad \text{Equation 18-1}$$

Where

$$\begin{aligned} E_{\text{pol}} &= \text{Emissions of a particular pollutant (lb/yr)} \\ \text{WC} &= \text{Quantity of waste combusted (tons/yr)} \\ \text{EF} &= \text{Emission factor (lb/ton)}. \end{aligned}$$

Emission factors for controlled-air medical waste incinerators are provided in Table 18-1 below. Emission factors for uncontrolled Institutional/Commercial Combustors are found in Table 18-2.

Table 18-1. Emission Factors for Controlled-Air Medical Waste Incinerators

Control Levels and Emission Factors (lb/ton) ^{a,b}										
Pollutant	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 ₂	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	1.28E-02	ND	3.09E-04	ND	ND	4.08E-04	2.10E-04	1.51E-04	ND	ND
Arsenic	2.42E-04	ND	3.27E-05	3.95E-08	1.42E-04	3.27E-05	1.19E-05	1.46E-05	ND	5.01E-05
Beryllium	6.25E-06	ND	ND	ND	ND	ND	ND	3.84E-06	ND	ND
Cadmium	5.48E-03	ND	1.78E-04	ND	6.97E-03	7.43E-02	2.46E-05	9.99E-05	1.30E-05	5.93E-04
Chlorine	1.05E-01	ND	ND	ND	ND	ND	ND	ND	ND	ND
Chromium	7.75E-04	ND	2.58E-04	2.15E-06	4.13E-04	1.03E-03	3.06E-04	1.92E-04	3.96E-05	6.58E-04
Dibenzo-Furans	7.15E-05	ND	ND	8.50E-06	4.92E-06 ^d	4.92E-06 ^d	1.47E-06	9.47E-08	ND	1.73E-09
HCl	3.35E+01	1.90	2.82	5.65	1.00	1.39E-01	1.27E+01	9.01E-01	9.43E-02	4.98E-01
Hydrogen Fluoride	1.49E-01	ND	ND	ND	ND	ND	ND	1.33 x10 ⁻²	ND	ND
Pb	7.28E-02	ND	1.60E-03	9.92E-05	7.94E-02	6.98E-02	6.25E-05	9.27E-05	5.17E-05	4.70E-03
Manganese	5.67E-04	ND	ND	ND	4.66E-04	6.12E-04	ND	ND	ND	ND
Mercury	1.07E-01	ND	3.07E-02	ND	1.55E-02	1.73E-02	1.11E-01	9.74E-03	3.56E-04	1.81E-02
Nickel	5.90E-04	ND	5.30E-04	ND	3.28E-04	2.54E-03	4.54E-04	2.84E-04	ND	4.84E-04
PCBs	4.65E-05	ND	ND	ND	ND	ND	ND	ND	ND	ND
POM ^e	9.28E-05	ND	ND	1.12E-05	6.76E-06 ^d	6.76E-06 ^d	1.81E-06	1.49E-07	ND	1.90E-09
2,3,7,8-TCDD ^f	5.47E-08	ND	ND	6.72E-09	1.29E-10 ^e	1.29E-10 ^e	5.61E-10	8.23E-10	ND	1.73E-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 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. Each POM emission factor was estimated by adding the emission factors for Total Chlorodibenzodioxins (Total CDD) to the Total Chlorodibenzofurans (Total CDF).

^f. TCDD = Tetrachlorodibenzo-p-dioxin.

^g. From Section 2.3 of AP-42.

Table 18-2. Emission Factors for Uncontrolled Institutional/Commercial Combustors

Pollutant	Emission Factor (lb/ton)	
	Single Chamber ^a	Multiple Chamber ^a
	[SCC 5-02-001-02] ^b	[SCC 5-02-001-01] ^b
Criteria Pollutants		
CO	20.0	10.0
NO _x	2.0	3.0
Total PM	15.0	7.0
PM ₁₀	5.7	4.7
SO ₂	2.5	2.5
VOC	15.0	3.0
HAPs		
Cadmium	ND	ND
Chromium (VI)	ND	ND
Hydrogen Chloride	ND	10
Pb	ND	ND
Mercury	ND	ND

Note: Emission factors are in units of pounds pollutant emitted per ton of waste burned. ND = No Data

^a "Commercial/Institutional" type.

^b SCC: Source Category Codes are discussed in Appendix C.

18.3 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). Classified waste incinerators are usually operated by the base Information Systems office.

18.4 Example Problems

1. Approximately 36,500 pounds of medical waste were combusted in the air medical waste incinerator during the year. Calculate the annual PM₁₀ emissions.

PM₁₀ emissions are calculated by multiplying the tons of waste combusted by the PM₁₀ emission factor listed in Table 18-1 for uncontrolled incinerators.

$$\frac{36,500\text{lbs}}{2,000\text{lbs/ton}} = 18.25 \text{ tons}$$

$$\begin{aligned} E_{\text{pol}} &= \text{WC} \times \text{EF} \\ E_{\text{PM}_{10}} &= 18.25 \text{ tons/yr} \times 3.04 \text{ lb/ton} \\ E_{\text{PM}_{10}} &= \mathbf{55.48 \text{ lb/yr.}} \end{aligned}$$

2. A 3-chambered classified waste incinerator with no emissions control device burned 12,200 pounds of waste during the year. Calculate the SO₂ emissions.

$$\begin{aligned} E_{\text{SO}_2} &= \frac{12,200\text{lb/yr}}{2,000\text{lb/ton}} \times 2.5 \text{ lb/ton} \\ E_{\text{SO}_2} &= \mathbf{15.25 \text{ lb/yr.}} \end{aligned}$$

18.5 References

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

U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources* (AP-42), Section 2.3, "Medical Waste Incineration," July 1993.

U.S. Environmental Protection Agency, WebFIRE (Factor Information Retrieval System), <http://cfpub.epa.gov/oarweb/index.cfm?action=fire.main>.

19 LABORATORY CHEMICALS

19.1 Introduction

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 of. 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.

19.2 Emission Calculations

The manner in which laboratory chemicals are used makes quantifying emissions difficult. “Loss” means the chemical is not part of the product or the solid waste stream. As such, the general assumption is it is emitted to the air. The challenge for the lab operator is to estimate the maximum total mass of any given chemical that could actually have been emitted during any given period of time. In order to develop the quantities required to conduct the mass balance, the operator simply determines the amount of unused chemical remaining in the inventory: (A) determines the original quantity from the previous inventory (B) and subtracts A from B yielding the difference C. The operator must then determine the amount of chemical that may have been purchased or otherwise added to the inventory during the period in question (D). At this point, the sum of C + D yields the total quantity of chemical that must be accounted for during the period in question (E). From this value, the lab operator must subtract the amount of chemical still in use in solutions or mixtures in the lab, all forms of the chemical that were disposed of as waste, and any non-waste amount(s) that were shipped off-site, or other off-premise use. The result is **the maximum amount of the chemical that could actually have been emitted to the air from the lab over the period of time between (A) and (B)**. Using this derived quantity and the equation below, the operator can then determine the emissions of the particular chemical/pollutant.

Based on this methodology, VOC and/or volatile HAP emissions from laboratory chemicals can be estimated using the following equation:

$$E_{\text{pot}} = QC \times D \times \left(\frac{WP}{100} \right) \quad \text{Equation 19-1}$$

Where

- E_{pot} = Emissions of a particular pollutant (lb/yr)
- QC = Quantity of a particular chemical/reagent not accounted for in the product/waste stream (gal/yr)
- D = Density of the chemical/reagent (lb/gal)
- WP = Weight percent of the regulated pollutant found in the chemical/reagent (%)
- 100 = Factor for converting weight percent to weight fraction.

19.3 Information Resources

Information regarding the types and quantities of laboratory chemicals/reagents used can usually be obtained from the laboratories which use the chemicals (e.g., fuels laboratory, medical clinic laboratory). 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 MSDS, other product literature, or from the manufacturer.

19.4 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. They are not part of the final product(s) nor accounted for in the solid waste stream and, thus, are assumed to have been emitted into the air. 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:

$$E_{\text{pol}} = \text{QC} \times \text{D} \times \left(\frac{\text{WP}}{100} \right)$$

$$E_{\text{VOC}} = 20 \text{ gal/yr} \times 6.75 \text{ lb/gal} \times \left(\frac{100}{100} \right)$$

$$E_{\text{VOC}} = \mathbf{135 \text{ lb/yr.}}$$

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

$$E_{\text{pol}} = \text{QC} \times \text{D} \times \left(\frac{\text{WP}}{100} \right)$$

$$E_{\text{methylene chloride}} = 10 \text{ gal/yr} \times 11.08 \text{ lb/gal} \times \left(\frac{100}{100} \right)$$

$$E_{\text{methylene chloride}} = \mathbf{110.8 \text{ lb/yr}}$$

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

$$\begin{aligned} E_{\text{pol}} &= QC \times D \times \left(\frac{WP}{100} \right) \\ E_{\text{VOC}} &= 25 \text{ gal/yr} \times 9.0 \text{ lb/gal} \times \left(\frac{49}{100} \right) \\ E_{\text{VOC}} &= \mathbf{110.25 \text{ lb/yr}} \\ E_{\text{formaldehyde}} &= 25 \text{ gal/yr} \times 9.0 \text{ lb/gal} \times \left(\frac{37}{100} \right) \\ E_{\text{formaldehyde}} &= \mathbf{83.25 \text{ lb/yr}} \\ E_{\text{methanol}} &= 25 \text{ gal/yr} \times 9.0 \text{ lb/gal} \times \left(\frac{12}{100} \right) \\ E_{\text{methanol}} &= \mathbf{27 \text{ lb/yr.}} \end{aligned}$$

19.5 References

U.S. Environmental Protection Agency, *Environmental Management Guide for Small Laboratories*, EPA 233-B-00-001, May 2000.

20 LANDFILLS

20.1 Introduction

Only a few Air Force installations may have active solid waste landfills but most installations have 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 (MSW) (i.e., typical household waste), commercial and industrial organic wastes, municipal wastewater 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 50 percent by volume CH₄, 45 percent CO₂, 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. Passive gas collection systems typically vent directly to the atmosphere without any control device. Active gas collection systems typically send the gas to a control device such as flare, turbine, or internal combustion (IC) engine. Air Force landfills with active gas control typically utilize a flare to combust the landfill gas.

In general, a three step process is used when disposing of waste in an active landfill. This includes spreading the waste, compacting the waste, and covering the waste with soil. The covering of waste with soil is typically performed using heavy equipment (e.g., bulldozers, graders) and results in airborne emissions of fugitive dust or PM. 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 not addressed in this chapter.

20.2 Emission Calculations

The Landfill Gas Emissions Model (LandGEM version 3.02, released May 12, 2005) is an automated tool, in the form of a Microsoft Excel™ spreadsheet, that was developed by the EPA for estimating emission rates from MSW landfills. The model can be used to estimate uncontrolled emissions of total landfill gas (TFG), CH₄, CO₂, NMOC, and individual air pollutants from landfills.

The LandGEM model does not directly calculate emissions from landfills that have emission control systems installed. However, the equations to calculate controlled emissions rely upon the uncontrolled emissions calculated by the LandGEM model.

20.2.1 Uncontrolled Emissions from Landfills

The LandGEM model estimates most landfill uncontrolled emissions to include total landfill gas (TLG), CH₄, CO₂, and NMOC. Additionally, LandGEM will calculate emissions for various individual air pollutants from landfills shown in Table 20-1.

Table 20-1. LandGEM Individual Air Pollutants

Parameter	Common Name	Type	Molecular Weight	Default Concentration (ppmv) ^a
TLG			NA	1,000,000
CH ₄			16.04	500,000
CO ₂			44.01	450,000
NMOC <i>[None or unknown co-disposal]</i>			NA	595 ^b
NMOC <i>[Co-disposal]</i>			NA	2,420 ^b
1,1,1-Trichloroethane	methyl chloroform	HAP	133.41	0.48
1,1,2,2-Tetrachloroethane		HAP/VOC	167.85	1.11
1,1-Dichloroethane	ethylidene dichloride	HAP/VOC	98.97	2.35
1,1-Dichloroethene	vinylidene chloride	HAP/VOC	96.94	0.20
1,2-Dichloroethane	ethylene dichloride	HAP/VOC	98.96	0.41
1,2-Dichloropropane	propylene dichloride	HAP/VOC	112.99	0.18
2-Propanol	isopropyl alcohol	VOC	60.11	50.10
2-Propanone	acetone		58.08	7.01
Acrylonitrile		HAP/VOC	53.06	6.33
Benzene <i>[None or unknown co-disposal]</i>		HAP/VOC	78.11	1.91
Benzene <i>[Co-disposal]</i>		HAP/VOC	78.11	11.10
Bromodichloromethane		VOC	163.83	3.13
Butane		VOC	58.12	5.03
Carbon disulfide		HAP/VOC	76.13	0.58
Carbon monoxide			28.01	141.00
Carbon tetrachloride		HAP/VOC	153.84	0.004
Carbonyl sulfide		HAP/VOC	60.07	0.49
Chlorobenzene		HAP/VOC	112.56	0.25
Chlorodifluoromethane			86.47	1.30
Chloroethane	ethyl chloride	HAP/VOC	64.52	1.25
Chloroform		HAP/VOC	119.39	0.03
Chloromethane		VOC	50.49	1.21
Dichlorobenzene ^c		HAP/VOC	147	0.21
Dichlorodifluoromethane			120.91	15.70
Dichlorofluoromethane		VOC	102.92	2.62
Dichloromethane	methylene chloride	HAP	84.94	14.30
Dimethyl sulfide	methyl sulfide	VOC	62.13	7.82
Ethane			30.07	889.00
Ethanol		VOC	46.08	27.20
Ethyl mercaptan	ethanethiol	VOC	62.13	2.28
Ethylbenzene		HAP/VOC	106.16	4.61
Ethylene dibromide		HAP/VOC	187.88	0.001
Fluorotrichloromethane		VOC	137.38	0.76
Hexane		HAP/VOC	86.18	6.57
Hydrogen sulfide			34.08	35.50

Table 20-1. [Con't] LandGEM Individual Air Pollutants

Parameter	Common Name	Type	Molecular Weight	Default Concentration (ppmv)
Mercury (total) ^d		HAP	200.61	2.92E-04
Methyl ethyl ketone		VOC	72.11	7.09
Methyl isobutyl ketone		HAP/VOC	100.16	1.87
Methyl mercaptan		VOC	48.11	2.49
Pentane		VOC	72.15	3.29
Tetrachloroethylene	Perchloroethylene	HAP	165.83	3.73
Propane		VOC	44.09	11.10
t-1,2-Dichloroethene		VOC	96.94	2.84
Toluene [<i>None or unknown co-disposal</i>]		HAP/VOC	92.13	39.30
Toluene [<i>Co-disposal</i>]		HAP/VOC	92.13	165.00
Trichloroethene	Trichloroethylene	HAP/VOC	131.4	2.82
Vinyl chloride		HAP/VOC	62.5	7.34
Xylenes		HAP/VOC	106.16	12.10

Note: This list include potential LFG constituents for which test data was available from multiple sites, and is not all-inclusive of potential LFG constituents.

^a Default concentrations of shaded components vary depending on whether the landfill accepted co-disposal of hazardous waste.

^b NMOC concentrations modeled as hexane.

^c Only the para isomer of dichlorobenzene is a Title III-Listed HAP.

^d No data were available to speciate total mercury into elemental and organic forms.

The introductory screen of the LandGEM model describes the purpose of the tool and the various functions, which are accessed by way of tabs at the bottom of the spreadsheet screen (as shown on the next page). The model requires the following user inputs in order to calculate uncontrolled air emissions from a landfill.

- Year the landfill opened
- Year the landfill closed (optional to have the model calculate the closure year)
- Waste design capacity
- Annual waste deposited in the landfill.

The LandGEM model provides a number of options to tailor the results to the site conditions. Options include default values for CH₄ generation rate and generation capacity for modeling air emission inventories or for modeling CAA compliance. Parameter options are available to model landfills located in conventional and in arid regions (i.e., regions receiving less than 25 inches of rainfall per year). Parameter options are also available for landfills that permitted co-disposal of hazardous solid wastes. Model results report the concentrations of individual pollutants over time and are presented as an emissions inventory table of all pollutants for a user specified year (see the *Inventory* tab of the model). The emissions inventory tables from various landfills can be easily copied into one spreadsheet table to prepare a combined emissions inventory for all of the landfills at an installation.

INTRODUCTION

LandGEM - Landfill Gas Emissions Model, Version 3.02
U.S. Environmental Protection Agency

Model Design:

Worksheet Name	Function
INTRO	Contains an overview of the model and important notes about using LandGEM
USER INPUTS	Allows users to provide landfill characteristics, determine model parameters, select up to four gases/pollutants (total landfill gas, methane, carbon dioxide, NMOC, and 46 air pollutants), and enter waste acceptance rates
POLLUTANTS	Allows users to edit air pollutant concentrations and molecular weights for existing pollutants and add up to 10 new pollutants
INPUT REVIEW	Allows users to review and print model inputs
METHANE	Calculates methane emission estimates using the first-order decomposition rate equation
RESULTS	Shows tabular emission estimates for up to four gases/pollutants (selected in the USER INPUTS worksheet) in megagrams per year, cubic meters per year, and user's choice of a third unit of measure (average cubic feet per minute, cubic feet per year, or short tons per year)
GRAPHS	Shows graphical emission estimates for up to four gases/pollutants (selected in the USER INPUTS worksheet) in megagrams per year, cubic meters per year, and user's choice of a third unit of measure (selected in the RESULTS worksheet)
INVENTORY	Displays tabular emission estimates for all gases/pollutants for a single year specified by users
REPORT	Allows users to review and print model inputs and outputs in a summary report

About LandGEM:
LandGEM is based on a first-order decomposition rate equation for quantifying emissions from the decomposition of landfilled waste in municipal solid waste (MSW) landfills. The software provides a relatively simple approach to estimating landfill gas emissions. Model defaults are based on empirical data from U.S. landfills. Field test data can also be used in place of model defaults when available. Further guidance on EPA test methods, Clean Air Act (CAA) regulations, and other guidance regarding landfill gas emissions and control technology requirements can be found at <http://www.epa.gov/trashfill/landfill/landfog.html>

LandGEM is considered a screening tool — the better the input data, the better the estimates. Often, there are limitations with the available data regarding waste quantity and composition, variation in design and operating practices over time, and changes occurring over time that impact the emissions potential. Changes to landfill operation, such as operating under wet conditions through leachate recirculation or other liquid additions, will result in generating more gas at a faster rate. Defaults for estimating emissions for this type of operation are being developed to include in LandGEM along with defaults for conventional landfills (no leachate or liquid additions) for developing emission inventories and determining CAA applicability. Refer to the Web site identified above for future updates.

IMPORTANT NOTES!
The following user inputs MUST be completed in the USER INPUTS worksheet:

- Landfill open year
- Landfill closure year or Waste design capacity
- Annual waste acceptance rates from open year to current year or closure year

Other important Notes:

- LandGEM is based on the gas generated from anaerobic decomposition of landfilled waste which has a methane content between 40 and 60 percent.
- When using LandGEM to comply with the CAA, the methane content of the landfill gas must remain fixed at 50% by volume (the model default value).
- Default pollutant concentrations used by LandGEM have already been corrected for air infiltration, as stated in AP-42. If a user-specified value for NMOC concentration is used based on site-specific data, then it must be corrected for air infiltration.
- When comparing results from LandGEM with measurements of extracted gas collected at a site, the landfill owner/operator must adjust for air infiltration prior to any comparisons.
- One megagram is equivalent to one metric ton.

USER INPUTS tab.

INTRO | **USER INPUTS** | POLLUTANTS | INPUT REVIEW | METHANE | RESULTS | GRAPHS | INVENTORY | REPORT

20.2.2 Controlled Emissions from Landfills

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). Since landfill collection and control systems are not 100 percent efficient some portion of the emissions are released uncontrolled into the atmosphere. If the efficiency of the collection system is not known, the EPA recommends an efficiency of 75 percent for estimation purposes. In regards to the control device, efficiencies can vary by the control device type (i.e., boiler/steam turbine, flare, gas turbine, or IC engine and constituent). Table 20-2 lists the control efficiency of the various control types by constituent. Controlled CH₄, NMOC, and speciated emissions can be calculated using the following equation.

$$E_{C-Pollutant} = \left[E_{UC-Pollutant} \left(1 - \frac{\eta_{collection}}{100} \right) \right] + \left[\left(E_{UC-Pollutant} \left(\frac{\eta_{collection}}{100} \right) \right) \left(1 - \frac{\eta_{control}}{100} \right) \right] \quad \text{Equation 20-1}$$

(Equation 20-1 Continued)

Where

- $E_{C-Pollutant}$ = Controlled mass emissions of pollutant, Mg/yr
 $E_{UC-Pollutant}$ = Uncontrolled mass emissions of pollutant, Mg/yr (from LandGEM)
 $\eta_{collection}$ = Collection efficiency of the landfill gas collection system, percent (assume 75 percent if not known)
 $\eta_{control}$ = Control efficiency of the landfill gas control or utilization device, percent (Table 20-2).

Table 20-2. Control Efficiencies for Landfill Gas Constituents

Control Device	Constituent ^a	Control Efficiency (%)	
		Average	Range
Boiler/Steam Turbine (SCC 50100423)	NMOC	98.0	96-99+
	Halogenated Species ^a	99.6	87-99+
	Non-Halogenated Species	99.8	67-99+
Flare ^b (SCC 50100410) ^c (SCC 50300601)	NMOC	99.2	90-99+
	Halogenated Species ^a	98.0	91-99+
	Non-Halogenated Species	99.7	38-99+
Gas Turbine	NMOC	94.4	90-99+
	Halogenated Species ^a	99.7	98-99+
	Non-Halogenated Species	98.2	97-99+
IC Engine	NMOC	97.2	94-99+
	Halogenated Species ^a	93.0	90-99+
	Non-Halogenated Species	86.1	25-99+

^a. Halogenated species are those containing atoms of chlorine, bromine, fluorine, or iodine. For any equipment, the control efficiency for mercury should be assumed to be zero. See Section 2.4.4.2 of AP-42 for methods to estimate emissions of SO₂, CO₂, and HCl.

^b. Where information on equipment was given in the reference, test data were taken from enclosed flares. Control efficiencies are assumed to be equally representative of open flares.

^c. For a discussion regarding SCCs, see Appendix C.

20.2.3 Fugitive PM Emissions from Landfills

Bulldozers and graders are the principal types of heavy equipment used to cover the solid waste with soil at an active landfill. Fugitive dust emission factors for both bulldozing and grading operations are available in Section 11.9 of AP-42. Table 20-3 provides the emission factors which can be used with the following equation to estimate fugitive dust emissions from soil covering operations at active landfills:

$$E_{pol} = [EF_B \times 2.205 \times OT_B] + [EF_G \times 2.205 \times 1.609 \times MT] \quad \text{Equation 20-2}$$

Where

- E_{pol} = Emissions of a particular pollutant (lb/yr) [Note: The pollutant will be either TSP or PM₁₀]
 EF_B = Bulldozing Emission Factor (kg/hr)
2.205 = Unit conversion factor (lb/kg)
 OT_B = Estimated bulldozer operating time during the year (hr/yr)
 EF_G = 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 20-3. Fugitive Dust Emission Factors from Bulldozing and Grading Operations

Operation	Emission Factor Values ^a		Emission Factor Units
	TSP	PM ₁₀	
Bulldozing (Overburden material)	$5.7 (s)^{1.2}/(M)^{1.3}$	0.75	lb/hr
Grading	$0.0034(S)^{2.5}$	0.60	lb/VMT ^b

Note: Emission factors were extracted from Table 11.9-1 of AP-42.

^a Symbols stand for the following: s = material silt content (%); M = material moisture content (%); and S = average vehicle speed (miles per hour). If s and M are unknown, assume 6.9% for s and 7.9% for M.

^b VMT = Vehicle miles traveled.

20.3 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 (CH₄ generation rate constant) to use when calculating uncontrolled emissions.

20.4 Example Problem

An Air Force facility has an inactive landfill that was closed in 2001. The landfill originally opened in 1988 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 waste 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 annual emission rate of total NMOC (considered the same as VOC) and of methylene chloride (dichloromethane) for an emissions inventory for calendar year 2006.

Open the **LandGEM** (Version 3.02) spreadsheet model and click on the “User Inputs” tab at the bottom of the screen and enter the landfill name or ID at the top. Under section 1: **PROVIDE LANDFILL CHARACTERISTICS**, input the **Landfill Open Year, 1988**, and the **Landfill Closure Year, 2001**. If the landfill is currently open you can have LandGEM calculate the estimated closure year by completing the two fields below the **Landfill Closure Year**.

Under section 2: **DETERMINE MODEL PARAMETERS**, select *Inventory Conventional* for both the **Methane Generation Rate** and the **Potential Methane Generation Capacity**. Select *Inventory No or Unknown Co-disposal* for **NMOC Concentration** and accept *CAA – 50% by volume* for **Methane Content**.

Under section 3. **SELECT GAS/POLLUTANTS**, change **Gas/Pollutant #3** to *Dichloromethane (methylene chloride) – HAP*. Accept the remaining default gas/pollutant values. Next input any model remarks in the **Description/Comments**: field.

Finally under section 4. **ENTER WASTE ACCEPTANCE RATES**, input the waste accepted for each year the landfill was open. In this example that is 50,000 tons/year or 45,455 Mg/year.

At this point the model has completed all calculations. The user can select the **REPORT** tab to get a detailed summary of all the calculations. The Summary Report is broken down into Input Review, Pollutant Parameters, Graphs, and Results.

For air emission inventory use, the **INVENTORY** tab will prepare summary of all emissions for a user specified calendar year. Enter the inventory year at the top of the screen. The table lists uncontrolled gas and pollutant emissions in metric tons per year (Mg/year) and standard tons (short tons/year). The appropriate data column can be copied to another spreadsheet and combined with similar calculations for other landfills at an installation to summarize the installation's landfill emissions for the inventory year.

The objective of this problem is to determine the 2006 annual emissions from the landfill for NMOC and dichloromethane. Scroll down to the Results section of the **REPORT** tab and find the table labeled Dichloromethane (methylene chloride) – HAP and NMOC. Find 2006 on the left side of the table and read across the table to the right. The Dichloromethane emissions are 1.646E-01 Mg/year and the NMOC emissions are 7.158E+00 Mg/year for the year 2006.

Because this example landfill had a collection and control system, the equation in section 20.2.2 for controlled emissions must be used to calculate the emissions.

For NMOC:

$$E_{C-NMOC} = \left[E_{UC-NMOC} \left(1 - \frac{\eta_{collection}}{100} \right) \right] + \left[\left(E_{UC-NMOC} \right) \left(\frac{\eta_{collection}}{100} \right) \left(1 - \frac{\eta_{control}}{100} \right) \right] \quad \text{Equation 20-3}$$

Where

$$\begin{aligned} E_{UC-NMOC} &= 7.158 \text{ Mg/yr (from LandGEM)} \\ \eta_{collection} &= 75\% \text{ (assumed)} \\ \eta_{control} &= 94.4\% \text{ (Table 20-2, Flare, NMOC).} \end{aligned}$$

$$E_{C-NMOC} = 1.890 \text{ Mg/yr}$$

Converting from Mg/year to lb/year (1 Mg = 2,204.623 lb)

$$E_{C-NMOC} = \mathbf{4,166.10 \text{ lb/yr.}}$$

For Methylenechloride:

$$E_{C-Methylenechloride} = \left[E_{UC-Methylenechloride} \left(1 - \frac{\eta_{collection}}{100} \right) \right] + \left[\left(E_{UC-Methylenechloride} \right) \left(\frac{\eta_{collection}}{100} \right) \left(1 - \frac{\eta_{control}}{100} \right) \right] \quad \text{Equation 20-4}$$

Where

$$\begin{aligned} E_{UC-Methylenechloride} &= 0.1646 \text{ Mg/yr (from LandGEM)} \\ \eta_{collection} &= 75\% \text{ (assumed)} \\ \eta_{control} &= 98.0\% \text{ (Table 20-2, Flare, Halogenated).} \end{aligned}$$

Substituting,

$$\begin{aligned} E_{C-Methylenechloride} &= 0.0420 \text{ Mg/yr} \\ E_{C-Methylenechloride} &= \mathbf{92.53 \text{ lb/yr.}} \end{aligned}$$

20.5 References

U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources* (AP-42), Section 2.4, "Municipal Solid Waste Landfills," November 1998.

U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources* (AP-42), Section 11.9, "Western surface Coal Mining," October 1998.

U.S. Environmental Protection Agency, Landfill Gas Emissions Model (LandGEM), Version 3.02, May 2005.

21 MISCELLANEOUS CHEMICAL USE

21.1 Introduction

Miscellaneous chemicals are defined for the purposes of this document as chemicals not specifically addressed in other sections of this document. These chemicals are generally commercially purchased items used in small quantities usually less than one pound and may include such items as household cleaners, light lubricating oils, adhesives, sealants, and small volumes of paint. Unless specifically identified in the base's air permit, these items are not reportable. Information pertaining to the composition of miscellaneous chemicals can be obtained from the base's MSDS data base, other product literature, or from the manufacturer and made available if requested by state regulators.

Applicable regulations and governing air pollution control agencies should first be consulted prior to including this source category, as these chemicals are typically exempt from regulatory consideration under federal and state or local air pollution control agency air quality regulations (permitting, emissions inventory requirements, other regulatory requirements).

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 AEI. Examples include heavy lubricants/oils, greases, hydraulic fluids, glycol deicers, non-solvent (aqueous) cleaners, etc.

21.2 Emission Calculations

If it is necessary to estimate emissions of miscellaneous chemicals consult with the local air pollution control agency for methods and cutoffs or use a material mass balance approach. Using the mass balance equation, emissions equal the total amount of product used minus the total amount of product remaining times the weight fraction (weight percent divided by 100) of the pollutant in the chemical.

$$E_{\text{pol}} = \text{QC} \times \text{D} \times \left(\frac{\text{WP}}{100} \right) \quad \text{Equation 21-1}$$

Where

E_{pol}	=	Emissions of a particular pollutant (lb/yr)
QC	=	Quantity of chemical product used minus quantity remaining (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.

21.3 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) 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 MSDS, other product literature, or from the manufacturer.

21.4 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%) Antimony Trioxide (2%) Pb Phosphite (1%)
General Adhesive	1.5	6.2	76%	Toluene (15%)

Calculate the VOC and HAP emissions from these chemicals.

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

$$E_{\text{pol}} = \text{QC} \times \text{D} \times \left(\frac{\text{WP}}{100} \right)$$

$$E_{\text{VOC}} = 12 \text{ gal/yr} \times 6.5 \text{ lb/gal} \times \left(\frac{100}{100} \right)$$

$$E_{\text{VOC}} = \mathbf{78.00 \text{ lb/yr.}}$$

b. Calculate the VOC emissions from the general purpose cleaner.

$$E_{\text{pol}} = \text{QC} \times \text{D} \times \left(\frac{\text{WP}}{100} \right)$$

$$E_{\text{VOC}} = 9 \text{ gal/yr} \times 8.4 \text{ lb/gal} \times \left(\frac{30}{100} \right)$$

$$E_{\text{VOC}} = \mathbf{22.68 \text{ lb/yr.}}$$

c. 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.)

$$E_{\text{pol}} = \text{QC} \times \text{D} \times \left(\frac{\text{WP}}{100} \right)$$

$$E_{\text{VOC}} = 6 \text{ gal/yr} \times 9.3 \text{ lb/gal} \times \left(\frac{85}{100} \right)$$

$$E_{\text{VOC}} = \mathbf{47.43 \text{ lb/yr}}$$

$$E_{\text{toluene}} = 6 \text{ gal/yr} \times 9.3 \text{ lb/gal} \times \left(\frac{35}{100} \right)$$

$$E_{\text{toluene}} = \mathbf{19.53 \text{ lb/yr.}}$$

$$E_{\text{methylene chloride}} = 6 \text{ gal/yr} \times 9.3 \text{ lb/gal} \times \left(\frac{20}{100}\right)$$

$$E_{\text{methylene chloride}} = \mathbf{11.16 \text{ lb/yr}}$$

$$E_{\text{antimony}} = 6 \text{ gal/yr} \times 9.3 \text{ lb/gal} \times \left(\frac{2}{100}\right)$$

$$E_{\text{antimony}} = \mathbf{1.12 \text{ lb/yr}}$$

$$E_{\text{lead}} = 6 \text{ gal/yr} \times 9.3 \text{ lb/gal} \times \left(\frac{1}{100}\right)$$

$$E_{\text{lead}} = \mathbf{0.56 \text{ lb/yr.}}$$

d. Calculate the VOC and HAP emissions from the general adhesive.

$$E_{\text{pol}} = \text{QC} \times \text{D} \times \left(\frac{\text{WP}}{100}\right)$$

$$E_{\text{VOC}} = 1.5 \text{ gal/yr} \times 6.2 \text{ lb/gal} \times \left(\frac{76}{100}\right)$$

$$E_{\text{VOC}} = \mathbf{7.07 \text{ lb/yr}}$$

$$E_{\text{toluene}} = 1.5 \text{ gal/yr} \times 6.2 \text{ lb/gal} \times \left(\frac{15}{100}\right)$$

$$E_{\text{toluene}} = \mathbf{1.40 \text{ lb/yr.}}$$

e. Finally, sum the total VOC and HAP emissions.

$$E_{\text{VOC(total)}} = 78.00 \text{ lb/yr} + 22.68 \text{ lb/yr} + 47.43 \text{ lb/yr} + 7.07 \text{ lb/yr}$$

$$E_{\text{VOC(total)}} = \mathbf{155.18 \text{ lb/yr.}}$$

$$E_{\text{HAP(total)}} = 19.53 \text{ lb/yr} + 11.16 \text{ lb/yr} + 1.12 \text{ lb/yr} + 0.56 \text{ lb/yr} + 1.40 \text{ lb/yr}$$

$$E_{\text{HAP(total)}} = \mathbf{33.77 \text{ lb/yr.}}$$

22 NON-DESTRUCTIVE INSPECTION

22.1 Introduction

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 ethanol, 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) 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) and spot check inspection penetrants. With this technique, the entire amount of chemical used is assumed to be emitted into the atmosphere.

22.2 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

$$E_{\text{pol}} = [(VA - VR) \times D] \times \left[\frac{WP}{100} \right] \quad \text{Equation 22-1}$$

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) [D = specific gravity of the chemical x 8.33 lb/gal]
WP	=	Weight percent of the pollutant in the chemical (%)
100	=	Factor for converting weight percent to a weight fraction.

b. Spray Applications

$$E_{\text{pol}} = VU \times D \times \left[\frac{WP}{100} \right] \quad \text{Equation 22-2}$$

Where

E_{pol}	=	Emissions of a particular pollutant (lb/yr)
VU	=	Volume of chemical used (gal/yr)
D	=	Density of the chemical (lb/gal) [D = specific gravity of the chemical \times 8.33 lb/gal]
WP	=	Weight percent of the pollutant in the chemical (%)
100	=	Factor for converting weight percent to a weight fraction.

The amount of chemical used in a spraying application is assumed to be emitted into the atmosphere in its entirety. For tank baths only the amount of chemicals that are directly evaporated are of concern.

22.3 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 MSDS, other product literature, or from the manufacturer.

22.4 Example Problem

Three chemicals are used in the process of cleaning and inspecting metal parts. Calculate the VOC, HAP and ODS emissions.

Chemical	Specific Gravity	Density (lb/gal)	Component(s)	Use Technique	Fresh Solvent Added/Used (gal/yr)	Waste Solvent Removed (gal/yr)
Inspection Penetrant	0.91	7.2	100% Petroleum Hydrocarbons	Tank Bath	100	95
Penetrant Remover	1.30	10.8	99% Methyl Chloroform 1% 1,4-Dioxane	Tank Bath	90	80
Isopropyl Alcohol	0.79	6.6	100% Isopropyl Alcohol	Sprayed On	8	Not Applicable

a. Calculate the VOC emissions in the inspection penetrant.

$$E_{\text{pol}} = [(VA - VR) \times D] \times \left[\frac{WP}{100} \right]$$

$$E_{\text{VOC}(\text{penetrant})} = [(100 \text{ gal/yr} - 95 \text{ gal/yr}) \times 7.2 \text{ lb/gal}] \times \left[\frac{100}{100} \right]$$

$$E_{\text{VOC}(\text{penetrant})} = \mathbf{36.0 \text{ lb/yr.}}$$

b. Using the example information provided above, calculate the emissions associated with the penetrant remover. Methyl chloroform is a HAP and an ODS. 1,4-Dioxane is a HAP and a VOC.

$$E_{\text{pol}} = [(VA - VR) \times D] \times \left[\frac{WP}{100} \right]$$

$$E_{\text{methyl chloroform}} = [(90 \text{ gal/yr} - 80 \text{ gal/yr}) \times 10.8 \text{ lb/gal}] \times \left[\frac{99}{100} \right]$$

$$E_{\text{methyl chloroform}} = \mathbf{106.92 \text{ lb/yr}}$$

$$E_{1,4\text{-Dioxane}} = [(90 \text{ gal/yr} - 80 \text{ gal/yr}) \times 10.8 \text{ lb/gal}] \times \left[\frac{1}{100}\right]$$

$$E_{1,4\text{-Dioxane}} = \mathbf{1.08 \text{ lb/yr}}$$

$$E_{\text{VOC(remover)}} = \mathbf{1.08 \text{ lb/yr.}}$$

- c. Using the information provided above, calculate the emissions associated with the isopropyl alcohol. Isopropyl alcohol is a VOC.

$$E_{\text{pol}} = \text{VU} \times \text{D} \times \left[\frac{\text{WP}}{100}\right]$$

$$E_{\text{VOC(alcohol)}} = 8 \text{ gal/yr} \times 6.6 \text{ lb/gal} \times \left[\frac{100}{100}\right]$$

$$E_{\text{VOC(alcohol)}} = \mathbf{52.8 \text{ lb/yr.}}$$

- d. Sum up the total VOC, total HAP, and total ODS emissions.

$$E_{\text{VOC(total)}} = 36.00 \text{ lb/yr} + 1.08 \text{ lb/yr} + 52.8 \text{ lb/yr}$$

$$E_{\text{VOC(total)}} = \mathbf{89.88 \text{ lb/yr}}$$

$$E_{\text{HAP(total)}} = 106.92 \text{ lb/yr} + 1.08 \text{ lb/yr}$$

$$E_{\text{HAP(total)}} = \mathbf{108.00 \text{ lb/yr}}$$

$$E_{\text{ODS(total)}} = \mathbf{106.92 \text{ lb/yr.}}$$

23 OPEN BURNING/OPEN DETONATION (OB/OD) OF ENERGETIC MATERIALS

23.1 Introduction

Disposal of bulk explosives, bulk propellants, small arms ammunition, high explosive incendiary (HEI) cartridges, bomb fuses, mines, flares/signals, and other munitions is often accomplished through OB/OD 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 cost considerations.

Munitions and assembled energetic materials are items in which the explosive material is contained in a metal casing. Munitions include small arms ammunition and HEI cartridges. Examples of assembled energetic materials include, bomb fuses, mines, flares/signals, and other similar items. Bulk energetic materials include bulk explosives (e.g., TNT, Composition B, RDX, smokeless powder) and bulk propellants (e.g., ammonium perchlorate, M-3, M-9, M-43, MK-6). 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 compositions of some common propellants and explosives are provided in Table 23-1. The mass of energetic material (MEM) and composition of common munitions and assembled energetic materials are provided in Table 23-2.

Beginning in the 1980's the DOD began conducting tests in an effort to quantify emissions from OB/OD operations. Much of this testing was at the Army's Dugway Proving Ground in Utah and culminated in the development of an Open Burn/Open detonation Dispersion Model (OBODM) (reference 1). The model includes a database of emission factors for a number of munitions and explosives. More recently, the EPA released Chapter 15, Ordnance Detonation, of AP-42 which includes emission factors for munitions, assembled energetic materials, explosives, and propellants. Emission factors for these sources are provided in Tables I-1 through I-12 in Appendix I.

The emission factors are in units of mass of pollutant emitted per quantity of 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) is usually attached. When a donor charge is used, the MEM used to calculate emissions includes the MEM contained in the munitions and the MEM of the donor charge used to help initiate the detonation.

Alternatively, the composition and MEM for most munitions used in the military can be obtained from the Army's Munitions Items Disposition Action System (MIDAS) at <https://midas.dac.army.mil/>. 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 is important to note that in many cases MIDAS will also list "alternative" energetic components/parts for a munition (identified by the abbreviation "ALT"). The mass of these alternative components/parts should not be included when determining the MEM for the munition.

23.2 Emission Calculation

The following equations are used to calculate emissions from emission factors:

(1) Open Burning of Munitions

$$E_{\text{pol}} = \text{QM} \times \text{EF} \quad \text{Equation 23-1}$$

Where

$$\begin{aligned} E_{\text{pol}} &= \text{Emissions of a particular pollutant (lb/yr)} \\ \text{QM} &= \text{Quantity of the munition open burned during the year (items/yr, rounds/yr)} \\ \text{EF} &= \text{Emission factor (lb/item, lb/round)}. \end{aligned}$$

(2) OB/OD of Assembled Energetic Materials, Explosives, and Propellants

$$E_{\text{pol}} = \text{QM} \times \text{EF} \quad \text{Equation 23-2}$$

Where

$$\begin{aligned} E_{\text{pol}} &= \text{Emissions of a particular pollutant (lb/yr)} \\ \text{QM} &= \text{Total mass of energetic material which is OB/OD during the year (lb/yr)} \\ \text{EF} &= \text{Emission factor (lb/lb)}. \end{aligned}$$

(3) Open Detonation of Munitions and Assembled Energetic Materials (also applicable to Bombing Range Activities)

$$E_{\text{pol}} = (\text{QM}_{\text{EM}} \times \text{EF}_{\text{EM}}) + (\text{QM}_{\text{DC}} \times \text{EF}_{\text{DC}}) \quad \text{Equation 23-3}$$

Where

$$\begin{aligned} E_{\text{pol}} &= \text{Emissions of a particular pollutant (lb/yr)} \\ \text{QM}_{\text{EM}} &= \text{Quantity of the munition open detonated during the year (items/yr, lb/yr)} \\ \text{EF}_{\text{EM}} &= \text{Emission factor of munition or assembled energetic material (lb/item, lb/lb)} \\ \text{QM}_{\text{DC}} &= \text{Quantity of donor charge open detonated during the year (lb/yr)} \\ \text{EF}_{\text{DC}} &= \text{Emission factor for donor charge (lb/lb)}. \end{aligned}$$

23.3 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 (OB/OD) 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) may be available from the base EOD shop.

The availability of emission factors for the various types of munitions used by the Air Force is limited and in many cases emission factors are not available, particularly in a test and development environment, making estimating emissions from munitions difficult. To facilitate emission estimations, surrogate emission factors may need to be used.

Table 23-1. 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 23-2. Composition of Common Munitions and Assembled Energetic Materials

DODIC	Munitions Type	Mass of Energetic Material (grams/munition)	Energetic Composition (Major Ingredients only)
A890	20 mm HEI Cartridge, M56A4	48.6	69.2% nitrocellulose, 17.9% RDX, 6.8% nitroglycerin
B470	40 mm HEI Cartridge, M384	59	90.3% RDX, 5.9% nitrocellulose, 1.9% stearic acid, 1.5% nitroglycerin
J473	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
MG11	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
M943	Cartridge, Impulse, MK107	24.6	70.7% nitrocellulose, 20.3% nitroglycerin, 4.9% potassium nitrate, 4.1% barium nitrate
L410	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
F762	Fuse, Tail Bomb, FMU-139A/B	126	100% tetryl
F841	Fuse, Tail Bomb, FMU-54A/B	163.9	99.9% tetryl
	Gas Generator, GGU-2/A	95.3	Composition is classified
K145	Mine, Claymore, M18A1	681	100% C-4
L231	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
L306	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
F372	T45E7 Adapter-booster	73.2	98% tetryl, 2% graphite

23.4 Example Problem

Approximately 45 pounds of TNT were open detonated during the year along with twenty 40-mm high explosive cartridges (M383). A donor charge of approximately 10 grams of C-4 explosive was used per 40 mm cartridge.

a. Calculate the NO_x and benzene emissions associated with the open detonation of the TNT.

$$E_{\text{pol}} = \text{QM} \times \text{EF}$$

Pollutant Criteria	QM Detonated (lb/yr)		Emission Factor (lb/lb)	=	Emissions (lb/yr)
NO _x (NO + NO ₂ ; as NO ₂)	45	x	1.0 x 10 ⁻²	=	0.45
HAP					
Benzene	45	x	4.1 x 10 ⁻⁶	=	1.85 x 10⁻⁴

Calculate the emissions associated with the open detonation of the 40 mm cartridges.

Emission factors are not available in Appendix I for C-4, but Table 23-1 shows that the composition of C-4 is 91% RDX. Therefore, estimate the emissions from C-4 by using the emission factors for RDX in the calculations.

20 Cartridges x 10 grams C-4/cartridge x 1 lb/453.6 grams = 0.44 lb C-4/yr detonated.

$$E_{\text{pol}} = (\text{QM}_{\text{EM}} \times \text{EF}_{\text{EM}}) + (\text{QM}_{\text{DC}} \times \text{EF}_{\text{DC}})$$

Pollutant Criteria	Cartridges (items/yr)		Emission Factor (lb/item)	+	Donor Charge (lb/yr)		Emission Factor (lb/lb)	=	Emissions (lb/yr)
NO _x	20	x	1.6 x 10 ⁻³	+	0.44	x	1.5 x 10 ⁻³	=	0.033
HAP									
Benzene	20	x	7.4 x 10 ⁻⁶	+	0.44	x	6.9 x 10 ⁻⁶	=	1.51 x 10⁻⁴

23.5 References

U.S. Army West Desert Test Center, *Open Burn/Open Detonation Dispersion Model (OBODM)*, Model and Users Guide, February 1998.

U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors-Volume I: Stationary Point and Area Sources* (AP-42), Section 15.x, "Ordnance Detonation," July 2006.

U.S. Army Defense Ammunition Center, *Munitions Items Disposition Action System (MIDAS)*, Central Library Version 74, 1 May 1998.

24 OPEN/PREScribed BURNING

24.1 Introduction

Open burning and prescribed burning are used in the disposal of agricultural refuse and the management of natural resources. Emissions of concern include criteria pollutants and the HAPs acetaldehyde and POM.

Open Burning

Open burning is performed on some Air Force installations as a means of disposing of a various types of landscape and agricultural refuse such as leaves, wood, forest residue, field crops (including grasses and wild hay), weeds, etc. Current regulations prohibit the open burning of hazardous wastes with the exception of OB/OD of explosives (see Chapter 23).

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.

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.

24.2 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.

$$E_{\text{pol}} = \text{MB} \times \text{EF} \quad \text{Equation 24-1}$$

Where

$$\begin{aligned} E_{\text{pol}} &= \text{Emissions of pollutant during the year (lb/yr)} \\ \text{MB} &= \text{Mass of MB during the year (ton/yr)} \\ \text{EF} &= \text{Emission Factor (lb/ton)}. \end{aligned}$$

For open/prescribed burning of certain types of 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).

$$\text{MB} = \text{AB} \times \text{FLF} \quad \text{Equation 24-2}$$

Where

$$\begin{aligned} \text{MB} &= \text{Mass of MB during the year (ton/yr)} \\ \text{AB} &= \text{Area of MB (acres/yr)} \\ \text{FLF} &= \text{Fuel Loading Factor (tons/acre)}. \end{aligned}$$

The emission factors associated with open/prescribed burning are found in Tables 24-1 through 24-4 below.

Table 24-1. Criteria Pollutant Emission Factors for Open Burning of Agricultural Materials

Refuse Category	PM ^a (lb/ton)	CO (lb/ton)	Non-methane VOC (lb/ton)	NO _x (lb/ton)	Fuel Loading Factors (ton/acre)
Wood (SCC 5-02-002-01)	17	140	19	4	ND
Field Crops (SCC 5-02-002-03)					
Unspecified	21	117	18	b	2
Grasses	16	101	15	b	ND
Wild Hay (Headfire Burning)	32	139	17	b	1.0
Wild Hay (Backfire Burning)	17	150	13	b	1.0
Weeds (SCC 5-02-002-05)					
Unspecified	15	85	9	b	3.2
Russian thistle (tumbleweed)	22	309	1.5	b	0.1
Tales (wild reeds)	5	34	21	b	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

Note: 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. See Appendix C for a discussion of SCCs. Emission factors are expressed as weight (pounds) of pollutant emitted per weight (tons) of refuse burned. ND = No Data.

^a. PM from most agricultural refuse burning has been found to be submicron in size.

^b. 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 24-2. Criteria Pollutant Emission Factors for Leaf Burning

Leaf Species	PM ^a (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

Note: The general SCC for the “Wood/Vegetation/Leaves” category is 5-03-002-01.

See Appendix C for a discussion of SCCs.

Emission factors are expressed as weight (pounds) of pollutant emitted per weight (tons) of refuse burned.

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.

^a. The majority of PM is submicron in size.

Table 24-3. HAP Emission Factors for Open Burning of Agricultural Materials

Refuse Category	Acetaldehyde (lb/ton)	POM (lb/ton)
Wood/Vegetation/Leaves (SCC 5-03-002-01)	1.46	0.013

Note: Emission factors are expressed as weight (pounds) of pollutant emitted per weight (tons) of refuse burned. See Appendix C for a discussion of SCCs.

Table 24-4. Emission Factors for Prescribed Burning

Fire/Fuel Configuration	Phase ^a	Pollutants (lb/ton)					Fuel Mix (%)
		Particulate			Carbon Monoxide	NonCH4 VOCs	
		PM _{2.5}	PM ₁₀	Total			
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	NA
Conifer Short needle	F	14	16	24	144	4.2	33
	S	28	30	38	452	8.4	67
	Fire	24	26	34	350	ND	NA
Long needle	F	12	12	18	90	3.4	33
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	NA
10–30% 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	NA
Sagebrush	F	30	32	46	156	6.8	ND
	S	26	30	46	212	14.6	ND
	Fire	26	30	46	206	13.8	NA
Chaparral shrub communities	F	14	16	32	112	16.4	ND
	S	24	26	46	266	31.2	ND
Line fire Conifer Long needle (pine)	Heading	ND	80	100	400	ND	ND
	Backing	ND	40	40	250	ND	ND
Palmetto/gallberry	Heading	ND	30	34	300	ND	ND
	Backing	ND	30	30	200	ND	ND
	Fire	ND	16 - 44	ND	ND	ND	ND
Chaparral grasslands	Heading	16	18	30	124	7	ND
	Fire	ND	20	20	150	0	ND

Note: 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.

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.

ND = No Data; NA = Not Applicable.

^a F = flaming; S = smoldering; Fire = weighted average of F and S.

24.3 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) for additional information, such as the estimated mass (tons) of a specific vegetation per area (acre) of land.

24.4 Example Problem

An 18 acre field of wild hay was open burned using the “headfire burning” method. Calculate both the PM and POM emissions:

a. First step is to calculate the mass of wild hay burned.

$$\begin{aligned} \text{MB} &= \text{AB} \times \text{FLF} \\ \text{MB} &= (18 \text{ acres/yr}) \times (1.0 \text{ tons/acre}) \\ \text{MB} &= \mathbf{18.0 \text{ tons/yr}} \end{aligned}$$

b. Second step is to calculate the pollutant emissions using the appropriate emission factors.

$$E_{\text{pol}} = \text{MB} \times \text{EF}$$

Pollutant	Mass Material Burned (tons/yr)		Emission Factor (lb/ton)	=	Emissions (lb/yr)
PM	18.0	x	32	=	576.00
POM	18.0	x	0.013	=	0.23

24.5 References

U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors-Volume I: Stationary Point and Area Sources* (AP-42), Section 2.5, “Open Burning,” October 1992 (Reformatted January 1995).

U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors Volume I: Stationary Point and Area Sources* (AP-42), Section 13.1, “Wildfires and Prescribed Burning,” October 1996.

25 ODSs

25.1 Introduction

ODSs are found in a variety of products used on Air Force installations. Class I and Class II ODSs regulated under Title VI of the CAA are listed below in Tables 25-1 and 25-2 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), 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 25-1. Class I ODSs

Substance	Chemical Name	ODP ^a	CAS Number
Group I			
CFCl ₃ (CFC-11)	Trichlorofluoromethane	1.0	75-69-4
CF ₂ Cl ₂ (CFC-12)	Dichlorodifluoromethane	1.0	75-71-8
C ₂ F ₃ Cl ₃ (CFC-113)	1,1,1-Trichlorotrifluoroethane	0.8	354-58-5
	1,1,2-Trichlorotrifluoroethane	0.8	76-13-1
C ₂ F ₄ Cl ₂ (CFC-114)	Dichlorotetrafluoroethane	1.0	76-14-2
C ₂ F ₅ Cl (CFC-115)	Monochloropentafluoroethane	0.6	76-15-3
(All isomers of the above chemicals)			
Group II			
CF ₂ ClBr (Halon 1211)	Bromochlorodifluoromethane	3.0	353-59-3
CF ₃ Br (Halon 1301)	Bromotrifluoromethane	10.0	75-63-8
C ₂ F ₄ Br ₂ (Halon 2402)	Dibromotetrafluoroethane	6.0	124-73-2
(All isomers of the above chemicals)			
Group III			
CF ₃ Cl (CFC-13)	Chlorotrifluoromethane	1.0	75-72-9
C ₂ FCl ₅ (CFC-111)	Pentachlorofluoroethane	1.0	354-56-3
C ₂ F ₂ Cl ₄ (CFC-112)	Tetrachlorodifluoroethane	1.0	76-12-0
C ₃ FCl ₇ (CFC-211)	Heptachlorofluoropropane	1.0	422-78-6
C ₃ F ₂ Cl ₆ (CFC-212)	Hexachlorodifluoropropane	1.0	3182-26-1
C ₃ F ₃ Cl ₅ (CFC-213)	Pentachlorotrifluoropropane	1.0	2354-06-5
C ₃ F ₄ Cl ₄ (CFC-214)	Tetrachlorotetrafluoropropane	1.0	29255-31-0
C ₃ F ₅ Cl ₃ (CFC-215)	Trichloropentafluoropropane	1.0	1599-41-3
C ₃ F ₆ Cl ₂ (CFC-216)	Dichlorohexafluoropropane	1.0	661-97-2
C ₃ F ₇ Cl (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
C ₂ H ₃ Cl ₃	Methyl Chloroform (1,1,1-trichloroethane)	0.1	71-55-6
(All isomers except 1,1,2-trichloroethane)			
Group VI			
CH ₃ Br	Methyl bromide	0.6	74-83-9

Table 25-1. [Con't] Class I ODSs

Substance	Chemical Name	ODP ^a	CAS Number
Group VII			
CHBr ₂		1.0	
CHF ₂ Br (HBFC-2201)		0.74	
CH ₂ FBr		0.73	
C ₂ H ₂ FBr ₄		0.3 - 0.8	
C ₂ H ₂ F ₂ Br ₃		0.5 - 1.8	
C ₂ H ₂ F ₃ Br ₂		0.4 - 1.6	
C ₂ H ₂ F ₄ Br		0.7 - 1.2	
C ₂ H ₂ FBr ₃		0.1 - 1.1	
C ₂ H ₂ F ₂ Br ₂		0.2 - 1.5	
C ₂ H ₂ F ₃ Br		0.7 - 1.6	
C ₂ H ₃ FBr ₂		0.1 - 1.7	
C ₂ H ₃ F ₂ Br		0.2 - 1.1	
C ₂ H ₄ Br		0.07 - 0.1	
C ₃ H ₂ FBr ₆		0.3 - 1.5	
C ₃ H ₂ F ₂ Br ₅		0.2 - 1.9	
C ₃ H ₂ F ₃ Br ₄		0.3 - 1.8	
C ₃ H ₂ F ₄ Br ₃		0.5 - 2.2	
C ₃ H ₂ F ₅ Br ₂		0.9 - 2.0	
C ₃ H ₂ F ₆ Br		0.7 - 3.3	
C ₃ H ₂ FBr ₅		0.1 - 1.9	
C ₃ H ₂ F ₂ Br ₄		0.2 - 2.1	
C ₃ H ₂ F ₃ Br ₃		0.2 - 5.6	
C ₃ H ₂ F ₄ Br ₂		0.3 - 7.5	
C ₃ H ₂ F ₅ Br		0.9 - 1.4	
C ₃ H ₃ FBr ₄		0.08 - 1.9	
C ₃ H ₃ F ₂ Br ₃		0.1 - 3.1	
C ₃ H ₃ F ₃ Br ₂		0.1 - 2.5	
C ₃ H ₃ F ₄ Br		0.3 - 4.4	
C ₃ H ₄ FBr ₃		0.03 - 0.3	
C ₃ H ₄ F ₂ Br ₂		0.1 - 1.0	
C ₃ H ₄ F ₃ Br		0.07 - 0.8	
C ₃ H ₅ FBr ₂		0.04 - 0.4	
C ₃ H ₅ F ₂ Br		0.07 - 0.8	
C ₃ H ₆ FBr		0.02 - 0.7	
Group VIII			
CH ₂ BrCl	Chlorobromomethane	0.12	

^a Ozone Depletion Potential

Table 25-2. Class II ODSs

Substance	ODP ^a
CHFC1 ₂ -Dichlorofluoromethane (HCFC-21)	0.04
CHF ₂ Cl-Chlorodifluoromethane (HCFC-22)	0.055
CH ₂ FCl-Chlorofluoromethane (HCFC-31)	0.02
C ₂ HFCl ₄ -(HCFC-121)	0.01 - 0.04
C ₂ HF ₂ Cl ₃ -(HCFC-122)	0.02 – 0.08
C ₂ HF ₃ Cl ₂ -(HCFC-123)	0.02 – 0.06
C ₂ HF ₄ Cl-(HCFC-124)	0.02 – 0.04
C ₂ H ₂ FCl ₃ -(HCFC-131)	0.007 – 0.05
C ₂ H ₂ F ₂ Cl ₂ -(HCFC-132b)	0.008 – 0.05
C ₂ H ₂ F ₃ Cl-(HCFC-133a)	0.02 – 0.06
C ₂ H ₃ FCl ₂ -(HCFC-141b)	0.11
C ₂ H ₃ F ₂ Cl-(HCFC-142b)	0.065
C ₃ HCFC1 ₆ -(HCFC-221)	0.015 – 0.07
C ₃ HF ₂ Cl ₅ -(HCFC-222)	0.01 – 0.09
C ₃ HF ₃ Cl ₄ -(HCFC-223)	0.01 – 0.08
C ₃ HF ₄ Cl ₃ -(HCFC-224)	0.01 – 0.09
C ₃ HF ₅ Cl ₂ -(HCFC-225ca)	0.025
C ₃ HF ₅ Cl-(HCFC-225cb)	0.033
C ₃ HF ₆ Cl-(HCFC-226)	0.02 – 0.10
C ₃ H ₂ FCl ₅ -(HCFC-231)	0.05 – 0.09
C ₃ H ₂ F ₂ Cl ₄ -(HCFC-232)	0.008 – 0.10
C ₃ H ₂ F ₃ Cl ₃ -(HCFC-233)	0.007 – 0.23
C ₃ H ₂ F ₄ Cl ₂ -(HCFC-234)	0.01 – 0.28
C ₃ H ₂ F ₅ Cl-(HCFC-235)	0.03 – 0.52
C ₃ H ₃ FCl ₄ -(HCFC-241)	0.004 – 0.09
C ₃ H ₃ F ₂ Cl ₃ -(HCFC-242)	0.005 – 0.13
C ₃ H ₃ F ₃ Cl ₂ -(HCFC-243)	0.007 – 0.12
C ₃ H ₃ F ₄ Cl-(HCFC-244)	0.009 – 0.14
C ₃ H ₄ FCl ₃ -(HCFC-251)	0.001 – 0.010
C ₃ H ₄ F ₂ Cl ₂ -(HCFC-252)	0.005 – 0.04
C ₃ H ₄ F ₃ Cl-(HCFC-253)	0.003 – 0.030
C ₃ H ₅ FCl ₂ -(HCFC-261)	0.002 – 0.020
C ₃ H ₅ F ₂ Cl-(HCFC-262)	0.002 – 0.020
C ₃ H ₆ FCl-(HCFC-271)	0.001 – 0.030
All isomers of the above chemicals	

^a Ozone Depletion Potential.

25.2 Emission Calculations

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. The Federal CAA Toolbox recommends the following emissions calculations:

$$E_i \text{ (lb/yr)} = (Q_{\text{make-up}} - Q_{\text{disposed}}) \times P \times C_i \quad \text{Equation 25-1}$$

Where

- Q_{make-up} = Annual amount of ODS make-up, gallons (gal)
- Q_{disposed} = Annual amount of ODS disposed (gal)
- P = ODS density, (lb/gal)
- C_i = Chemical *i* speciation, fraction (%).

25.3 Information Resources

Records/data maintained by the Hazardous Materials Pharmacy should be used to identify which products on base contain ODSs and to identify which shops use them. The weight percent of ODS in each applicable product can be determined from MSDS 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:

Table 25-3. ODS Type and Possible Location

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) 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.

25.4 Example Problem

Approximately 15 gallons of Freon 13 were added to a base air conditioning system during the year. Ten gallons were removed/recovered during the year. Calculate the annual emissions.

$$\begin{aligned}
 E_i \text{ (lb/yr)} &= (Q_{\text{make-up}} - Q_{\text{disposed}}) \times P \times C_i \\
 E_{\text{voc}} &= (15-10) \times (8.0) \times \left(\frac{100}{100}\right) \\
 &= 40 \text{ lb/yr} \\
 &= (40\text{lb})/(365 \text{ days} \times 24\text{hrs}) = \mathbf{0.0046 \text{ lb/hr.}}
 \end{aligned}$$

25.5 References

“Clean Air Act Compliance Tool Box,” The Air Force Center for Environmental Excellence, 7 May 06, <<http://www.afcee.brooks.af.mil/products/air/federal/emisest/aircond.html>>.

U.S. Environmental Protection Agency, Class I Ozone-Depleting Substances, <<http://www.epa.gov/ozone/ods.html>>.

U.S. Environmental Protection Agency, Class II Ozone-Depleting Substances, <<http://www.epa.gov/ozone/ods2.html>>.

26 PESTICIDE APPLICATION

26.1 Introduction

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. Pesticide application data can be found at the Integrated Pesticide Information Management System (IPMIS) which is available through the Armed Forces Pest Management Board web site at <http://www.afpmb.org/ipmis.htm>.

26.2 Emission Calculations

a. VOC emissions from pesticide application.

(1) VOC Emissions (if weight percent VOC is known)

$$E_{\text{VOC}} = \text{QP} \times \left[\frac{\text{WP}_{\text{VOC}}}{100} \right] \quad \text{Equation 26-1}$$

Where

E_{VOC}	=	Emissions of VOC (lb/yr)
QP	=	Quantity of pesticide applied (lb/yr)
WP_{VOC}	=	Weight percent of VOC in the pesticide (%)
100	=	Factor for converting weight percent to a weight fraction.

Note: If the mass (pounds) of pesticide applied is not known, but the volume (gallons) is, the mass can be calculated by multiplying the volume by the pesticide density (lb/gal). If the density is not known, but the specific gravity is, the density can be calculated by multiplying the specific gravity by the density of water (8.33 lb/gal).

(2) VOC Emissions (if weight percent VOC is unknown)

Divide the pesticide into its two major component groups, active ingredients and inert portions. A list of active ingredients may be available on the pesticide container, manufacturer's MSDS, or in Chapter 9.2.2 of AP-42. As stated in AP-42, EPA is concerned with only VOC emissions which are expected to occur within 30 days after application. 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). 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), and type of application (e.g., surface application, soil incorporation). The VOC emissions can be estimated using the following equation:

$$E_{\text{VOC}} = \left[\text{QP} \times \left(\frac{\text{WP}_{\text{active}}}{100} \right) \times 0.0005 \times \text{EF} \right] + \left[\text{QP} \times \left(\frac{\text{WP}_{\text{inert}}}{100} \right) \times \left(\frac{\text{WP}_{\text{VOC-inert}}}{100} \right) \right] \text{ Equation 26-2}$$

Where

E_{VOC}	=	Emissions of VOC (lb/yr)
QP	=	Quantity of pesticide applied (lb/yr)
$\text{WP}_{\text{active}}$	=	Weight Percent of Active Ingredient portion in pesticide (%)
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 (%)
$\text{WP}_{\text{VOC-inert}}$	=	Weight Percent VOC in the Inert portion of the pesticide (%)
100	=	Factor for converting weight percent to a weight fraction.

It is important to note that the weight percent VOC in the inert portion of the pesticide ($\text{WP}_{\text{VOC-inert}}$) is not the same as the weight percent VOC in the entire pesticide (WP_{VOC}). In some cases, the $\text{WP}_{\text{VOC-inert}}$ can be derived by reviewing the inert ingredients (and their corresponding weight percentages) listed in the MSDS. If the $\text{WP}_{\text{VOC-inert}}$ is not known, then use the appropriate average value listed in Table 26-1.

Emission factors associated with the active ingredient portion of pesticides are listed in Table 26-2. 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 are listed in Table 26-3.

Table 26-1. Average VOC Contents of the Inert Portion of Various Pesticide Formulations

Formulation Type	Average VOC Content of Inert Portion (wt. %)
Aqueous concentrate	21
Dry flowable	28
Dust/powder	21
Emulsifiable concentrate	56
Flowable (aqueous) concentrate	21
Gel, paste, cream	40
Granule/flake	25
Impregnated material	38
Microencapsulated	23
Oils	66
Paint/coatings	64
Pellet/tablet/cake/briquette	27
Pressurized gas	29
Pressurized liquid/sprays/foggers	39
Soluble powder	12
Solution/liquid (ready to use)	20
Suspension	15
Wetable powder	25

Table 26-2. Uncontrolled VOC Emission Factors for Pesticide Active Ingredients

Application Method	Vapor Pressure Range (mm Hg at 20 to 25°C)	Emission Factor (lb/ton) ^a
Surface application (SCC ^b 24-61-800-001)	1 x 10 ⁻⁴ to 1 x 10 ⁻⁶ >1 x 10 ⁻⁴	700 1,160
Soil incorporation (SCC _b 24-61-800-002)	<1E-06 1E-04 to 1E-06 >1E-04	5.4 42 104

^a. Emission Factors are in units of pounds VOC emitted per ton of active ingredient applied.

^b. SCC: Source Classification Code (See Appendix C).

Table 26-3. Vapor Pressures for Common Pesticide Active Ingredients

Active Ingredient	Vapor Pressure ^a	Active Ingredient	Vapor Pressure ^a	Active Ingredient	Vapor Pressure ^a
1,3-Dichloropropene	29	Dichlobenil	1.0E-03	Norflurazon	2.0E-08
2,4-D acid	8.0E-06	Dicofol	4.0E-07	Oxamyl	2.3E-04
Acephate	1.7E-06	Dicrotofos	1.6E-04	Oxyfluorfen	2.0E-07
Alachlor	1.4E-05	Dimethoate	2.5E-05	Parathion (ethyl parathion)	5.0E-06
Aldicarb	3.0E-05	Dinocap	4.0E-08	PCNB	1.1E-04
Aldoxycarb	9.0E-05	Disulfoton	1.5E-04	Pendimethalin	9.4E-06
Amitraz	2.6E-06	Diuron	6.9E-08	Permethrin	1.3E-08
Amitrole (aminotriazole)	4.4E-07	Endosulfan	1.7E-07	Phorate	6.4E-04
Atrazine	2.9E-07	EPTC	3.4E-02	Phosmet	4.9E-07
Azinphos-methyl	2.0E-07	Ethalfuralin	8.8E-05	Profenofos	9.0E-07
Benefin (benfluralin)	6.6E-05	Ethion	2.4E-06	Prometon	7.7E-06
Benomyl	<1.0E-10	Ethoprop (ethoprophos)	3.8E-04	Prometryn	1.2E-06
Bifenox	2.4E-06	Fenamiphos	1.0E-06	Propachlor	2.3E-04
Bromacil acid	3.1E-07	Fenthion	2.8E-06	Propanil	4.0E-04
Bromoxynil butyrate ester	1.0E-04	Fluometuron	9.4E-07	Propargite	3.0E-03
Butylate	1.3E-02	Fonofos	3.4E-04	Propazine	1.3E-07
Captan	8.0E-08	Isofenphos	3.0E-06	Propoxur	9.7E-06
Carbaryl	1.2E-06	Lindane	3.3E-05	Siduron	4.0E-09
Carbofuran	6.0E-07	Linuron	1.7E-05	Simazine	2.2E-08
Chlorobenzilate	6.8E-06	Malathion	8.0E-05	Tebuthiuron	2.0E-06
Chloroneb	3.0E-03	Methamidophos	8.0E-04	Terbacil	3.1E-07
Chloropicrin	18	Methazole	1.0E-06	Terbufos	3.2E-04
Chlorothalonil	1.0E-03 (estimated)	Methiocarb (mercaptodimethur)	1.2E-04	Thiobencarb	2.2E-05
Chlorpyrifos	1.7E-05	Methomyl	5.0E-05	Thiodicarb	1.0E-07
Clomazone (dimethazone)	1.4E-04	Methyl parathion	1.5E-05	Toxaphene	4.0E-06
Cyanazine	1.6E-09	Metolachlor	3.1E-05	Triallate	1.1E-04
Cyromazine	3.4E-09	Metribuzin	<1.0E-05	Tribufos	1.6E-06
DCNA (dicloran)	1.3E-06	Mevinphos	1.3E-04	Trichlorfon	2.0E-06

Active Ingredient	Vapor Pressure ^a	Active Ingredient	Vapor Pressure ^a	Active Ingredient	Vapor Pressure ^a
DCPA (chlorthal-dimethyl; Dacthal®)	2.5E-06	Molinate	5.6E-03	Trifluralin	1.1E-04
Diazinon	6.0E-05	Naled	2.0E-04	Triforine	2.0E-07

^a All vapor pressure values reported as mm Hg at 20–25 °C.

b. HAP emissions associated with pesticide application. 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. This is done by either reviewing the MSDS, 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 by the amount (mass) of pesticide applied.

$$E_{\text{HAP}} = \text{QP} \times \left[\frac{\text{WP}_{\text{HAP}}}{100} \right] \quad \text{Equation 26-3}$$

Where

- E_{HAP} = Emissions of a particular HAP (lb/yr)
- QP = Quantity of pesticide applied (lb/yr)
- WP_{HAP} = Weight percent of HAP in the pesticide (%)
- 100 = Factor to convert weight percent to a weight fraction.

As noted above, if the mass (pounds) of pesticide applied is not known but the volume (gallons) is, then the mass can be calculated from the density (lb/gal) or specific gravity of the pesticide.

26.3 Information Resources

Information about the names, EPA Registration Numbers, 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, the 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
- IPMIS. <http://www.afpmb.org/ipmis.htm>.

26.4 Example Problem

Twenty-five gallons of Dursban™ insecticide were applied to the ground surface. Dursban is an emulsifiable concentrate with the following composition (percent 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. First, calculate the mass of the pesticide applied.

$$\begin{aligned}\text{Mass} &= \text{Volume} \times \text{Density} \\ \text{Density} &= (\text{Specific Gravity}) \times (\text{Density of Water})\end{aligned}$$

$$\begin{aligned}\text{Density} &= 0.999 \times 8.33 \text{ lb/gal} \\ \text{Density} &= \mathbf{8.32 \text{ lb/gal}} \\ \text{Mass} &= 25 \text{ gal/yr} \times 8.32 \text{ lb/gal} \\ \text{Mass} &= \mathbf{208.00 \text{ lb/yr}}\end{aligned}$$

b. Second, calculate the HAP emissions. The only HAP is methyl chloroform.

$$\begin{aligned}E_{\text{HAP}} &= \text{QP} \times \left[\frac{\text{WP}_{\text{HAP}}}{100} \right] \\ E_{\text{methyl chloroform}} &= 208.00 \text{ lb/yr} \times \left[\frac{35.5}{100} \right] \\ E_{\text{methyl chloroform}} &= \mathbf{73.84 \text{ lb/yr.}}\end{aligned}$$

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.

$$E_{\text{VOC}} = \left[\text{QP} \times \left(\frac{\text{WP}_{\text{active}}}{100} \right) \times 0.0005 \times \text{EF} \right] + \left[\text{QP} \times \left(\frac{\text{WP}_{\text{inert}}}{100} \right) \times \left(\frac{\text{WP}_{\text{VOC inert}}}{100} \right) \right]$$

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 ($\text{WP}_{\text{VOC inert}}$), must first be determined.

d. The vapor pressure of the active ingredient (chlorpyrifos) is 1.7×10^{-5} mm Hg (from Table 26-3). Based on this vapor pressure and the fact that the pesticide is applied to the surface, the appropriate emission factor is 700 lb/ton (from Table 26-2).

e. The weight percent VOC in the inert portion ($\text{WP}_{\text{VOC-inert}}$) can be calculated using MSDS information. Although both inert ingredients (light aromatic naphtha and methyl chloroform) are VOCs, methyl chloroform is not considered a VOC since it has 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.

$$\begin{aligned}\text{WP}_{\text{VOC-inert}} &= \left[\frac{42.1\%}{42.1\% + 35.5\%} \right] \times 100 \\ \text{WP}_{\text{VOC-inert}} &= \mathbf{54.25\%}\end{aligned}$$

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

$$E_{\text{VOC}} = \left[\text{QP} \times \left(\frac{\text{WP}_{\text{active}}}{100} \right) \times 0.0005 \times \text{EF} \right] + \left[\text{QP} \times \left(\frac{\text{WP}_{\text{inert}}}{100} \right) \times \left(\frac{\text{WP}_{\text{VOC inert}}}{100} \right) \right]$$

$$E_{\text{VOC}} = [208 \text{ lb/yr} \times \left(\frac{22.4}{100}\right) \times (0.0005 \text{ ton/lb}) \times 700 \text{ lb/ton}] + [208.00 \text{ lb/yr} \times \left(\frac{42.1+35.5}{100}\right) \times \left(\frac{54.25}{100}\right)]$$

$$E_{\text{VOC}} = \mathbf{103.87 \text{ lb/yr.}}$$

26.5 References

Emissions Inventory Improvement Program (EIIP), *Volume III: Chapter 9, "Pesticides - Agricultural and Nonagricultural,"* June 2001.

U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources* (AP-42), Section 9.2.2, "Pesticide Application," January 1995.

27 PRINTING OPERATIONS

27.1 Introduction

The six basic processes of the printing industry include web offset lithography, web letterpress, rotogravure, flexography, screen, and plateless. Emissions of concern from printing operations include VOC and organic HAPs, which originate from the chemicals associated with printing, such as inks and solvents. Such emissions vary with printing process, ink formulation and coverage, press size and speed, and operating time. Further guidance on printing operations can be found in Sections 4.9.1 and 4.9.2 of AP-42 and in the EIIP Technical Report.

27.2 Emission Calculations

Emissions associated with printing operations can be estimated using the following equation:

$$E_{\text{pol}} = \left[(VP - VR) \times \left(D \times \left(\frac{WP}{100} \right) \right) \right] \times \left[1 - \left(\frac{P}{100} \right) \right] \quad \text{Equation 27-1}$$

Where

E_{pol}	=	Emissions of a particular pollutant (lb/yr)
VP	=	Volume of ink purchased (gal/yr)
VR	=	Volume of ink recycled (gal/yr)
D	=	Density of solvent (lb/gal)
WP	=	Weight percent of the pollutant in the solvent (%)
P	=	Solvent remaining in product and destroyed in dryer (%)
100	=	Factor for converting percent to a decimal fraction.

Note: Values for P are included in Table 27-1 below.

Emissions associated with print line components such as the dryer can be calculated using the following equation:

$$E_{\text{pol}} = \left(\frac{I \times S \times D}{100} \right) \times \left(\frac{100 - P}{100} \right) \quad \text{Equation 27-2}$$

Where

E_{pol}	=	Emissions of a particular pollutant from print line (lb/yr)
I	=	Volume of ink use (gal/yr)
S	=	Solvent content of ink (volume %)
D	=	Density of solvent (lb/gal)
P	=	Solvent remaining in product and destroyed in dryer (%)

Note: Values for S and P are included in Table 27-1 below.

27.3 Information Resources

Information necessary to calculate emissions from printing operations can be obtained from the shop that uses the equipment. Information on the VOC content, HAP composition, and density (or specific gravity) of the solvent can usually be obtained from the product literature (e.g., MSDS,

container label, technical specification sheet), the commercial vendor, or the product manufacturer. Additional emission factors for printing operations are included in EPA's FIRE data system.

Table 27-1. Typical Parameters for Computing Solvent Emissions from Printing Lines

Process	Solvent Content of Ink (Volume %) [S] ^a	Solvent Remaining In Product Plus That Destroyed in Dryer (%) [P] ^{a,b}
Web Offset Lithography		
Publication	40	40 (hot air dryer) 60 (direct flame dryer)
Newspaper	5	100
Web Letterpress		
Publication	40	40
Newspaper	0	NA ^c
Rotogravure	75	2-7
Flexography	75	2-7

^a. Values for S and P are typical. Specific values for S and P should be obtained from a source to estimate its emissions.

^b. For certain packaging products, amounts of solvent retained is regulated by the Food and Drug Administration (FDA).

^c. NA = not applicable

27.4 Example Problem

A base printing operation purchases 120 gallons of ink in a year to print a publication utilizing a web offset lithography printing process with a hot air dryer. Twenty-four gallons of ink were recycled over the year. Literature associated with the ink indicates the density of the ink is 7.65 lb/gal and contains 88 percent VOC by weight. Calculate annual VOC emissions from printing operations, including the dryer.

Calculate the VOC emissions from printing:

$$E_{\text{VOC}} = [(VP - VR) \times (D \times (\frac{WP}{100}))] \times [1 - (\frac{P}{100})]$$

$$E_{\text{VOC}} = [(120 - 24) \times (7.65 \times (\frac{88}{100}))] \times [1 - (\frac{40}{100})]$$

$$E_{\text{VOC}} = \mathbf{387.76 \text{ lb/yr}}$$

Calculate the VOC emissions associated with print line components:

$$E_{\text{VOC}} = (\frac{I \times S \times D}{100}) \times (\frac{100 - P}{100})$$

$$E_{\text{VOC}} = (\frac{96 \times 40 \times 7.65}{100}) \times (\frac{100 - 40}{100})$$

$$E_{\text{VOC}} = \mathbf{176.26 \text{ lb/yr}}$$

Calculate the total VOC emissions associated with the printing operations.

$$\text{Total } E_{\text{VOC}} = 387.76 \text{ lb/yr} + 176.26 \text{ lb/yr}$$

$$\text{Total } E_{\text{VOC}} = \mathbf{564.02 \text{ lb/yr.}}$$

27.5 References

U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources* (AP-42), Section 4.9.1, “General Graphic Printing,” April 1981.

U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources* (AP-42), Section 4.9.2, “Publication Gravure Printing,” April 1981.

28 ROCKET ENGINE TESTING

28.1 Introduction

The EPA has determined that rocket engine test firing facilities may be major sources for emissions of both criteria air pollutants and HAPs.

A typical solid-fuel rocket motor consists of a motor body, a nozzle, an igniter assembly, and a propelling charge. The igniter assembly may include an ignition charge, an initiation charge, a black powder charge, and a black powder booster charge.

28.2 Emission Calculations

a. Emission Calculations by Item

EPA has published emission factors for a limited number of rocket motors in AP-42. The following are two rockets that might be fired from a variety of rotary-wing, other low speed aircraft, as well as from high performance aircraft.

The 2.75-inch Flechette, MK40 Mod 3 Motor (DODIC H459) is designed to deliver a variety of warheads and develops a nominal thrust of 720 pounds for a burn time between 1.55 and 1.69 seconds. This ammunition is used during combat and on firing ranges during training.

The 2.75-inch M267 Practice Warhead, MK66 Mod 3 Motor (DODIC H974) develops a nominal thrust of 1,300 pounds for a burn time between 1.05 and 1.10 seconds. This ammunition is used on firing ranges during training; it is not used during combat.

Emission factors for criteria pollutant and the principal HAPs are provided in Table 28-1. These emission factors are only associated with the use of the rocket motor; emissions associated with the impact and/or detonation of the warhead are not addressed.

b. Emission Calculations by Propellant

The following equation can be used to estimate emissions based on the quantity and type of propellant used:

$$E_{\text{pol}} = \text{QM} \times \text{EF} \quad \text{Equation 28-1}$$

Where

$$\begin{aligned} E_{\text{pol}} &= \text{Emissions of a particular pollutant (lb/yr)} \\ \text{QM} &= \text{Total mass of energetic material which is OB/OD during the year (lb/yr)} \\ \text{EF} &= \text{Emission factor (lb/lb)}. \end{aligned}$$

Emission factors for a number of commonly used propellants are provided in Tables I-10 through I-12 in Appendix I.

Table 28-1. Emission Factors for 2.75-inch MK40 and MK66 Rocket Motors

Pollutant	MK40 Mod 3 Rocket Motor	MK66 Mod 3 Rocket Motor
Criteria and Gases		
CO	1.5E+00	5.3E-01
NO _x	2.6E-02	ND
PM ₁₀	1.1E-01	1.6E-01
PM _{2.5}	1.0E-01	1.7E-01
TSP	1.0E-01	1.5E-01
Methane	2.2E-02	6.2E-03
HAPs		
Acetaldehyde	4.8E-04	2.0E-04
Benzene	1.7E-03	3.8E-04
Cadmium	1.2E-03	6.6E-04
Formaldehyde	3.4E-04	2.5E-04
Lead	5.1E-02	7.0E-02
Methylene Chloride	2.8E-03	1.3E-04
Naphthalene	1.1E-04	8.6E-06
Toluene	1.1E-04	4.7E-05
Zinc	1.9E-03	8.6E-04

Note: All values presented as lbs/item.

Table 28-2. Emission Factors for Missiles Testing^a

Pollutant	Emission Factor (lb/lb)
Criteria Pollutants	
CO	1.10E-04
NO _x	4.90E-03
PM ₁₀	5.50E-02
PM _{2.5}	3.85E-02
HAPs	
PAHs	1.72E-07
Benzene	3.90E-07
Formaldehyde	5.00E-08
HCl	4.30E-02
Vinyl Chloride	1.00E-09
Antimony	9.00E-08
Arsenic	1.50E-08
Cadmium	9.00E-09
Chromium ⁺⁶	7.50E-08
Pb	1.65E-06
Manganese	3.00E-06
Nickel	1.88E-06
Selenium	7.50E-09

^a CO, NO_x, Aluminum Oxide, and HCl emission factors were those reported to Utah Directorate of Air Quality in January 1995, from Hill Air Force Base. (Summary of unserviceable Explosives Disposal at the Hill Range Complex in connection with Variance during Calendar Year 1994). The higher emission factor of Minuteman OB and OD was used. All PM is assumed to be PM₁₀. PM and PM₁₀ emission factors were assumed to be those for aluminum oxide (TSP). All other constituents, emission factors are from AB 2588 Air Toxics "Hot Spots" Proposed Propellant Open Burn Emission Factors, Gencorp, Aerojet Propulsion Division, February 1992.

c. Emission Calculations by Modeling

Gaseous emissions from rocket engine testing can also 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

28.3 Example Problem

Static firing of missiles in a Missile Test Area typically consists of 5 to 15 Minuteman Missiles (MM) per year (Mark 58 and AGM-65 missiles). Using the emission factors from Table 28-2 the following equation is used:

$$E_{\text{Pol}} = \text{MM} \times \text{EF} \times N$$

Where

$$\begin{aligned} E_{\text{Pol}} &= \text{Total quantity of emissions for a particular pollutant (lb)} \\ \text{MM} &= \text{Total Net Explosive Weight of Motor Propellant (lb)} \\ \text{EF} &= \text{Emission Factor (lb/lbMM)} \\ N &= \text{Number of Rocket Motors.} \end{aligned}$$

Determine the NO_x emissions resulting from the firing of a MM (MM = 3,671 lb and it has three motors).

$$\begin{aligned} E_{\text{NOX}} &= (4.90\text{E-}03 \text{ lb/lb}) \times (3,671 \text{ lb}) \times (3 \text{ motors}) \\ E_{\text{NOX}} &= \mathbf{55.29 \text{ lb.}} \end{aligned}$$

28.4 References

U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources* (AP-42), Section 15.6, "Rockets, Rocket Motors, and Igniters," September 2006.

U.S. Army West Desert Test Center, *Open Burn/Open Detonation Dispersion Model (OBODM), Model and Users Guide*, February 1998.

U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors-Volume I: Stationary Point and Area Sources* (AP-42), Section 15.x, "Ordnance Detonation," July 2006.

29 SITE REMEDIATION

29.1 Introduction

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) or petroleum products (e.g., jet fuel, diesel fuel, gasoline). Identification, investigation, and cleanup of these sites fall 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 resulting contaminated air stream is either exhausted directly to the atmosphere or is vented to a control device (e.g., activated carbon adsorber, catalytic oxidizer). This section focuses on estimating air emissions from two common site remediation technologies which may result in air emissions. These two technologies include 1) soil vapor extraction (SVE) and 2) pump and treat groundwater extraction utilizing air stripping. Emissions of concern include total VOC and organic HAPs.

29.1.1 Soil Vapor Extraction

SVE is a method used to remove VOCs from subsurface vadose zone (i.e., unsaturated) soil. This technology involves applying a vacuum to one or more extraction wells to create air flow from inlet air wells or the ground surface through the vadose zone soil (i.e., unsaturated soil above the water table) 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 at the surface. The residual air stream is then either exhausted directly to the atmosphere or is vented to a control device (e.g., carbon adsorption, flare, catalytic oxidizer, IC engine).

29.1.2 Pump and Treat Utilizing Air Stripping

The phrase "pump and treat" refers to the removal of contaminated groundwater from wells or trenches and its subsequent treatment above ground. A widely used method 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 stripping tower. A packed-tower air stripper consists of a cylindrical column that contains a water distribution system above an engineered packing with an air distributor below. Water containing VOCs is distributed at the top of the column and flows generally downward through the packing material. At the same time, air is introduced at the bottom of the column and flows upward through the packing (countercurrent flow). The packing provides an extended surface area and impedes the flow of both fluids, extending the contact time between them. As water and air contact, VOCs move from the water to the air. The water leaves the bottom of the column depleted of VOCs. The VOCs transferred to the air exit the top of the column in the air stream. The contaminated air is then either released into the atmosphere or vented to a control device (e.g., carbon adsorption, flare, catalytic oxidizer, IC engine).

29.2 Emission Calculations

a. Soil Vapor Extraction

In order to calculate the emissions from SVE, 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:

$$E_{\text{pol}} = \text{QA} \times \text{C} \times \text{MW} \times (1.581 \times 10^{-7}) \times t \times \left[1 - \left(\frac{\text{CE}}{100}\right)\right] \quad \text{Equation 29-1}$$

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	=	Total time that SVE process was in operation (hr/yr)
CE	=	Efficiency of any control device treating the extracted air prior to releasing to the atmosphere (%)
100	=	Factor for converting percent efficiency to fractional efficiency.

Calculations must be performed separately for each extraction well and the results added together to get the total emissions. Whenever total VOC is measured in an air stream, the concentration will be measured “as” a certain hydrocarbon. (Usually it is the compound used to calibrate the VOC analyzer, such as CH₄, 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.

If a combustion source (e.g., flare, IC engine, turbine) 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 be calculated as follows:

$$E_{\text{pol}} = \text{Q} \times \text{C} \times \left(\frac{\text{RE}}{100}\right) \times (5.042 \times 10^{-4}) \times t \times \left[1 - \left(\frac{\text{CE}}{100}\right)\right] \quad \text{Equation 29-2}$$

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 that the Pump-and-Treat system operation was in operation (hr/yr)
CE	=	Efficiency of any control device treating the contaminated air leaving the air stripper prior to releasing to the atmosphere (%)
100	=	Factor for converting percent efficiency to fractional efficiency.

If a combustion source (e.g., flare, IC engine, turbine) is used to control the extracted air, then the emissions (i.e., combustion by-products) generated from the control device must also be addressed and calculated.

29.3 Information Resources

Base CEV should have the information, or be able to obtain the information, needed to calculate emissions from site remediation operations involving either SVE or groundwater air stripping. Remediation emissions data may also be available from the contractor operating the remediation system(s) at the base.

29.4 Example Problems

a. Problem # 1

An SVE process is being used to remove perchloroethylene (PCE) from subsurface soil. 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 ft³/min. The average concentration of PCE in the extracted air was 215 ppm. The extracted air was vented to a catalytic oxidizer prior to being exhausted to the atmosphere. The approximate efficiency of the catalytic oxidizer is 97%. The molecular weight of PCE is 165.8. Calculate the VOC and HAP emissions.

(1) It can be assumed that there are no VOC emissions from the SVE process since PCE is not considered a VOC, as per 40 CFR 21.100.

(2) Since PCE is a HAP and not a VOC, emissions of PCE should be calculated.

$$E_{\text{pol}} = QA \times C \times MW \times (1.581 \times 10^{-7}) \times t \times [1 - (\frac{CE}{100})]$$

$$E_{\text{PCE}} = 120 \text{ ft}^3/\text{min} \times 215 \text{ ppmv} \times 165.8 \text{ lb/lb-mole} \times (1.581 \times 10^{-7} \text{ lb-mole min/ft}^3 \text{ ppmv hr}) \times 1,200 \text{ hr/yr} \times [1 - (\frac{97}{100})]$$

$$E_{\text{PCE}} = \mathbf{24.35 \text{ lb/yr.}}$$

b. Problem # 2

JP-4 fuel is being removed from groundwater by “pump and treat” process. 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
TOC	205

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 benzene emissions.

(1) VOC emissions are calculated using the average TOC concentration

$$E_{\text{pol}} = Q \times C \times \left(\frac{\text{RE}}{100}\right) \times (5.042 \times 10^{-4}) \times t \times \left[1 - \left(\frac{\text{CE}}{100}\right)\right]$$

$$E_{\text{VOC}} = 30 \text{ gal/min} \times 205 \text{ mg/l} \times \left(\frac{95}{100}\right) \times (5.042 \times 10^{-4} \text{ lb liters min/mg gal hr}) \times 850 \text{ hr/yr} \times \left[1 - \left(\frac{0}{100}\right)\right]$$

$$E_{\text{VOC}} = \mathbf{2,503.92 \text{ lb/yr.}}$$

(2) Since benzene, ethylbenzene, hexane, naphthalene, toluene, and xylene are all HAPs, the emissions of each of these pollutants need to be calculated. Below is a sample demonstrating the process using benzene.

$$E_{\text{pol}} = Q \times C \times \left(\frac{\text{RE}}{100}\right) \times (5.042 \times 10^{-4}) \times t \times \left[1 - \left(\frac{\text{CE}}{100}\right)\right]$$

$$E_{\text{benzene}} = 30 \text{ gal/min} \times 8 \text{ mg/l} \times \left(\frac{95}{100}\right) \times (5.042 \times 10^{-4} \text{ lb liters min/mg gal hr}) \times 850 \text{ hr/yr} \times \left[1 - \left(\frac{0}{100}\right)\right]$$

$$E_{\text{benzene}} = \mathbf{97.71 \text{ lb/yr.}}$$

29.5 References

U.S. Environmental Protection Agency, *Estimating Air Emissions from Petroleum UST Cleanups*, June 1989.

Agency for Toxic Substances and Disease Registry, *Toxicology Profile for Jet Fuels JP-4 and JP-7*, June 1995, <http://www.atsdr.cdc.gov/toxprofiles/tp76.html>.

30 SMALL ARMS FIRING

30.1 Introduction

Most Air Force installations have a firing range used for small arms training. The main pollutants of concern from small arms firing are CO and Pb. CO is emitted from the detonation of the energetic material inside the ammunition. Pb emissions typically come from the primer (which usually contains lead styphnate) and from the projectile (i.e., the bullet or slug). In addition to lead styphnate, some types of ammunition may also contain lead azide as an ingredient in the energetic material. No methodology is available for estimating the Pb emissions contributed by the projectile. It is important to note, however, that for target practicing purposes many firing ranges are now using ammunition with non-Pb (e.g., plastic) projectiles. This ammunition is commonly referred to as “green ammo.”

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 PM and Pb emissions into the atmosphere.

30.2 Emission Calculations

Emissions from small arms firing can be estimated using the following equation:

$$E_{\text{Pol}} = \text{NR} \times \text{EF}_{\text{Pol}} \times \left[1 - \left(\frac{\text{CE}}{100}\right)\right] \quad \text{Equation 30-1}$$

Where

- E_{Pol} = Emissions of a pollutant (lb/yr)
- NR = Number of rounds of a particular type of ammunition fired during the year (rounds/yr)
- EF_{Pol} = Quantity of lead compounds contained in the ammunition (lb/round)
- CE = Control efficiency of filters, if applicable (%)
- 100 = Factor for converting percent efficiency to fractional efficiency.

Emission factors for commonly used small arms ammunition is provided in Tables I-1 through I-3 in Appendix I.

30.3 Information Resources

The Security Police organization is usually responsible for operating the base firing range and 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). If the firing range is equipped with a filtration system, bioenvironmental engineering, 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.

30.4 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 Pb emissions from this type of source

is 90%. There were 212,715 rounds of 5.56 mm ammunition (M855) and 97,275 rounds of 9 mm ammunition fired in the range during the year. No other type of weapon was used. Calculate the CO and Pb emissions from the range.

a. The first step is to calculate the emissions resulting from the 5.56 mm ammunition:

$$E_{\text{Pb}} = \text{NR} \times \text{EF}_{\text{Pb}} \times \left[1 - \left(\frac{\text{CE}}{100}\right)\right]$$

$$E_{\text{CO}} = 212,715 \text{ rounds/yr} \times 1.6 \times 10^{-3} \text{ lb/round} \times \left[1 - \left(\frac{0}{100}\right)\right]$$

$$E_{\text{CO}} = \mathbf{340.34 \text{ lb/yr}}$$

$$E_{\text{Pb}} = 212,715 \text{ rounds/yr} \times 5.1 \times 10^{-6} \text{ lb/round} \times \left[1 - \left(\frac{90}{100}\right)\right]$$

$$E_{\text{Pb}} = \mathbf{1.08 \times 10^{-1} \text{ lb/yr}}$$

b. The second step is to calculate the emissions resulting from the 9mm ammunition:

$$E_{\text{Pb}} = \text{NR} \times \text{EF}_{\text{Pb}} \times \left[1 - \left(\frac{\text{CE}}{100}\right)\right]$$

$$E_{\text{CO}} = 97,275 \text{ rounds/yr} \times 1.6 \times 10^{-3} \text{ lb/round} \times \left[1 - \left(\frac{0}{100}\right)\right]$$

$$E_{\text{CO}} = \mathbf{155.64 \text{ lb/yr}}$$

$$E_{\text{Pb}} = 97,275 \text{ rounds/yr} \times 5.1 \times 10^{-6} \text{ lb/round} \times \left[1 - \left(\frac{90}{100}\right)\right]$$

$$E_{\text{Pb}} = \mathbf{4.96 \times 10^{-2} \text{ lb/yr}}$$

c. The final step is to add together the emissions associated with each weapon

$$\text{Total } E_{\text{CO}} = 340.34 \text{ lb/yr} + 155.64 \text{ lb/yr}$$

$$\text{Total } E_{\text{CO}} = \mathbf{495.98 \text{ lb/yr}}$$

$$\text{Total } E_{\text{Pb}} = 1.08 \times 10^{-1} \text{ lb/yr} + 4.96 \times 10^{-2} \text{ lb/yr}$$

$$\text{Total } E_{\text{Pb}} = \mathbf{1.58 \times 10^{-1} \text{ lb/yr}}$$

30.5 References

U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources* (AP-42), Section 15.1, "Small Cartridges < 30 mm," January 2007.

U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources* (AP-42), Section 15.2, "Medium Cartridges 30–75 mm," January 2007.

31 SOLVENT CLEANING MACHINES

31.1 Introduction

Solvent cleaning 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 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., inadequate cleaning, causing corrosion).

Organic solvents may be composed of non-halogenated compounds, halogenated compounds, or a mixture of both. Common non-halogenated 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 halogenated solvents include methylene chloride, perchloroethylene (tetrachloroethylene), trichloroethylene, 1,1,1-trichloroethane (methyl chloroform), carbon tetrachloride, and chloroform. Many of the compounds found in organic solvents are classified as a VOC, a HAP, or both. It is 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, methyl ethyl ketone, 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 VOCs.

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.

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 adsorption 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.

31.2 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 by 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 by the weight fraction (weight percent divided by 100) of the pollutant in the solvent.

$$E_{\text{pol}} = [(V_A - V_R - V_C) \times D] \times \left[\frac{\text{WP}}{100} \right] \quad \text{Equation 31-1}$$

Where

- E_{pol} = Emissions of a particular pollutant (lb/yr)
- V_A = Volume of fresh solvent added to the machine (gal/yr)
- V_R = Volume of waste solvent removed from the machine for disposal, recycling, or reclamation (gal/yr)
- V_C = 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
- 100 = Factor for converting weight percent to a weight fraction.

It is important to note that in many cases the weight percent VOC content of a solvent is not available. For example, most MSDS 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 weight percent VOC content is available in units of grams per liter (g/L), then VOC emissions can be calculated using the following equation:

$$E_{\text{VOC}} = (V_A - V_R - V_C) \times (C_{\text{VOC}} \times 3.785 \times 0.002205) \quad \text{Equation 31-2}$$

Where

E_{VOC}	=	Emissions of VOC (lb/yr)
V_A	=	Volume of fresh solvent added to the machine (gal/yr)
V_R	=	Volume of waste solvent removed from the machine for disposal, recycling, or reclamation (gal/yr)
V_C	=	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 weight percent VOC content is available in units of pounds per gallon (lb/gal), then VOC emissions can be calculated using the following equation:

$$E_{\text{VOC}} = (V_A - V_R - V_C) \times C_{\text{VOC}} \quad \text{Equation 31-3}$$

Where

E_{VOC}	=	Emissions of VOC (lb/yr)
V_A	=	Volume of fresh solvent added to the machine (gal/yr)
V_R	=	Volume of waste solvent removed from the machine for disposal, recycling, or reclamation (gal/yr)
V_C	=	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 weight percent 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.

Emission rates for solvent cleaning machines should be estimated from solvent consumption data for the particular degreasing operation under consideration.

31.3 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 (e.g., 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), the commercial vendor (if applicable), or the solvent manufacturer. For solvents purchased from a government supply center such as the DLA or the General Services Administration (GSA), information on a solvent can usually be obtained from the applicable supply center (DLA or GSA) where the solvent was purchased.

31.4 Example Problem

445 gallons of fresh solvent were delivered to the maintenance shop during the year, while 390 gallons of waste solvent were picked up. There are no control devices used with the solvent cleaning machines. The MSDS provides the data below:

The solvent is composed of: Petroleum Naphtha 37%; Ethyl Acetate 25%; Methylene Chloride (Dichloromethane) 20%; Acetone 10%; and Isopropyl Alcohol 8%. The solvent has a Specific Gravity of 0.86.

Calculate the VOC and HAP emissions associated with these solvent cleaning machines.

a. Review the listing of ingredients to determine which ones, if any, are HAPs. The only ingredient on the HAP listing is methylene chloride.

b. 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. Calculate the solvent density using the specific gravity.

$$\begin{aligned} \text{Density} &= \text{Specific Gravity} \times 8.33 \text{ lb/gal} \\ \text{Density} &= 0.86 \times 8.33 \text{ lb/gal} \\ \text{Density} &= \mathbf{7.17 \text{ lb/gal}} \end{aligned}$$

d. Calculate the VOC and methylene chloride emissions

$$\begin{aligned} E_{\text{pol}} &= [(V_A - V_R - V_C) \times D] \times \left[\frac{\text{WP}}{100} \right] \\ E_{\text{VOC}} &= [(445 \text{ gal/yr} - 390 \text{ gal/yr} - 0 \text{ gal/yr}) \times 7.17 \text{ lb/gal}] \times \left[\frac{90}{100} \right] \\ E_{\text{VOC}} &= \mathbf{354.92 \text{ lb/yr}} \\ E_{\text{Methylene chloride}} &= [(445 \text{ gal/yr} - 390 \text{ gal/yr} - 0 \text{ gal/yr}) \times 7.17 \text{ lb/gal}] \times \left[\frac{20}{100} \right] \\ E_{\text{Methylene chloride}} &= \mathbf{78.87 \text{ lb/yr.}} \end{aligned}$$

31.5 References

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

U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources (AP-42)*, Section 4.6, "Solvent Degreasing," Reformatted January 1995.

32 STATIONARY IC ENGINE EQUIPMENT

32.1 Introduction

Several types of stationary IC 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. Some state/local regulators may classify certain types of AGSE as stationary IC engine equipment, but most types of AGSE are considered mobile sources. For this reason, AGSE is not specifically addressed in this chapter (see Air Emissions Inventory Guidance, Volume II, Mobile Sources, chapter 42, *Flightline and Ground Support Equipment*). The emissions of concern from IC engines include HAPs, NO_x, TOC, CO, PM, and SO_x.

Emergency generators are usually the most common type of stationary IC 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).

Stationary IC 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 IC 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 SO_x, jet kerosene emission factors associated with IC 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 IC 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 may be needed to drive the internal compressor. The balance is available to drive an external load, such as an electric generator.) Most stationary IC engine equipment used in the Air Force are powered with reciprocating engines, although a few installations may have large electric generators which are powered by gas turbine engines.

Three generic techniques are used to control NO_x emissions from reciprocating engines and gas turbines:

1. Parametric controls (timing and operating at a leaner air/fuel ratio for reciprocating engines and water injection for gas turbines);
2. 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
3. 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.

32.2 Emissions Calculations

There are two methods which can be used to calculate the emissions from stationary combustion engines. Emissions from stationary combustion engines can be calculated based on fuel usage and fuel-specific emission factor or on the brake-specific emission factor, usage in hours, rated power available, and load factor. Additionally, a third alternative method can be used specifically for emergency generators.

a. Fuel Consumption Method

The recommended method for calculating emissions from stationary combustion engines is to simply multiply the engine fuel consumption times the appropriate emission factor. The following equation is used:

$$E_{\text{pol}} = QF \times EF \quad \text{Equation 32-1}$$

Where

$$E_{\text{pol}} = \text{Emissions of a particular pollutant (lb/yr)}$$

QF = Quantity of fuel burned (gal/yr)
 EF = Emission factor (lb/10³gal).

b. Rated Power Method

A second method for calculating emissions from stationary combustion engines involves using the engine's peak power output, 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. The following equation is used:

$$E_{\text{pol}} = \left[\frac{\text{PP} \times \text{OT}}{1000} \right] \times \text{EF} \quad \text{Equation 32-2}$$

Where

E_{pol} = Emissions of a particular pollutant (lb/yr)
 PP = Rated power output of engine (hp)
 OT = Operating time of the engine (hr/yr)
 1000 = Factor for converting "hp-hr" to "10³ hp-hr"
 EF = Emission Factor (lb/10³ hp-hr).

If engine peak power output data is not available it can be estimated using the following equation:

$$\text{PP} = \text{PO} \times \left(\frac{\text{LF}}{100} \right) \quad \text{Equation 32-3}$$

Where

PO = Rated power output of engine (hp)
 LF = Loading Factor (% of Maximum Power)
 100 = Factor to convert percent to a decimal fraction.

c. Alternative Method for Emergency Generators

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:

$$E_{\text{pol}} = \left(\frac{\text{PD} \times 1.341 \times \text{OT}}{1000} \right) \times \text{EF} \quad \text{Equation 32-4}$$

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 that 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 stationary IC engines operating on various fuels are presented in Tables 32-1 through 32-5. Typical load factors for commonly used equipment are provided in Appendix J.

32.3 Information Resources

Civil Engineering is usually responsible for operating/maintaining stationary IC equipment on base (except AGSE) and should be contacted to obtain specific information (e.g., power rating, fuel consumption, operating time) on each piece of equipment. Additionally, Supply Fuels Maintenance may also be a source of information regarding fuel consumption.

32.4 Example Problem

Calculate the annual NO_x emissions for a diesel-fired emergency generator with a rated power output of 420 hp. 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.

$$\begin{aligned}
 E_{\text{pol}} &= QF \times EF \\
 E_{\text{NO}_x} &= (0.550 \times 10^3 \text{ gal/yr}) \times (604 \text{ lb}/10^3 \text{ gal}) \\
 E_{\text{NO}_x} &= \mathbf{332.20 \text{ lb/yr.}}
 \end{aligned}$$

32.5 References

U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources* (AP-42), Section 3.1, “Stationary Gas Turbines,” April 2000.

U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources* (AP-42), Section 3.2, “Natural Gas-Fired Reciprocation Engines,” July 2000.

U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources* (AP-42), Section 3.3, “Gasoline and Diesel Industrial Engines,” October 1996.

U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources* (AP-42), Section 3.4, “Large Stationary Diesel And All Stationary Dual-Fuel Engines,” October 1996.

U.S. Environmental Protection Agency, *Median Life, Annual Activity, and Loading Factor Values for Nonroad Engine Emissions Modeling*, EPA420-P-04-005, April 2004.

Table 32-1. Emission Factors for Uncontrolled Gasoline IC Engines

Pollutant ^a	Emission Factor (lb/10 ³ gal) ^b	Emission Factor (lb/10 ³ hp-hr) ^c
CO	7,900	439
CO ₂	19,500	1,080
NO _x	205	11
PM ^d	12.6	0.721
PM ₁₀ ^d	12.6	0.721
SO _x	10.6	0.591
TOC	382	21.6

Note: These emission factors are for engines in SSC 2-02-003-01 and 2-03-003-01.

^a No emission factors are currently available for HAPs 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.

Table 32-2. Emission Factors for Uncontrolled Diesel IC Engines

Pollutant	Emission Factor (lb/10 ³ gal) ^a	Emission Factor (lb/10 ³ hp-hr) ^b
Criteria Pollutants		
CO	130	6.68
NO _x	604	31
PM ^c	42.5	2.2
PM ₁₀ ^c	42.5	2.2
SO _x	39.7	2.05
TOC	49.3	2.5
HAPs		
Acetaldehyde	1.05E-01	5.40E-03
Acrolein	1.30E-02	6.48E-04
Benzene	1.28E-01	6.50E-03
1,3-Butadiene	5.00E-03	2.74E-04
Formaldehyde	1.62E-01	8.30E-03
Naphthalene	1.20E-02	5.94E-04
Polycyclic Aromatic Hydrocarbons (PAH) ^d	2.30E-02	1.00E-03
Toluene	5.60E-02	2.90E-03
Xylenes	3.90E-02	2.00E-03

Note: These emission factors are for engines in SSC 2-02-001-02 and 2-03-0013-01.

^a Pounds pollutant emitted per thousand gallons of fuel burned. These emission factors are from the EPA's FIRE program. The "lb/10³ gal" HAP emission factors were calculated by multiplying the "lb/MMBtu" emission factors listed in FIRE by the typical heating value of diesel fuel (137 MMBtu/10³ gal).

^b Pounds pollutant emitted per thousand horsepower-hour (power output). These emission factors are from Section 3.3 of AP-42. The "lb/10³ hp-hr" HAP emission factors were calculated by multiplying the "lb/MMBtu" emission factors listed in AP-42 by an average brake-specific fuel consumption (BSFC) value of 7 MMBtu/10³ hp-hr.

^c All particulate is assumed to be less than 1 μm in size.

^d For inventory purposes, assume PAH is the same as POM.

Table 32-3. Emission Factors for Uncontrolled Dual-Fuel IC Engines

Pollutant	Emission Factor (lb/MMBtu) ^a	Emission Factor (lb/10 ³ hp-hr) ^b
Criteria Pollutants		
CO	1.16 ^c	7.5 ^c
NO _x	2.7 ^c	18 ^c
PM	0.31 ^d	2.2 ^e
PM ₁₀	0.29 ^d	2.0 ^e
SO _x	0.1 ^d	0.7 ^e
VOC ^g	0.2 ^c	1.32 ^c
HAPs^f		
Benzene	4.50E-03 ^e	3.15E-02 ^g
Formaldehyde	5.40E-03 ^e	3.78E-02 ^g
Naphthalene	1.40E-03 ^e	9.80E-03 ^g
Styrene	9.31E-06 ^e	6.52E-05 ^g
Toluene	5.20E-03 ^e	3.66E-02 ^g
Xylene, mixed isomers	1.03E-03 ^e	9.11E-03 ^g

Note: Emission factors are for engines in SSC 2-02-0041-02. Dual fuel assumes 95% natural gas and 5% diesel fuel.

^a 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/10³ gallons while the typical heating value for natural gas is 1,050 MMBtu/10⁶ cubic feet.

^b Pounds pollutant emitted per 1000 horsepower-hour (power output).

^c Emission factor from Section 3.4 of AP-42.

^d The "lb/MMBtu" emission factors for SO_x, PM, and PM10 were calculated by dividing the "lb/10³ horsepower-hour" emission factors found in the EPA's FIRE program by the typical brake-specific fuel consumption (BSFC) value of 7 MMBtu/10³ horsepower-hour.

^e Emission factor from the EPA's FIRE Program.

^f Based on the emission factor for Total Nonmethane Organic Compounds (TNMOC).

^g The "lb/10³ 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/10³ horsepower-hour.

Table 32-4. Emission Factors for Uncontrolled Natural Gas Engines

Pollutant	2-Cycle Lean Burn (lb/MMBtu) ^a	4-Cycle Lean Burn (lb/MMBtu) ^a	4-Cycle RichBurn (lb/MMBtu) ^a
SSC:	2-02-002-52	2-02-002-54	2-02-002-53
Criteria Pollutants & GHGs			
NO _x ^b (90 – 105% load)	3.17	4.08	2.21
NO _x ^b (< 90% load)	1.94	0.847	2.27
CO ^b (90 – 105% load)	0.386	0.317	3.72
CO ^b (< 90% load)	0.353	0.557	3.51
CO ₂ ^c	110	110	110
SO ₂ ^d	5.88E-04	5.88E-04	5.88 x 10 ⁻⁴
TOC ^e	1.64	1.47	0.358
CH ₄ ^f	1.45	1.25	0.23
VOC ^g	0.12	0.118	0.0296
PM ₁₀ (filterable) ^h	3.84E-02	7.71E-05	9.50E-03
PM _{2.5} (filterable) ^h	3.84E-02	7.71E-05	9.50E-03
PM Condensable ⁱ	9.91E-03	9.91E-03	9.91E-03

Table 32-4. [con't] Emission Factors for Uncontrolled Natural Gas Engines^a

Pollutant	2-Cycle Lean Burn (lb/MMBtu) ^a	4-Cycle Lean Burn (lb/MMBtu) ^a	4-Cycle Rich Burn (lb/MMBtu) ^a
SSC:	2-02-002-52	2-02-002-54	2-02-002-53
Trace Organic Compounds			
1,1,2,2-Tetrachloroethane ^j	6.63E-05	<4.00E-05	2.53E-05
1,1,2-Trichloroethane ^j	5.27E-05	<3.18E-05	<1.53E-05
1,1-Dichloroethane	3.91E-05	<2.36E-05	<1.13E-05
1,2,3-Trimethylbenzene	3.54E-05	2.30E-05	ND
1,2,4-Trimethylbenzene	1.11E-05	1.43E-04	ND
1,2-Dichloroethane	4.22E-05	<2.36E-05	<1.13E-05
1,2-Dichloropropane	4.46E-05	<2.69E-05	<1.30E-05
1,3,5-Trimethylbenzene	1.80E-05	3.38E-05	ND
1,3-Butadiene ^j	8.20E-04	2.67E-04	6.63E-04
1,3-Dichloropropene ^j	4.38E-05	<2.64E-05	<1.27E-05
2,2,4-Trimethylpentane ^j	8.46E-04	2.50E-04	ND
2-Methylnaphthalene ^j	2.14E-05	3.32E-05	ND
Acenaphthene ^j	1.33E-06	1.25E-06	ND
Acenaphthylene ^j	3.17E-06	5.53E-06	ND
Acetaldehyde ^{j,k,l}	7.76E-03	8.36E-03	2.79E-03
Acrolein ^{j,k}	7.78E-03	5.14E-03	2.63E-03
Anthracene ^j	7.18E-07	ND	ND
Benz(a)anthracene ^j	3.36E-07	ND	ND
Benzene ^j	1.94E-03	4.4E-04	1.58E-03
Benzo(a)pyrene ^j	5.68E-09	ND	ND
Benzo(b)fluoranthene ^j	8.51E-09	1.66E-07	ND
Benzo(e)pyrene ^j	2.34E-08	4.15E-07	ND
Benzo(g,h,i)perylene ^j	2.48E-08	4.14E-07	ND
Benzo(k)fluoranthene ^{j,k}	4.26E-09	ND	ND
Biphenyl ^j	3.95E-06	2.12E-04	ND
Butane	4.75E-03	5.41E-04	ND
Butyr/Isobutyraldehyde	4.37E-04	1.01E-04	4.86E-05
Carbon Tetrachloride ^j	6.07E-05	<3.67E-05	<1.77E-05
Chlorobenzene ^j	4.44E-05	<3.04E-05	<1.29E-05
Chloroethane ^j	ND	1.87E-06	ND
Chloroform ^j	4.71E-05	<2.85E-05	<1.37E-05
Chrysene ^j	6.72E-07	6.93E-07	ND
Cyclohexane	3.08E-04	ND	ND
Cyclopentane	9.47E-05	2.27E-04	ND
Ethane ^m	7.09E-02	1.05E-01	7.04E-02
Ethylbenzene ^j	1.08E-04	3.97E-05	<2.48E-05
Ethylene Dibromide ^j	7.34E-05	<4.43E-05	<2.13E-05
Fluoranthene ^j	3.61E-07	1.11E-06	ND
Fluorene ^j	1.69E-06	5.67E-06	ND
Formaldehyde ^{j,k}	5.52E-02	5.28E-02	2.05E-02
Indeno(1,2,3-c,d)pyrene ^j	9.93E-09	ND	ND
Isobutane	3.75E-03	ND	ND
Methanol ^k	2.48E-03	2.50E-03	3.06E-03
Methylcyclohexane	3.38E-04	1.23E-03	ND
Methylene Chloride ^j	3.61E-07	2.00E-05	4.12E-05
n-Hexane ^j	4.45E-04	1.11E-03	ND

Table 32-4. [Con't] Emission Factors for Uncontrolled Natural Gas Engines

Pollutant	2-Cycle Lean Burn (lb/MMBtu) ^a	4-Cycle Lean Burn (lb/MMBtu) ^a	4-Cycle RichBurn (lb/MMBtu) ^a
SSC:	2-02-002-52	2-02-002-54	2-02-002-53
n-Nonane	3.08E-05	1.10E-04	ND
n-Octane	7.44E-05	3.51E-04	ND
n-Pentane	1.53E-03	2.60E-05	ND
Naphthalene ^l	9.63E-05	7.44E-05	<9.71E-05
PAH ^l	1.34E-04	2.69E-05	1.41E-04
Perylene ^l	4.97E-09	ND	ND
Phenanthrene ^l	3.53E-06	1.04E-05	ND
Phenol ^l	4.21E-05	2.40E-05	ND
Propane	2.87E-02	4.19E-02	ND
Pyrene ^j	5.84E-07	1.36E-06	ND
Styrene ^l	5.48E-05	<2.36E-05	<1.19E-05
Tetrachloroethane ^l	ND	2.48E-06	ND
Toluene ^l	9.63E-04	4.08E-04	5.58E-04
Vinyl Chloride ^l	2.47E-05	1.49E-05	<7.18E-06
Xylene ^l	2.68E-04	1.84E-04	1.95E-04

Note ND = No Data; Reference Section 3.2 of AP-42.

^a Emission factors were calculated in units of (lb/MMBtu) based on procedures in EPA Method 19. To convert from (lb/MMBtu) to (lb/106 scf), multiply by the heat content of the fuel. If the heat content is not available, use 1,020 Btu/scf. To convert from (lb/MMBtu) to (lb/hp-hr) use the following equation: lb/hp-hr = lb/MMBtu x Heat input (MMBtu/hour) / operating horsepower (hp).

^b Emission tests with unreported load conditions were not included in the data set.

^c Based on 99.5% conversion of the fuel carbon to CO₂.

^d Based on 100% conversion of fuel sulfur to SO₂. Assumes sulfur content in natural gas of 2,000 gr/10⁶scf.

^e Emission factor for TOC is based on measured emission levels of 43 tests.

^f Emission factor for CH₄ is determined by subtracting the VOC and ethane emission factors from the TOC emission factor. Measured emission factor for CH₄ compares well with the calculated emission factor, 1.48 lb/MMBtu vs. 1.45 lb/MMBtu, respectively.

^g VOC emission factor is based on the sum of the emission factors for all speciated organic compounds less ethane and CH₄.

^h Considered ≤ 1 μm in aerodynamic diameter. Therefore, for filterable PM emissions, PM10(filterable) = PM2.5(filterable).

ⁱ No data were available for condensable PM emissions. The presented emission factor reflects emissions from 4SLB engines.

^j HAP as defined by Section 112(b) of the CAA.

^k For lean burn engines, aldehyde emissions quantification using CARB 430 may reflect interference with the sampling compounds due to the nitrogen concentration in the stack. The presented emission factor is based on FTIR measurements. Emissions data based on CARB 430 are available in the background report.

^l For rich burn engines, no interference is suspected in quantifying aldehyde emissions. The presented emission factors are based on FTIR and CARB 430 emissions data measurements.

^m Ethane emission factor is determined by subtracting the VOC emission factor from the NMHC emission factor.

Table 32-5. Emission Factors for Gas Turbine Engines

Pollutant	Natural Gas-Fired ^a	Distillate Oil-Fired ^b
NO _x - Uncontrolled	0.320	0.880
- Water-steam injection	0.130	0.240
- Lean-Premix	0.099	NA
CO - Uncontrolled	0.082	0.003
- Water-steam injection	0.030	0.076
- Lean-Premix	0.015	NA
N ₂ O	0.003	ND
Pb	ND	1.4E-05
SO ₂	0.94S ^c	1.01S ^c
CH ₄	8.6E-03	ND
VOC ^d	2.1E-03	4.1E-04
PM _(condensable) ^e	4.7E-03	7.2E-03
PM _(filterable) ^e	1.9E-03	4.3E-03
PM _(total) ^e	6.6E-03	1.2E-02
1,3-Butadiene	<4.3E-07	<1.6E-05
Acetaldehyde	4.0E-05	ND
Acrolein	6.4E-06	ND
Benzene	1.2E-05	5.5E-05
Ethylbenzene	3.2E-05	ND
Formaldehyde	7.4E-04	2.8E-04
Naphthalene	1.3E-06	3.5E-05
PAH	2.2E-06	4.0E-05
Toluene	1.3E-04	ND
Xylenes	6.4E-05	ND
Arsenic	NA	<1.1E-05
Beryllium	NA	<3.1E-07
Cadmium	NA	4.8E-06
Chromium	NA	1.1E-05
Pb	NA	1.4E-05
Manganese	NA	7.9E-04
Mercury	NA	1.2E-06
Nickel	NA	<4.6E-06 ^f
Selenium	NA	<2.5E-05 ^f

^a. Emission factors based on an average natural gas heating value (HHV) of 1,020 Btu/scf at 60 F.

^b. Emission factors based on an average distillate oil heating value of 139 MMBtu/10³ gallons.

^c. All sulfur in fuel assumed to be converted to SO₂. S = percent sulfur in fuel (e.g., if sulfur content is 3.4%, the S = 3.4). If S is not available, use 3.4E-03 lb/MMBtu for natural gas and 3.3E-02 lb/MMBtu for distillate oil.

^d. VOC emission are assumed to be equal to the sum of organic emissions.

^e. Emission factors are based on combustion turbines using water-steam injection.

^f. Compound was not detected. The emission factor is based on one-half of the detection limit.

Table 32-6. Typical Heat Content by Fuel Type^a

Fuel	Heating value			
	Lower (Btu/gal)	Lower (Btu/lb)	Higher (Btu/gal)	Higher (Btu/lb)
Gasoline	116,090	18,676	124,340	20,004
Diesel #2	128,450	18,394	137,380	19,673
Methanol	57,250	8,637	65,200	9,837
Ethanol	76,330	11,585	84,530	12,830
MTBE	93,540	15,091	101,130	16,316
Propane	84,250	19,900	91,420	21,594
Compressed Natural Gas	N/A	20,263	N/A	22,449
Hydrogen	N/A	52,217	N/A	59,806
Biodiesel	119,550	16,131	127,960	17,266

^a <http://www.afdc.energy.gov/afdc/pdfs/fueltable.pdf>.

33 SURFACE COATINGS

33.1 Introduction

Surface coating operations is the application of primers, paints, (e.g., enamels, lacquers, polyurethanes), thinners, stains, varnishes, shellacs, glazes, etc., for decorative and protective purposes. 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. The types of emissions of concern from surface operations include VOC, PM₁₀, PM_{2.5}, HAPs, and NH₃. Surface coating operations are either conducted in a booth with filters that control the PM with emissions of fine particulate, VOCs, HAPs, and NH₃ vented through an exhaust stack or outside the booth. or, if conducted outside of a booth, all emissions are considered to be fugitive emissions and emissions of PM are not reduced by a filter control efficiency.

Coating Formulations

Conventional coatings contain at least 30 volume percent solvents, to permit easy handling and application, and typically contain 70 to 85 percent solvents by volume. These solvents may be one component or a mixture of volatile ethers, acetates, aromatics, cellosolves, aliphatic hydrocarbons, and/or water. Coatings with 30 volume percent of solvent or less are called low solvent or "high solids" coatings.

Waterborne coatings, which have recently gained substantial use, are of several types: water emulsion, water soluble and colloidal dispersion, and electrocoat. Common ratios of water to solvent organics in emulsion and dispersion coatings are 80:20 and 70:30.

Two-part catalyzed coatings to be dried, powder coatings, hot melts, and radiation cured (ultraviolet and electron beam) coatings contain essentially no VOCs, although some monomers and other lower molecular weight organics may volatilize.

Coating Application Procedures

Conventional spray, which is air atomized and usually hand operated, is one of the most versatile coating methods. Colors can be changed easily, and a variety of sizes and shapes can be painted under many operating conditions. Conventional, catalyzed, or waterborne coatings can be applied with little modification. Conventional spray application causes a substantial amount of the atomized coating droplets to rebound off of the surface resulting in low efficiency from overspray (approximately 30–35 percent of the coating sticks to the intended surface) and high energy requirements for the air compressor. High volume low pressure (HVLP) spray application, now widely used, is more efficient (approximately 60–90 percent of the coating sticks to the intended surface) and, thus, has lowers emissions.

In airless spray, the paint is forced through an atomizing nozzle. Since volumetric flow is less, overspray is reduced. Less solvent is also required, thus reducing VOC emissions. Care must be taken for proper flow of the coating, to avoid plugging and abrading of the nozzle orifice.

Air-assisted airless spraying method uses a much lower hydraulic pressure 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 cannot 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.

Electrostatic spray is most efficient for low viscosity paints. Charged paint particles are attracted to an oppositely charged surface. Spray guns, spinning discs, or bell shaped atomizers can be used to atomize the paint. Application efficiencies of 90 to 95 percent are possible, with good "wraparound" and edge coating. Interiors and recessed surfaces are difficult to coat.

Electrodeposition uses a direct-current voltage applied between the coating bath (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.

In roller coating 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.

Dip coating allows objects to be 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.

In flow coating 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) 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 PM/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.

The most basic of coating applications is brush coating. This technique involves the use of brushes or hand rollers to apply the coating on the substrate.

Emissions and Controls

Essentially all of the VOC emitted from surface coating operations is from the solvents which are used in the paint formulations, used to thin paints at the coating facility, or used for cleanup. All unrecovered solvent can be considered potential emissions. Monomers and low molecular weight organics can be emitted from those coatings that do not include solvents, but such emissions are essentially negligible.

Emissions from surface coating for an uncontrolled facility can be estimated by assuming that all VOCs in the coatings are emitted. Usually, coating consumption volume will be known, and some information about the types of coatings and solvents will be available. The choice of a particular emission factor will depend on the coating data available. If no specific information is given for the coating, it may be estimated from the data in Table 33-1.

All solvents separately purchased to be used in surface coating operations and are not recovered, subsequently can be considered potential emissions. Such VOC emissions at a facility can result from onsite dilution of coatings with solvent, from "makeup solvents" required in flow coating and, in some instances, dip coating, and from the solvents used for cleanup. Makeup solvents are added to coatings to compensate for standing losses, concentration, or amount, and thus to bring the coating back to working specifications. Solvent emissions should be added to VOC emissions from coatings to get total emissions from a coating facility.

Typical ranges of control efficiencies are given in Table 33-3. Emission controls normally fall under 1 of 3 categories: modification in paint formula, process changes, or add-on controls.

Table 33-1. VOC Emission Factors for Uncontrolled Surface Coating

Available Information On Coating	Emissions Of VOC ^a (kg/L of Coating) or (lb/gal of Coating) ^b
Conventional or waterborne paints: VOC, weight percent (d) or VOC, volume percent (V)	d * (coating density)/100 V * (solvent density)/100
Waterborne paint: X = VOC as weight percent of total volatiles including water; and d = Total volatiles as wt% of coating or Y = VOC as volume percent of total volatiles including water; and V = total volatiles as volume percent of coating	d * X * (coating density)/100 V * Y * (solvent density)/100

Note: Emission Factors are based on a material balance assuming the entire VOC content is emitted.

^a For special purposes, factors expressed in kg per liter of coating less water may be desired. These can be computed as follows: [(kg per liter of coating)/(1 - (vol% water/100))] = kg per liter of coating less water

^b If coating density is not known, typical densities are given in Table 33-2. If solvent density is not known, the average density of solvent is 0.88 kg/L (7.36 lb/gal).

Table 33-2. Typical Densities and Solids Contents of Coatings

Solids	Density		Solids (vol. %)
	kg/L	lb/gal	
Enamel, air dry	0.91	7.6	39.6
Enamel, baking	1.09	9.1	42.8
Acrylic enamel	1.07	8.9	30.3
Alkyd enamel	0.96	8	47.2
Primer surfacer	1.13	9.4	49
Primer, epoxy	1.26	10.5	57.2
Varnish, baking	0.79	6.6	35.3
Lacquer, spraying	0.95	7.9	26.1
Vinyl, roller coat	0.92	7.7	12
Polyurethane	1.1	9.2	31.7
Stain	0.88	7.3	21.6
Sealer	0.84	7	11.7
Magnet wire enamel	0.94	7.8	25
Paper coating	0.92	7.7	22
Fabric coating	0.92	7.7	22

Table 33-3. Control Efficiencies for Surface Coating Operations

Control Option	Reduction (%)
Substitute waterborne coatings	60 - 95
Substitute low solvent coatings	40 - 80
Substitute powder coatings	92 - 98
Add afterburners/incinerators	95

Note: Values expressed as percent of total uncontrolled emission load.

33.2 Emission Calculations

a. VOC and Organic HAPs

The preferred method for estimating VOC and speciated organic emissions (including HAPs) from all surface coating operations (both open and vented coating operations) is the use of a material balance. Emissions are calculated using the following equations:

$$E_{POL} = VC \times D \times \frac{WP}{100} \times \left(1 - \frac{CE_{voc}}{100}\right) \quad \text{Equation 33-1}$$

Where

E_{POL}	=	Emissions of a particular pollutant (lb/yr) (VOC or organic HAP)
VC	=	Volume of coating used (gal/yr)
D	=	Density of the coating (lb/gal)
WP	=	Weight percent of the pollutant in the coating (%)

CE_{VOC} = Efficiency of the VOC/HAP control system (Note: CE equals zero if no control device is used).

Equipment such as hoods, spray booths, and totally enclosed processes will have a capture efficiency to consider when calculating emissions. The captured emissions can be calculated using the following equation.

$$E_{VOC,Captured} = E_{VOC} \times \left(\frac{CE}{100} \right) \quad \text{Equation 33-2}$$

Where

$E_{VOC,Captured}$ = Captured VOC emissions (lb/hr)
 E_{VOC} = Total VOC emissions (lb/hr)
 CE = Capture efficiency of VOCs directed into a hood/spray booth, etc. (%)
 100 = Factor for converting percent to a decimal fraction.

All unaccounted for VOCs can be assumed to be uncaptured fugitive emissions. The emissions can be calculated by the following equations:

$$E_{VOC,Fugitive} = E_{VOC} - E_{VOC,Captured} \quad \text{Equation 33-3}$$

Where

$E_{VOC,Fugitive}$ = Fugitive VOC emissions (lb/hr)
 E_{VOC} = Total VOC emissions (lb/hr)
 $E_{VOC,Captured}$ = Captured VOC emissions (lb/hr).

For open coating operations, the captured emission component is zero.

b. PM and Non-organic HAPs

The preferred method of estimating PM/PM₁₀ and non-organic HAPs emissions from vented coating operations is source testing. For open coating operations, the mass balance approach can be used to calculate PM and non-organic HAPs emissions. Stack sampling test reports often provide PM concentration data in grains per dry standard cubic feet (grains/dscf). An hourly emission rate can be determined based on this stack gas concentration using the following equation:

$$E_X = \frac{C_X \times V \times 60}{7000} \quad \text{Equation 33-4}$$

Where

E_X = Speciated emissions of pollutant X (lb/hr)
 C_X = Stack gas concentration of pollutant X (grain/dscf)
 V = Stack gas volumetric flow rate (dry standard cubic feet per minute (dscfm))
 60 = 60 min/hr
 7000 = 7000 grains/lb.

If stack sampling data are not available, the following equation (calculated by mass balance) can be used:

$$E_{PM} = Q \times C_{PM} \times \left(1 - \frac{TE}{100}\right) \times \left(1 - \frac{FE}{100}\right) \quad \text{Equation 33-5}$$

Where

E_{PM}	=	PM/PM ₁₀ emissions (lb/hr)
Q	=	Material usage rate (gal/hr)
C_{PM}	=	PM/PM ₁₀ or solids content of material (lb/gal)
TE	=	Transfer efficiency of the application equipment (%)
FE	=	Filter efficiency of the PM/PM10 control equipment (%)
100	=	Factor for converting percent to a fraction.

c. Ammonia (NH₃)

Ammonia is added to some water-based (e.g., latex) paints for pH adjustment. Usage is estimated to be 3.16 lb/ton of latex paint (0.017 lb/gallon). This emission factor is most applicable to water-based architectural and industrial maintenance coatings. (Note: At the time of publication of this document this value was derived from information from only one manufacturer and therefore, should be considered highly uncertain.)

Emission rates for surface coating should be estimated based on the material usage rate and content of VOCs/solids in the material or based on source testing.

33.3 Information Resources

Bioenvironmental Engineering should be able to provide a list of all shops that perform surface coating operations in a controlled space (e.g., paint booth). 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) 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 GSA. Information on these coatings (such as VOC content) can be obtained from GSA via one of the following:

- GSA’s Environmental Products Guide (<http://www.gsa.gov/enviro>)
- GSA’s Supply Catalog (<http://www.gsa.gov/gscatalog>)

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. Typical transfer efficiencies for various application methods are provided in Table 33-4.

Table 33-4. Transfer Efficiencies of Surface Coating Application Methods

Coating Application Method	Typical Transfer Efficiency (%)
Air Atomizing	30 ^a
Airless	40 ^a
Air-Assisted Airless	45 ^a
HVLP	65 ^a
Electrostatic	80 ^a
Dip-Coating	85 ^b
Flow-Coating	85 ^b
Electrodeposition (EDP)	95 ^b
Brush and Roller	100

^a Minimum value of a range listed in the 1997 Hickam AFB AEI prepared by Pacific Environmental Services (PES). PES cited an EPA paper titled "VOC Pollution Prevention Operations in the Surface Coating Industry" presented at the 9th World Clean Air Congress in 1992.

^b Value from the Air & Waste Management Association document "Air Pollution Engineering Manual" http://www.radtech.org/Industry/pdf_articles/woodctgsmayjun06.pdf

33.4 Example Problem

Given:

$$\begin{aligned} Q &= 25 \text{ gal/hr} \\ C_{\text{VOC}} &= 7 \text{ lb/gal} \\ \text{CE} &= 80\% \text{ (spray booth)} \end{aligned}$$

Find VOC emissions from the spray booth for this process.

$$\begin{aligned} E_{\text{VOC}} &= Q \times C_{\text{VOC}} \\ E_{\text{VOC}} &= 25 \text{ gal/hr} \times 7 \text{ lb/gal} \\ E_{\text{VOC}} &= \mathbf{175.0 \text{ lb/hr}} \end{aligned}$$

$$\begin{aligned} E_{\text{VOC,Captured}} &= E_{\text{VOC}} \times \text{CE} \\ E_{\text{VOC,Captured}} &= \left(\frac{80}{100}\right) \times (175 \text{ lb/hr}) \\ E_{\text{VOC,Captured}} &= \mathbf{140.0 \text{ lb/hr}} \end{aligned}$$

$$\begin{aligned} E_{\text{VOC,Fugitive}} &= E_{\text{VOC}} - E_{\text{VOC,Captured}} \\ E_{\text{VOC,Fugitive}} &= 175.00 \text{ lb/hr} - 140.00 \text{ lb/hr} \\ E_{\text{VOC,Fugitive}} &= \mathbf{35.0 \text{ lb/hr.}} \end{aligned}$$

33.5 References

U.S. Environmental Protection Agency, *Compilation of Air Pollution Emission Factors – Volume I: Stationary Point and Area Sources* (AP-42), Section 4.2.2.1, "General Industrial Surface Coatings," Reformatted January 1995.

Emissions Inventory Improvement Program (EIIP), Volume II: Chapter 7, *Preferred and Alternative Methods for Estimating Air Emissions from Surface Coating Operations*, July 2001.

Emissions Inventory Improvement Program (EIIP), Draft Final, *Estimating Ammonia Emissions from Anthropogenic Nonagricultural Sources*, April 2004.

H. R. Powers, "Economic and Energy Savings through Coating Selection", The Sherwin-Williams Company, Chicago, IL, February 8, 1978.

34 WASTE SOLVENT RECLAMATION

34.1 Introduction

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 handling, initial treatment, distillation, purification, and waste disposal. The emissions of concern from waste solvent reclamation include VOCs and PM. The following is a summary of each individual process.

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 might 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.

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.

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 the 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 temperature boiling points collect at the bottom. Design criteria for evaporating vessels depend on the waste solvent's 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.

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.

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).

34.2 Emission Calculations

Emissions from a waste solvent reclamation process may be calculated using the following equation and the emission factors provided in Table 34-1:

$$E_{\text{pol}} = Q \times D \times \left(\frac{\text{WP}}{100}\right) \times \left(\frac{1 \text{ ton}}{2000\text{lbs}}\right) \times \text{EF} \quad \text{Equation 34-1}$$

Where

- E_{pol} = Emissions of a particular pollutant (lb/yr)
- Q = Volume of solvent processed (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 (%)
- EF = Emission factor
- 100 = Factor for converting weight percent to a weight fraction.

Table 34-1. Emission Factors for Solvent Reclaiming

Source	Criteria Pollutant	Emission Factor Average (Range of values)
Storage tank vent ^a	VOCs	0.02 (0.004 – 0.09)
Condenser vent	VOCs	3.30 (0.52 – 8.34)
Incinerator stack ^b	VOCs	0.02
Incinerator stack	PM	1.44 (1.1 – 2.0)
Fugitive Emissions		
Spillage ^b	VOCs	0.20
Loading	VOCs	0.72 (0.00023 – 1.42)
Leaks	VOCs	ND
Open sources	VOCs	ND

Note: All values reported in units of lb/ton of reclaimed solvent. The data was obtained from AP-42 which references state air pollution control agencies and presurvey sampling. All emission factors are for uncontrolled process equipment, except those for the incinerator stack. Average factors are derived from the range of data points available. Ranges in parentheses. ND = no data.

^a Storage tank is a fixed roof design.

^b Only one value available.

34.3 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.

34.4 Example Problem

1,000 gallons of solvent are processed in a waste solvent reclamation system. There are no control devices used. The original MSDS for the solvent provides the data below:

The solvent is composed of: Petroleum Naphtha 37%; Ethyl Acetate 25%; MEK 20%; Acetone 10%; and Isopropyl Alcohol 8%. The solvent has a Specific Gravity of 0.86.

Calculate the storage tank vent VOC emissions associated with these solvent cleaning machines.

a. 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%.

b. Calculate the solvent density using the specific gravity.

$$\begin{aligned} \text{Density} &= \text{Specific Gravity} \times 8.33 \text{ lb/gal} \\ \text{Density} &= 0.86 \times 8.33 \text{ lb/gal} \\ \text{Density} &= \mathbf{7.17 \text{ lb/gal.}} \end{aligned}$$

c. Calculate the VOC emissions.

$$\begin{aligned} E_{\text{pol}} &= Q \times D \times \left(\frac{\text{WP}}{100} \right) \times \left(\frac{1 \text{ ton}}{2000 \text{ lbs}} \right) \times \text{EF} \\ E_{\text{VOC, tank vent}} &= (1,000 \text{ gal/yr}) \times (7.17 \text{ lb/gal}) \times \left(\frac{90}{100} \right) \times \left(\frac{1 \text{ ton}}{2000 \text{ lbs}} \right) \times (0.02 \text{ lb/ton}) \\ E_{\text{VOC, tank vent}} &= \mathbf{0.06 \text{ lb/yr.}} \end{aligned}$$

34.5 References

U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources* (AP-42), Section 4.7, "Waste solvent Reclamation," February 1980. (Reformatted January 1995).

35 WASTEWATER COLLECTION AND TREATMENT

35.1 Introduction

All Air Force installations operate wastewater collection systems for sanitary (domestic/household) wastewater and may also collect industrial wastewater from aircraft maintenance operations. Only a few Air Force installations operate their own wastewater treatment plant(s) to treat sanitary and/or industrial wastewater prior to discharging off-base. The main air pollutants of concern from wastewater collection and treatment are VOCs and organic HAPs found in the wastewater, a portion of which volatilize into the atmosphere as the wastewater travels through collection and treatment.

Collection Systems

There are many types of wastewater collection systems. In general, a collection system is located at or near the point of wastewater generation and is designed to receive one or more wastewater streams and direct them to treatment and/or storage systems. A typical wastewater collection system may include drains, manholes, trenches, junction boxes, sumps, lift stations, and weirs. Wastewater streams from different points throughout the installation normally enter the collection system through individual drains or trenches connected to a main sewer line. The drains and trenches are usually open to the atmosphere. Junction boxes, sumps, trenches, lift stations, and weirs may be located at various points within the collection system. Manholes into sewer lines permit service, inspection, and cleaning of the sewer line, and are typically located where sewer lines intersect or where there is a significant change in direction, grade, or sewer line diameter.

Junction boxes normally are sized to suit the total flow rate of all the entering streams. Sumps are used typically for collection and equalization of wastewater flow from trenches or sewer lines before treatment or storage. They are usually quiescent and open to the atmosphere. Lift stations are usually the last collection unit before the treatment system, accepting wastewater from one or several sewer lines. Their main function is to lift the collected wastewater to a treatment and/or storage system, usually by pumping.

Pretreatment And Treatment Systems

An Air Force installation might have various forms of pretreatment to prepare the collected wastewater for off-base discharge to a publicly owned treatment works (POTW). Pretreatment and treatment systems are usually composed of various types of impoundments (tanks or basins).

Treatment systems are divided into 3 categories: primary, secondary, or tertiary, depending on their design, operation, and application. In primary treatment systems, physical operations remove floatable and settleable solids. In secondary treatment systems, biological and/or chemical processes remove most of the organic matter in the wastewater. In tertiary treatment systems, additional processes remove constituents not taken out by secondary treatment. Wastewater pretreatment at Air Force installations typically consists of one or more forms of primary treatment.

Examples of pretreatment and primary treatment include oil/water separators, primary clarification, and flow equalization basins. The first process is often the removal of heavier solids and lighter oils by means of oil/water separators. Oils are usually removed continuously with a skimming device, while settled solids can be removed with a sludge removal system in the bottom of the tank. Pretreatment might also include alteration of the chemical or physical properties of the wastewater

by the addition of chemicals. Neutralization adjusts the pH of the wastewater by adding an acid or a base. Chemicals might also be added to precipitate heavy metals dissolved in the wastewater.

For those installations that operate wastewater treatment, primary treatment clarifiers are usually located near the beginning of the treatment process and are used to settle and remove settleable or suspended solids contained in the influent wastewater. Clarifiers are sized according to both the settling rate of the suspended solids and the thickening characteristics of the sludge. Floating scum is skimmed from the top of the clarifier, while sludge is typically removed continuously from the bottom of the clarifier.

Equalization basins are used to reduce fluctuations in the wastewater flow rate and organic content before the waste is sent to downstream treatment processes. Flow rate equalization results in a more uniform effluent quality in downstream settling units such as clarifiers. Biological treatment performance also benefits from reducing fluctuations in wastewater flow and concentration, protecting biological processes from upset or failure from shock loadings of toxic or treatment-inhibiting compounds.

Secondary and tertiary treatment are in operation at only a few Air Force installations. An example of a secondary treatment process is biodegradation. Biological waste treatment usually requires aeration of the wastewater to supply dissolved oxygen to the microorganisms that are degrading the waste constituents. Wastewaters with high pollutant concentrations are typically treated using an activated sludge system where biotreatment is followed by secondary clarification where the settled solids containing biomass are recycled from the clarifier back into the aeration basin. Biological wastewater treatment typically removes nearly all of the biodegradable organic pollutants from the wastewater with the result that there is little emission of criteria pollutants or HAPs.

Chlorine is usually added to disinfect the wastewater prior to discharging off-base. The chlorine is injected directly into the water and virtually all is chemically reduced to a soluble form, resulting in very little emitted into the atmosphere.

Many wastewater treatment plants with biological treatment include a sludge digester. Sludge digesters may produce substantial quantities of CH₄ gas and 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.

Emissions

VOCs are emitted from wastewater collection, treatment, and storage systems through volatilization of organic compounds at the liquid surface. Emissions can occur by diffusive or convective mechanisms, or both. Diffusion occurs when organic concentrations at the water surface are much higher than ambient air concentrations. The organics volatilize, or diffuse into the air, in an attempt to reach equilibrium between aqueous and vapor phases. Convection occurs when air flows over the water surface, sweeping organic vapors from the water surface into the air. The rate of volatilization relates directly to the speed of the air flow over the water surface. Other factors that can affect the rate of volatilization include the following:

- Wastewater surface area
- Wastewater and air temperatures
- Turbulence
- Wastewater retention time in the system
- Depth of the wastewater in the system

- Concentration of organic compounds in the wastewater and their physical properties
- Presence of a mechanism that inhibits volatilization, such as an oil film
- Competing removal mechanisms such as biodegradation.

35.2 Emission Calculations

The preferred method, according to the EPA (EIIP Volume II), for estimating emissions from Wastewater Collection/Treatment Plants is the use of a computer based emissions model. WATER9 is a publicly available computer program model developed by EPA that models the fate of organic compounds in wastewater collection systems and treatment units. WATER9 (Version 2.0, July 2004) includes useful features such as the ability to link treatment units to form a treatment system, the ability for recycle among units, and the ability to generate and save site-specific compound properties. WATER9 has databases with compound-specific data for over 2,000 chemicals. The mathematical equations used to calculate emissions in this model are based on the approaches described in *Air Emissions Models for Waste and Wastewater* (EPA-453/R-94-80A, 1994). The WATER9 model is available from the EPA at <http://www.epa.gov/ttnchie1/software/water/index.html>

Air emission estimates from wastewater collection and treatment can also be made using mass balance calculations as described in the following paragraphs.

a. VOC and Organic HAPs

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 TOC and specific organic compounds. (Note: For emission inventory purposes, TOC is considered synonymous with VOC.) Some of the specific organic compounds measured may include HAPs such as benzene, toluene, ethylbenzene, and xylenes (BTEX), 1,1,1-trichloroethane (methyl chloroform), etc. Emissions are calculated as follows:

$$E_{\text{pol}} = [\text{IC}_{\text{pol}} - \text{EC}_{\text{pol}}] \times (3.785) \times (2.205 \times 10^{-9}) \times \text{QWT} \quad \text{Equation 35-1}$$

Where

E_{pol}	=	Emission of a particular pollutant (lb/yr)
IC_{pol}	=	Influent concentration of the pollutant ($\mu\text{g/L}$)
EC_{pol}	=	Effluent concentration of the pollutant ($\mu\text{g/L}$) [Note: If effluent data is unavailable, assume $\text{EC}_{\text{pol}} = 0 \mu\text{g/L}$]
3.785	=	Unit conversion factor (L/gal)
2.205×10^{-9}	=	Unit conversion factor (lb/ μg)
QWT	=	Quantity of wastewater collected/treated (gal/yr).

Note: Using this material balance procedure will usually overestimate VOC and organic HAP emissions (i.e., a conservative estimate) because it assumes that the amount of each pollutant removed from the water (difference between the influent and effluent concentrations) is attributed entirely to evaporation. This does not take into consideration other possible (in-water) pollutant removal mechanisms, such as sorption, oxidation, and biodegradation.

b. Sludge Digester Gas Flare Emissions

Emissions from flares burning sludge digester off-gas can be calculated by multiplying the quantity of gas combusted by the appropriate emission factor.

$$E_{\text{pol}} = \text{QG} \times \text{D} \times 10^{-6} \times \text{EF} \quad \text{Equation 35-2}$$

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 35-1.

35.3 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 and/or maintaining the wastewater discharge permit(s).

35.4 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 BEE was contacted for this information. A review of the BEE’s analytical results shows that past sampling had been performed for 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.

Table 35-1. Emission Factors for Digester Gas Flares

Pollutant	Emission Factor ^a (lb/10 ⁶ ft ³ gas burned)
Criteria Pollutants	
CO	3.47
NO _x	28.3
PM	53.0
SO ₂	5.75
VOC	5.6
HAPs	
Benzene	3.97E-03
Carbon Tetrachloride	4.03E-04
Chlorobenzene	1.53E-03
Chloroform	1.43E-03
Dibenzofurans	1.36E-06
Methylene Chloride	1.19E-01
Naphthalene	5.55E-03
PCBs	3.39E-05
PAH (POM)	5.44E-01
Tetrachloroethylene	1.93E-03
Toluene	6.83E-02
1,1,1-Trichloroethane	5.66E-03
Trichloroethylene	6.99E-04
Vinyl Chloride	2.31E-03
o-Xylene	7.27E-03
Xylene (mixed isomers)	1.24E-02

^a Emission factors for external combustion of landfill gas are assumed to be similar for external combustion of wastewater treatment digester gas.

a. Calculate the VOC and organic HAP emissions from the wastewater (Note: As mentioned above, TOC is considered the same as VOC):

$$E_{\text{pol}} = [IC_{\text{pol}} - EC_{\text{pol}}] \times (3.785) \times (2.205 \times 10^{-9}) \times \text{QWT}$$

$$E_{\text{VOC}} = (225 \mu\text{g/L} - 102 \mu\text{g/L}) \times 3.785 \text{ L/gal} \times 2.205 \times 10^{-9} \text{ lb}/\mu\text{g} \times 262,545,000 \text{ gal/yr}$$

$$E_{\text{VOC}} = \mathbf{269.52 \text{ lb/yr}}$$

$$E_{\text{toluene}} = (8 \mu\text{g/L} - 3 \mu\text{g/L}) \times 3.785 \text{ L/gal} \times 2.205 \times 10^9 \text{ lb}/\mu\text{g} \times 262,545,000 \text{ gal/yr}$$

$$E_{\text{toluene}} = \mathbf{10.96 \text{ lb/yr}}$$

$$E_{\text{xylenes}} = (9 \mu\text{g/L} - 6 \mu\text{g/L}) \times 3.785 \text{ L/gal} \times 2.205 \times 10^9 \text{ lb}/\mu\text{g} \times 262,545,000 \text{ gal/yr}$$

$$E_{\text{xylenes}} = \mathbf{6.57 \text{ lb/yr}}$$

b. Calculate the emissions associated with the sludge digester gas flare (no site specific emissions sampling has been performed on this flare so the emission factors for landfill gas flares are used):

$$E_{\text{pol}} = QG \times D \times 10^{-6} \times EF$$

$$E_{\text{pol}} = 350 \text{ ft}^3/\text{day} \times 365 \text{ days/yr} \times 10^{-6} \times EF$$

$$E_{\text{pol}} = 0.128 \text{ million ft}^3/\text{yr} \times EF$$

Pollutant	Gas Burned (10 ⁶ ft ³ /yr)		Emission Factor (lb/10 ⁶ ft ³)		Emissions (lb/yr)
CO	0.128	x	3.47	=	0.44
NO _x	0.128	x	28.3	=	3.62
PM	0.128	x	53.0	=	6.78
SO ₂	0.128	x	5.75	=	0.74
VOC	0.128	x	5.6	=	0.71
Benzene	0.128	x	3.97 x 10 ⁻³	=	5.08 x 10⁻⁴
Carbon Tetrachloride	0.128	x	4.03 x 10 ⁻⁴	=	5.16 x 10⁻⁵
Chlorobenzene	0.128	x	1.53 x 10 ⁻³	=	1.96 x 10⁻⁴
Chloroform	0.128	x	1.43 x 10 ⁻³	=	1.83 x 10⁻⁴
Dibenzofurans	0.128	x	1.36 x 10 ⁻⁶	=	1.74 x 10⁻⁷
Methylene Chloride	0.128	x	1.19 x 10 ⁻¹	=	1.52 x 10⁻²
Naphthalene	0.128	x	5.55 x 10 ⁻³	=	7.10 x 10⁻⁴
PCBs	0.128	x	3.39 x 10 ⁻⁵	=	4.34 x 10⁻⁶
Polycyclic Organic Matter	0.128	x	5.44 x 10 ⁻¹	=	6.96 x 10⁻²
Tetrachloroethylene	0.128	x	1.93 x 10 ⁻³	=	2.47 x 10⁻⁴
Toluene	0.128	x	6.83 x 10 ⁻²	=	8.74 x 10⁻³
1,1,1 Trichloroethane	0.128	x	5.66 x 10 ⁻³	=	7.24 x 10⁻⁴
Trichloroethylene	0.128	x	6.99 x 10 ⁻⁴	=	8.95 x 10⁻⁵
Vinyl Chloride	0.128	x	2.31 x 10 ⁻³	=	2.96 x 10⁻⁴
o-Xylene	0.128	x	7.27 x 10 ⁻³	=	9.31 x 10⁻⁴
Xylene (mixed isomers)	0.128	x	1.24 x 10 ⁻²	=	1.59 x 10⁻³

35.5 References

U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources* (AP-42), Section 4.3, "Wastewater Collection, Treatment, And Storage," September 1991. (Reformatted January 1995).

U.S. Environmental Protection Agency, *Air Emission Models for Waste and Wastewater*, EPA-453/R-94-80A, November 1994.

U.S. Environmental Protection Agency, Emissions Inventory Improvement Program (EIIP), Volume II: Chapter 5, *Preferred and Alternative Methods for Estimating Air Emissions From Wastewater Collection and Treatment*, March 1997.

36 WELDING OPERATIONS

36.1 Introduction

Welding operations are typically performed at various maintenance, transportation, and Civil Engineering shops on Air Force installations. Although there are different types of welding operations (e.g., oxyfuel welding, arc welding, brazing, soldering, thermal cutting), electric arc welding is by far the most common type and the method with the greatest PTE 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 AEI.

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 PM and a few inorganic metal HAPs. Most of the PM produced by welding is less than 1 micron in size. For this reason, all PM emissions from welding are considered to be PM₁₀. In regards to HAPs, the typical metals of concern include manganese, nickel, chromium, cobalt, and Pb.

36.2 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:

$$E_{\text{pol}} = EC \times EF \quad \text{Equation 36-1}$$

Where

$$\begin{aligned} E_{\text{pol}} &= \text{Emissions of pollutant (lb/yr)} \\ EC &= \text{Mass of Electrode Consumed (10}^3 \text{ lb/yr)} \\ EF &= \text{Emission Factor (lb/10}^3 \text{ lb)}. \end{aligned}$$

PM₁₀ emission factors for welding operation are listed in Table 36-1 and HAP emission factors are listed in Table 36-2. If the welding rod in question is not listed in one of the tables, EPA's guidance is, "Select the welding rod that comes closest to the welding rod your client is using. Be sure to have them select a rod that is flux coated if their rod is flux coated and vice versa. Be sure to have them select a rod that can be used to weld the same base metal that they are welding."

36.3 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. Bioenvironmental Engineering may be able help identify the shops with welding operations.

36.4 Example Problem

A shop on base performs 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 PM and HAPs.

- a. First calculate the PM₁₀ emissions using the emission factor found in Table 36-1.

$$\begin{aligned} E_{\text{pol}} &= EC \times EF \\ E_{\text{PM}_{10}} &= (1.7 \times 10^3 \text{ lb}) \times (16.4 \text{ lb}/10^3 \text{ lb}) \\ E_{\text{PM}_{10}} &= \mathbf{27.88 \text{ lb.}} \end{aligned}$$

- b. The next step is to review Table 36-2 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.

$$\begin{aligned} E_{\text{pol}} &= EC \times EF \\ E_{\text{Mn}} &= (1.7 \times 10^3 \text{ lb}) \times (1.38 \text{ lb}/10^3 \text{ lb}) \\ E_{\text{Mn}} &= \mathbf{2.35 \text{ lb.}} \end{aligned}$$

36.5 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, "Electric Arc Welding," January 1995.

2. U.S. Environmental Protection Agency, *AP 42 Chapter 12: Metallurgical Industry - Frequent Questions*, Technology Transfer Network Clearinghouse for Inventories & Emission Factors, <http://www.epa.gov/ttn/chief/faq/faqc12.html>.

Table 36-1. PM₁₀ Emission Factors for Welding Operations

Welding Process ^a	Electrode Type (Last 2 Digits Of SCC)	Total Fume Emission Factor ^b (lb/10 ³ lb) ^b
SMAW (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-CI (-72)	18.2
ENiCrMo (-76)	11.7	
ENi-Cu (-80)	10.1	
GMAW (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 (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 (SCC 3-09-054)	EM12K (-10)	0.05

Note: All welding fumes are considered to be PM₁₀.

^a. SMAW = shielded metal arc welding; GMAW = gas metal arc welding; FCAW = flux cored arc welding; SAW = submerged arc welding.

^b. Mass of pollutant emitted per unit mass of electrode consumed.

Table 36-2. HAP Emission Factors for Welding Operations

Welding Process ^a	Electrode Type (Last 2 Digits of SCC)		HAP Emission Factor (lb/10 ³ lb) ^b				
			Cr	Co	Mn	Ni	Pb
SMAW (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-CI	(-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 (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 (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 (SCC 3-09-054)	EM12K	(-10)	ND	ND	ND	ND	ND

Note: ND = No Data.

^a SMAW = shielded metal arc welding; GMAW = gas metal arc welding; FCAW = flux cored arc welding; SAW = submerged arc welding.

^b Mass of pollutant emitted per unit mass of electrode consumed.

37 WET COOLING TOWERS

37.1 Introduction

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 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. Virtually all Air Force cooling towers are the induced (mechanical) draft type of towers.

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 PM 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.

37.2 Emission Calculations

PM emissions from cooling towers can be calculated by multiplying the circulation water flow by a total liquid drift factor and then times the fraction of total dissolved solids (TDS) in the circulating water. Since there is no PM₁₀ data for this source, assume PM₁₀ is equal to PM.

$$E_{PM} = WFR \times D \times 0.001 \times LDF \times \frac{TDS}{10^6} \quad \text{Equation 37-1}$$

Where

E_{PM}	=	Emissions of PM (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 TDS in the circulating water (ppm)
10 ⁶	=	Factor for converting “ppm” into “weight fraction”.

*If flow rate is only available in gallons per minute versus gallons per day, then an additional multiplication step must be added to the equation. The flow rate of gallons per minute would be multiplied by 1,440, the number of minutes per day, to achieve the gallons per day rate.

Total liquid drift factors (LDFs) are listed in Table 37-1 below. If the TDS concentration is unknown, use a manufacturer's maximum recommended cooling water TDS concentration or assume a typical value of 12,000 ppm.

Table 37-1. Total LDFs for Wet Cooling Towers

Cooling Tower Type	Applicable (SCCs)	Total LDF (lb/10 ³ gal) ^b
Induced (Mechanical)Draft	3-85-001-01	1.7
	3-85-001-20	
	3-85-002-01	
Natural Draft	3-85-001-02	0.073
	3-85-002-02	

^a. See Appendix C for a discussion regarding SCCs.

^b. Drift 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.

37.3 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 towers, the particular shop(s) responsible for operating the cooling tower(s) should be contacted for the necessary information.

37.4 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, operates constantly throughout the year, and has an average circulating water flow rate of approximately 20,000 gallons per day. According to past analytical results, the average TDSs concentration in the cooling tower water is approximately 14,000 ppm. Calculate the annual PM emissions.

$$E_{PM} = WFR \times D \times 0.001 \times LDF \times \left(\frac{TDS}{10^6} \right)$$

$$E_{PM} = 20,000 \text{ gal/day} \times 365 \text{ days/yr} \times 0.001 \times (1.7 \text{ lb}/10^3 \text{ gal}) \times \left(\frac{14,000 \text{ ppm}}{10^6} \right)$$

$$E_{PM} = \mathbf{173.74 \text{ lb/yr}}$$
 [Note: As mentioned above, assume PM₁₀ is equal to PM]

37.5 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, "Wet Cooling towers," January 1995.

38 WOODWORKING, SANDING, AND DISINTEGRATOR

38.1 Introduction

Most Air Force installations have operations that generate airborne PM in the form of dust, such as woodworking, fiberglass sanding, and document disintegrators. Typical woodworking shops on an Air Force base include Wood Hobby, Packing & Crating, and some Civil Engineering shops such as Vertical Construction. Fiberglass sanding operations might be done at an Aircraft Corrosion Facility, Auto Hobby Shop, or in the Civil Engineering shops. In most cases, the airborne dust is captured by a ventilation system and control device. Typically, the control device used is a sanding booth with particulate filters, cyclone, a baghouse (fabric filter), or a cyclone and baghouse in series. The dust captured by the control device is collected in a bin or other container which is emptied when full.

38.2 Emission Calculations

Mass Balance Approach – Total PM emissions from woodworking, sanding, and disintegrator operations can be calculated using a mass balance approach based on the estimated efficiency of the control device and the amount of dust collected during the year. The following equation is used:

$$E_{PM} = \left[\frac{MSD_{col}}{\left(\frac{eff}{100}\right)} \right] - MSD_{col} \quad \text{Equation 38-1}$$

Where

$$\begin{aligned} E_{PM} &= \text{Emissions of PM (lb/yr)} \\ MSD_{col} &= \text{Mass of dust collected (lb/yr)} \\ eff &= \text{Efficiency of control device (\%)}. \end{aligned}$$

Since the mass of dust collected during the year is not directly known, it must be calculated based on the volume collected and the density of the sawdust.

$$MSD_{col} = VSD_{col} \times D \quad \text{Equation 38-2}$$

Where

$$\begin{aligned} MSD_{col} &= \text{Mass of sawdust collected (lb/yr)} \\ VSD_{col} &= \text{Volume of sawdust collected (ft}^3\text{/yr)} \\ D &= \text{Density of the sawdust (lb/ft}^3\text{)}. \end{aligned}$$

For woodworking operations, if the mass of sawdust collected is unknown, it can be estimated by multiplying the volume collected by the density of sawdust. The density of the sawdust depends on the wood being used, the particle size, and the moisture content and is typically between 22 and 44 lb/ft³ for woods commonly used in Air Force shops. Similarly, typical density values for other dusts are provided in Table 38-1.

If the size of the PM emitted into the atmosphere is unknown, it is conservatively assumed that PM₁₀ emissions are equal to total PM emissions.

Table 38-1. Typical Density of Dusts

Type of Material	Typical Density (lb/ft ³)
Sawdust	22 – 44
Paper Dust	5
Plastic Powder	26 – 42
Fiberglass Powder	30

Emission Factor Approach – The appropriate regulatory agency should be contacted to determine an appropriate emission factor, since no standardized emission factor data are currently available. Use the following equation to estimate annual emissions from woodworking, sanding, and disintegrator operations when an emission factor is available:

$$E_{PM} = EF \times Q \times \left(1 - \frac{CE}{100}\right) \quad \text{Equation 38-3}$$

Where

- E_{PM} = Emissions of PM (lb/yr)
- EF = Emission factor for PM (e.g., lb/lb of wood processed)
- Q = Annual amount of material processed (maximum potential or actual) (lb/yr)
- CE = PM control efficiency (%)
- 100 = Factor for converting percent efficiency to a fraction.

38.3 Example Problem

A base has a Wood Hobby Shop which vents sawdust emissions to a cyclone separator followed by a fabric filter. The cyclone/filter manufacturer estimates the efficiency of the combined cyclone and filter (in regards to collecting sawdust) to be approximately 95%. The total amount of sawdust produced at the shop is not directly known. However, the rectangular bin used to collect the captured sawdust 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 per 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 is emptied by the number of times during the year in which the bin is emptied.

$$\text{Total Volume of Sawdust Collected} = (3 \text{ ft} \times 4 \text{ ft} \times 5 \text{ ft}) \times 12 \text{ time/yr} = 720 \text{ ft}^3/\text{yr}$$

The total mass of sawdust collected is then calculated by multiplying the total volume by the density of sawdust.

$$\text{Total Mass of Sawdust Collected (SD}_{col}) = 720 \text{ ft}^3 \times 11.5 \text{ lb/ft}^3$$

$$SD_{col} = 8,280.00 \text{ lb/yr}$$

b. The total amount of saw dust generated by the woodworking equipment can now be calculated as follows:

$$SD_{\text{total}} = \left[\frac{SD_{\text{col}}}{\left(\frac{\text{eff}}{100}\right)} \right]$$

$$SD_{\text{total}} = \left[\frac{8280\text{lb/yr}}{\left(\frac{95}{100}\right)} \right]$$

$$SD_{\text{total}} = \underline{8,715.79 \text{ lb/yr}}$$

c. Finally, the PM emissions can be calculated as follows:

$$\begin{aligned} E_{\text{PM}} &= SD_{\text{total}} - SD_{\text{col}} \\ E_{\text{PM}} &= 8715.79 \text{ lb/yr} - 8,280.00 \text{ lb/yr} \\ E_{\text{PM}} &= \mathbf{435.8 \text{ lb/yr.}} \end{aligned}$$

38.4 Information Resources

Information on woodworking and other particulate emissions operations can be obtained from the specific shops/organizations which operate woodworking, sanding, or disintegrator equipment (e.g., Wood Hobby Shop, Civil Engineering, Packing & Crating Shop, Auto Hobby Shop). BEE may be able to help identify the shops with these operations.

38.5 References

“Clean Air Act Compliance Tool Box,” The Air Force Center for Environmental Excellence, May 2006, <<http://www.afcee.brooks.af.mil/products/air/federal/emisest/abrblast.html>>.

U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources* (AP-42), Section 13.2.6, “Abrasive Blasting,” September 1997.

39 AIRCRAFT DEICING OPERATIONS

39.1 Introduction

Deicing involves the removal of frost, snow, or ice from aircraft surfaces or from paved areas including runways, taxiways, and gate areas. Anti-icing refers to the prevention of the accumulation of frost, snow, or ice on these same surfaces. Deicing and anti-icing operations can be performed by using mechanical means (e.g., brooms, brushes, plows) and through the application of chemical agents.

Hydrocarbon (HC) emissions result from the application of deicing fluid to both aircraft and runways. Common aircraft deicing fluids are a mixture of water and propylene glycol or ethylene glycol. These chemicals are slightly volatile and a fraction of the chemical is likely to evaporate after the deicing fluid is applied. Other chemicals present in runway deicing fluids include urea and other organic and inorganic salts, most of which are unlikely to contribute to HC emissions. A methodology for estimating HC emissions from aircraft and runway deicing operations based on emission indices from independent sources is presented here. Because of the different practices for deicing of runways and aircraft, these two operations are considered separately and have two different emission indices. Information regarding the concentration of the chemicals in the deicing fluid (by weight) should be obtained from MSDS sheets, deicing contractor, or the deicing fluid manufacturer. Common solutions are 50% propylene glycol in water or 50% ethylene glycol in water. In many cases, different chemical formulations are used for runway and aircraft deicing.

39.2 Emissions Calculations

The mass of organic chemical consumed (commonly propylene glycol or ethylene glycol) is determined by multiplying the volume of deicing fluid consumed by the density of the fluid and by the concentration of the chemical in the fluid. The calculated mass of organic chemical consumed is multiplied by an emission index to determine the hydrocarbon emissions from the application of the deicing fluid.

The overall methodology is expressed by:

$$E_{HC} = (QF_j \times D_j \times \frac{C_{ij}}{100} \times EI_{ij}) \quad \text{Equation 39-1}$$

Where

- E_{HC} = Annual HC emissions from deicing activities (pounds)
- QF_j = Quantity of deicing fluid used per year in operation type j (gallons)
- D_j = Density of deicing fluid used in operation type j (pounds/gallon)
- C_{ij} = Concentration of chemical i in deicing fluid for operation type j (percent by weight)
- EI_{ij} = Emission index for chemical used in deicing operation type j (pounds HC emissions per pound of chemical consumed)
- i = Chemical present in deicing fluid (propylene glycol, ethylene glycol, or other organic compound)
- j = Deicing operation (runway or aircraft deicing).

Quantities should be expressed in gallons and separated into fluid used for aircraft and runway deicing. This data requirement should not pose a problem because the two operations are usually

maintained separately. This information may be obtained from the airport operator, deicing contractor, or base operations department. The density of the deicing fluid may be obtained from Civil Engineering, the fluid manufacturer, or by calculation. The density should be expressed as pounds per gallon of fluid. To calculate the density of the deicing fluid, Equation 39-2 should be applied. The equation is performed for each component, and results are totaled to obtain the total density.

$$D = (D_w \times \frac{C_k}{100} \times SG_k) \quad \text{Equation 39-2}$$

Where

- D = Density of deicing fluid (pounds per gallon)
- D_w = Density of water (8.33 pounds per gallon)
- C_k = Concentration of component k in deicing fluid (percent)
- SG_k = Specific gravity of component k; specific gravity is a dimensionless ratio of the weight of the chemical to the weight of water
- k = Components of deicing fluid (water, ethylene glycol, propylene glycol, urea, polymer additives, etc.).

The concentration of each component in the deicing fluid should be obtained from the airport operator, deicing contractor, or fluid manufacturer. Concentrations for all fluid components, including water, should be obtained. Therefore, if a solution is given as 48% propylene glycol, then the remainder of the solution (52%) is assumed to be water. Specific gravity for common deicing fluid components is given in Table 39-1.

Table 39-1. Specific Gravity for Deicing Fluid Components

Fluid Component	Specific Gravity
Water	1.000
Ethylene Glycol	1.119
Propylene Glycol	1.036
Urea	1.323

39.3 Sample Calculation

A 50% ethylene glycol deicing fluid is considered as an example. The weight of the ethylene glycol component, following the above equation, is 8.345 pounds/gallon x (50/100) x 1.119 = 4.669 pounds ethylene glycol per gallon of fluid. The other component of the fluid is water, which is also 50% of the fluid by weight. The weight of the water component is 8.33 pounds/gallon x (50/100) x 1.000 = 4.173 pounds water per gallon of deicing fluid. The total density of the deicing fluid, then, is 4.669 + 4.173 = **8.842 pounds/gallon**.

An emission index of 0.0067 pounds HC emissions per pound of ethylene glycol applied should be used for runway deicing, and an emission index of 0.00011 pounds HC emissions per pound of ethylene glycol applied should be used for aircraft deicing. One should be careful to note that emissions are given per pound of ethylene glycol rather than per pound of deicing fluid, which also contains water. Equation 39-2 takes this into account by employing a concentration factor. The emission indices given for ethylene glycol solutions may also be applied to propylene glycol, which is somewhat less volatile than ethylene glycol.

39.4 References

U.S. Department of Transportation, Federal Aviation Administration, *Air Quality Procedures For Civilian Airports and Air Force Bases*, Appendix H: Stationary Sources, June 2, 2005.

U.S. Department of Transportation, Federal Aviation Administration, *Air Quality Procedures For Civilian Airports and Air Force Bases*, Addendum, September 2004.

U.S. Environmental Protection Agency, *Preliminary Data Summary – Airport Deicing Operations (Revised)*, August 2000.

40 GHG EMISSIONS

40.1 Introduction

Gases that trap heat in the atmosphere are often called GHGs. Some GHGs, such as CO₂, occur naturally and are emitted to the atmosphere through natural processes and human activities. Other GHGs (e.g., fluorinated gases) are created and emitted solely through human activities.

In addition to CO₂, combustion of fuels at stationary sources results in emissions of five GHGs: CH₄, N₂O, CO, NO₂, and non-methane VOCs. For the first two of these GHGs (CH₄ and N₂O), global warming potential values have been developed, which allow for normalization of all emissions to a common unit of metric tons of carbon equivalent. No Global Warming Potential values have yet been developed for the other three types of gases (CO, NO_x, and non-methane VOCs); thus, they cannot be included in a GHG inventory.

Other than CH₄ and N₂O, gases emitted from the combustion of fuels at stationary sources are not considered major contributors to climate change. Data on gases such as CO, NO_x, and non-methane VOCs are already collected by state environmental or air quality agencies to determine state compliance with CAA regulations.

In general, emissions of CH₄ and N₂O will vary with the type of fuel combusted, the size and vintage of the combustion technology, the maintenance and operation of this technology, and the type of pollution control technology used. N₂O is produced from the combustion of fuels, and the mechanisms of its formation are fairly well understood. The level of N₂O emissions depends on the combustion temperature, with the highest N₂O emissions at a temperature of 1,000 degrees Kelvin. For combustion temperatures below 800 or above 1200 degrees Kelvin, the N₂O emissions are negligible.

CH₄, CO, and non-methane VOCs are unburned gaseous combustibles that are emitted in small quantities due to incomplete combustion; more of these gases are released when combustion temperatures are relatively low. Emissions of these gases are also influenced by technology type, size, vintage, maintenance, operation, and emission controls. Larger, higher efficiency combustion facilities tend to have higher temperatures and thus, lower emission factors for these gases. Emissions may range several orders of magnitude above the average for facilities that are improperly maintained or poorly operated, such as may be the case for many older units. Similarly, during start-up periods, combustion efficiency is lowest, and emissions of CO and non-methane VOCs are higher than during periods of full operation.

40.2 Emission Calculations

Stationary Sources

Emissions estimation for stationary combustion involves the following process:

- a. Identify all types of fuel directly combusted in your operations;
- b. Identify annual consumption of each fuel;
- c. Select the appropriate adjusted emission factor for each fuel;
- d. Calculate each fuel's CO₂ emissions and convert to metric tons;
- e. Calculate each fuel's CH₄ and N₂O emissions and convert to metric tons; and
- f. Convert CH₄ and N₂O emissions to CO₂ equivalent (CO₂e) and sum all subtotals.

Step 1: Identify all types of fuel directly combusted in your operations.

Fuel types can include, for example, coal, residual fuel oil, distillate fuel (diesel), LPG, and natural gas.

Step 2: Determine annual consumption of each fuel.

This can be done by direct measurement, recording fuel purchase, or sales invoices measuring any stock change (measured in MMBtus, gallons or therms). If your fuel consumption is not available in MMBtus, gallons or therms, you can convert it using the conversion factors in Table 40-1.

Table 40-1. Conversion Factors

Unit	Multiplied by	Equals
Barrels	42.0	Gallons
Therms of Natural Gas	0.1	MMBtu ^a
Thousand Cubic feet of Natural Gas	1.03	MMBtu
Metric Tons of Coal, "Other Industry"	24.79	MMBtu
Metric Tons of Coal, Residential & Commercial"	26.323	MMBtu

^a MMBtu = million BTUs.

Source: Energy Information Administration, Annual Energy Review 2000 (2002).

Step 3: Select the appropriate emission factor for each fuel from Tables 40-2 and 40-3.

Each fuel type has a specific emission factor that relates the amount of CO₂, CH₄, or N₂O emitted per unit of fuel consumed (either in kilograms per MMBtu of fuel, or kilograms per gallon of fuel). CO₂ emission factors depend almost completely on the carbon content of the fuel. CH₄ and N₂O emission factors also depend on the type of combustion device and the combustion conditions.

- **CO₂.** Table 40-2 provides CO₂ emission factors for the most common fuel types in kilograms of CO₂ per MMBtu and in kilograms of CO₂ per gallon for liquid fuels. If you burn a fuel that is not listed in Table 40-2, such as refinery fuel gas, you should estimate an emission factor based on the specific properties of the fuel and document those properties. The CO₂ emission factors provided in Table 40-2 already incorporate a factor for the fraction of carbon oxidized. The CO₂ fraction reflects the fact that slightly less than 100% of the fuel consumed is completely combusted.
- **CH₄ and N₂O.** Table 40-3 presents CH₄ and N₂O emission factors by activity sector and fuel type. For petroleum products, emission factors for CH₄ and N₂O are provided in kilograms per gallon consumed.

Step 4: Calculate each fuel's CO₂ emissions and convert to metric tons.

If the fuel consumption is expressed in MMBtu, use Equation 40-1. If fuel is expressed in gallons, use Equation 40-2

$$E_{\text{Tot}} = EF_{\text{Pol}} \times FC \times 0.001 \quad \text{Equation 40-1}$$

Where fuel consumption is expressed in MMBtu,

$$E_{\text{Tot}} = \text{Total emissions (metric tons)}$$

EF_{Poi} = Emission factor (kg CO₂, CH₄, N₂O/Btu)
 FC = Fuel consumed (MMBtu)
 0.001 = Conversion factor (metric tons/kg).

OR

$$E_{Tot} = EF_{Poi} \times FC \times 0.001 \quad \text{Equation 40-2}$$

Where fuel consumption is expressed in gallons,

E_{Tot} = Total emissions (metric tons)
 EF_{Poi} = Emission factor (kg CO₂, CH₄, N₂O /gallon)
 FC = Fuel consumed (gallon)
 0.001 = Conversion factor (metric tons/kg).

Step 5: If you are reporting CH₄ and N₂O emissions, calculate each fuel's CH₄ and N₂O emissions and convert to metric tons.

If your fuel consumption is expressed in MMBtu, use Equation 40-1. If it is expressed in gallons, use Equation 40-2. Note, non-CO₂ gases may be de minimis.

Step 6: Convert CH₄ and N₂O Emissions to CO₂e and sum all subtotals.

Use the global warming potential factors from Table 40-4 to convert CH₄ and N₂O to CO₂e. To incorporate non-CO₂ gases in your GHG emissions inventory, the mass estimates of these gases will need to be converted to CO₂e. To do this, multiply the non-CO₂ GHG emissions in units of mass by its global warming potential (GWP). Table 40-4 lists the 100-year GWPs to be used to express emissions on a CO₂e basis.

Table 40-2. Emission Factors and Oxidation Rates for Stationary Combustion

Fuel	kg CO ₂ /MMBtu (CA.)	kg CO ₂ /MMBtu (U.S.)	kg CO ₂ /gallon	Fraction of Carbon Oxidized	Adjusted kg CO ₂ /MMBtu (CA.)	Adjusted kg CO ₂ /MMBtu (U.S.)	Adjusted kg CO ₂ /gallon
Coal and Natural Gas							
Residential Coal	92.77	95.33	NA	99.0%	91.84	94.38	NA
Commercial Coal	92.77	95.33	NA	99.0%	91.84	94.38	NA
Industrial "Other" Coal	93.00	93.98	NA	99.0%	92.07	93.04	NA
Utility Coal	NA	94.45	NA	99.0%		93.51	NA
Natural Gas	NA	53.05	NA	99.5%		52.78	NA
Petroleum							
Distillate Fuel (Diesel)	NA	73.15	10.15	99.0%		72.42	10.15
Kerosene	NA	72.31	9.77	99.0%		71.59	9.77
Liquefied Petroleum Gas (LPG)	NA	62.30	5.95	99.0%		61.68	5.95
MOGAS	NA	70.91	8.87	99.0%		70.20	8.87
Reformulated Gasoline						69.73	
Residual Fuel	NA	78.80	11.79	99.0%		78.01	11.79

Propane	NA	NA	5.70	99.5%		NA	5.70
Butane	NA	NA	6.52	99.5%		NA	6.52
Methanol (neat)	NA	NA	4.11	99.0%		NA	4.11
Still Gas	NA	64.20	NA	99.5%		63.88	

Note: Emission factors are based on complete combustion and HHV. Emission factors for coking and utility coals are not given for California because they are not consumed in the state.

Sources: Emission factors are derived from California Energy Commission, Inventory of California Greenhouse Gas Emissions and Sinks: 1990-1999 (November 2002); and Energy Information Administration, Emissions of GHGs in the United States 2000 (2001), Table B1, page 140. Propane and butane emission factors and fractions oxidized from U.S. Environmental Protection Agency, Compilation of Air Pollutant Emission Factors, AP-42, Fifth Edition, Methanol emission factor is calculated from the properties of the pure compounds; the fraction oxidized is assumed to be the same as for other liquid fuels.

Table 40-3. CH₄ and N₂O Emission Factors for Stationary Combustion by Sector and Fuel Type

NON-PETROLEUM FUELS			
Sector	Fuel	kg CH ₄ /MMBtu	kg N ₂ O/MMBtu
Industrial	Coal	0.0111	0.0016
	Petroleum	0.0022	0.0007
	Natural Gas	0.0059	0.0001
	Wood	0.0351	0.0047
Commercial/Institutional	Coal	0.0111	0.0016
	Petroleum	0.0111	0.0007
	Natural Gas	0.0059	0.0001
	Wood	0.3514	0.0047
PETROLEUM FUELS			
Sector	Fuel	kg CH ₄ /MMBtu	kg N ₂ O/MMBtu
Industrial	Distillate Fuel	0.0003	0.0001
	Kerosene	0.0003	0.0001
	LPG	0.0002	0.0001
	Residual Fuel	0.0003	0.0001
Commercial/Institutional	Distillate Fuel	0.0014	0.0001
	Kerosene	0.0014	0.0001
	LPG	0.0010	0.0001
	Motor Gasoline	0.0013	0.0001
	Residual Fuel	0.0015	0.0001
Residential	Distillate Fuel	0.0014	0.0001
	Kerosene	0.0014	0.0001
	LPG	0.0010	0.0001
	Motor Gasoline	0.0013	0.0001
	Propane	9.1E-05	4.1E-04
	Butane	9.1E-05	4.1E-04

Note: All emission factors have been converted to HHV, assuming LHV is 95% of HHV for coal and petroleum and is 90% of HHV for natural gas and wood.

Sources: Emission factors are derived from: U.S. EPA, "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2000" (2002), Table C-2, page C-2. EPA obtained original emission factors from the IPCC, Revised IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual (1996), Tables 1-15 through 1-19, pages 1.53-1.57.

Table 40-4. Comparison of GWP

GHG	GWP – Second Assessment Report	GWP – Third Assessment Report
CO ₂	1	1
CH ₄	21	23
N ₂ O	310	296

GWPs were developed by the IPCC to quantify the globally averaged relative radiative forcing effects of a given GHG, using CO₂ as the reference gas. In 1996, the IPCC published a set of GWPs for the most commonly measured GHGs in its Second Assessment Report (SAR). In 2001, the IPCC published its Third Assessment Report (TAR), which adjusted the GWPs to reflect new information on atmospheric lifetimes and an improved calculation of the radiative forcing of CO₂. However, SAR GWPs are still used by international convention and the U.S. to maintain the value of the CO₂ “currency.” To maintain consistency with international practice, the Registry requires participants to use GWPs from the SAR when determining de minimis emissions, establishing baselines, and making baseline adjustments. For comparison, participants may also calculate their inventories using TAR values. As the IPCC publishes additional updates to GWP, these values may also be used for comparison.

Mobile Sources

1. The method for estimating CO₂ emissions from mobile sources includes three steps:
 - a. Identify total annual fuel consumption by fuel type;
 - b. Select the appropriate CO₂ emission factor from Table 40-5; and
 - c. Multiply fuel consumed by the emission factor to calculate total CO₂ emissions and convert kilograms to metric tons.

$$E_{\text{CO}_2} = \text{FC} \times \text{EF}_{\text{CO}_2} \times 0.0011 \quad \text{Equation 40-3}$$

Where

$$\begin{aligned} E_{\text{CO}_2} &= \text{Total emissions (tons)} \\ \text{FC} &= \text{Total amount of fuel used during the period (gal)} \\ \text{EF}_{\text{CO}_2} &= \text{Emission factor (kg CO}_2\text{/gal)} \\ 0.0011 &= \text{Conversion factor (tons/kg).} \end{aligned}$$

2. The method for estimating emissions of CH₄ and N₂O from mobile sources involves five steps:
 - a. Identify the vehicle types, fuel, and model years of all the vehicles you own and operate;
 - b. Identify the annual mileage by vehicle type;
 - c. Select the appropriate emission factor for each vehicle and fuel type (using Table 40-2);
 - d. Calculate each vehicle type CH₄ and N₂O emissions and convert grams to metric tons; and
 - e. Sum the emissions over each vehicle and fuel type;

$$E_{\text{Poi}} = \text{EF}_{\text{Poi}} \times \text{M} \times 9.072\text{E-}04 \quad \text{Equation 40-4}$$

Where

$$\begin{aligned} E_{\text{Poi}} &= \text{Total emissions (tons)} \\ \text{EF}_{\text{Poi}} &= \text{Emission factor by vehicle and fuel type (g/mi)} \\ \text{M} &= \text{Annual mileage} \\ 9.072\text{E-}04 &= \text{Conversion factor ton/g.} \end{aligned}$$

Table 40-5. CO₂ Emission Factors for Transport Fuels

Fuel	Kg CO₂ /gallon
Aviation Gas	8.24
Biodiesel	9.52
CA Low Sulfur Diesel	9.96
CA Reformulated Gasoline (5.7% ethanol)	8.55
Diesel #2 (“non-California”)	10.05
Ethanol (E85)	6.10
Fischer Tropsch Diesel	9.13
Jet Fuel, Kerosene (Jet A or A-1)	9.47
Jet Fuel, Naphtha (Jet B)	9.24
Kerosene	9.67
LNG	4.37
LPG	5.92
Methanol	4.10
MOGAS (“non-California”)	8.78
Propane	5.67
Residual Oil	11.67
Fuels with Other Units of Measure	
Compressed Natural Gas (CNG) per them	5.28
CNG per gasoline gallon equivalent	6.86
Hydrogen per kg	0.0

Note: Emission factors are based on complete combustion and HHV.

Source: California Energy Commission, Inventory of California Greenhouse Gas Emissions and Sinks: 1990-1999 (November 2002); Energy Information Administration, Emissions of GHGs in the United States 2000, (2001), Table B1, page 140, see <http://www.eia.doe.gov/oiaf/1605/ggrpt>; propane and butane emission factors and fractions oxidized from AP-42, Fifth Edition, see <http://www.epa.gov/ttn/chief/ap42/index.html>. Methanol emission factor is calculated from the properties of the pure compounds; the fraction oxidized is assumed to be the same as for other liquid fuel.

Table 40-6. CH₄ and N₂O Emission Factors for Mobile Sources

Vehicle Type/Model Year	CH ₄ (g/mile)	N ₂ O (g/mile)
Passenger Cars - Gasoline		
Model Year 1966-1972	0.22	0.02
Model Year 1973-1974	0.19	0.02
Model Year 1975-1979	0.11	0.05
Model Year 1980-1983	0.07	0.08
Model Year 1992	0.06	0.08
Model Year 1993	0.06	0.07
Model Year 1994-1999	0.05	0.05
Model Year 2000-Present	0.05	0.04
Passenger Cars – Alternative Fuels and Diesel		
CNG Model Year 2000-Present	0.04	0.04
LPG Model Year 2000-Present	0.04	0.04
E85 Model Year 2000-Present	0.04	0.04
Diesel All Model Years	0.01	0.02
Light Duty Truck (<5750 GVWR) - Gasoline		
Model Year 1966-1972	0.22	0.02
Model Year 1973-1974	0.23	0.02
Model Year 1975-1979	0.14	0.07
Model Year 1980-1983	0.12	0.13
Model Year 1984-1991	0/11	0.14
Model Year 1992	0.09	0.11
Model Year 1993	0.07	0.08
Model Year 1994-1999	0.06	0.06
Model Year 2000-Present	0.05	0.06
Light Duty Truck – Alternative Fuels and Diesel		
CNG Model Year 2000-Present	0.05	0.06
LPG Model Year 2000-Present	0.05	0.06
E85 Model Year 2000-Present	0.05	0.06
Diesel All Model Years	0.01	0.03
Heavy-Duty Vehicle (>5751 GVWR) - Gasoline		
Model Year 1981 and Older	0.43	0.04
Model Year 1982-1984	0.42	0.05
Model Year 1985-1986	0.20	0.05
Model Year 1987	0.18	0.09
Model Year 1988-1989	0.17	0.09
Model Year 1990-Present	0.12	0.20
Heavy-Duty Trucks – Diesel and Alternative Fuels		
Model Year 1966-1982	0.10	0.05
Model Year 1983-1995	0.08	0.05
Model Year 1996-Present	0.06	0.05
CNG, LNG	3.48	0.05
FTD, Biodiesel	0.06	0.05
Motorcycles		
Model Year 1966-1995	0.42	0.01
Model Year 1996-Present	0.09	0.01

Source: Derived from California Energy Commissions, Inventory of California Greenhouse Gas Emissions and Sinks: 1990-1999 (November 2002).

40.3 References

U.S. Environmental Protection Agency, Emissions Inventory Improvement Program (EIIP), Volume 8: Chapter 2, *Methods for Estimating Methane and Nitrous Oxide Emissions from Stationary Combustion*, August 2004.

California Climate Action Registry, *Reporting Entity-Wide Greenhouse Gas Emissions*, Version 2.2, Chapter 7, “Direct Emissions from Mobile Combustion,” March 2007.

California Climate Action Registry, *Reporting Entity-Wide Greenhouse Gas Emissions*, Version 2.2, Chapter 8, “Direct Emissions from Stationary Combustion,” March 2007.

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APPENDIX A - HAPS

Table A-1. HAPs (Alphabetical Order)

CAS No.	Chemical Name	CAS No.	Chemical Name
75070	Acetaldehyde	126998	Chloroprene
60355	Acetamide		Chromium Compounds
75058	Acetonitrile		Cobalt Compounds
98862	Acetophenone		Coke Oven Emissions
53963	2-Acetylaminofluorene	1319773	Cresols/Cresylic acid (isomers and mixture)
107028	Acrolein	95487	o-Cresol
79061	Acrylamide	108394	m-Cresol
79107	Acrylic acid	106445	p-Cresol
107131	Acrylonitrile	98828	Cumene
107051	Allyl chloride		Cyanide Compounds ¹
92671	4-Aminobiphenyl	94757	2,4-D, salts and esters
62533	Aniline	3547044	DDE
90040	o-Anisidine	334883	Diazomethane
	Antimony Compounds	132649	Dibenzofurans
	Arsenic Compounds (inorganic including arsine)	96128	1,2-Dibromo-3-chloropropane
1332214	Asbestos	84742	Dibutylphthalate
71432	Benzene (including benzene from gasoline)	106467	1,4-Dichlorobenzene(p)
92875	Benzidine	91941	3,3-Dichlorobenzidene
98077	Benzotrichloride	111444	Dichloroethyl ether (Bis(2-chloroethyl)ether)
100447	Benzyl chloride	542756	1,3-Dichloropropene
	Beryllium Compounds	62737	Dichlorvos
92524	Biphenyl	111422	Diethanolamine
117817	Bis(2-ethylhexyl)phthalate (DEHP)	121697	N,N-Diethyl aniline (N,N-Dimethylaniline)
542881	Bis(chloromethyl)ether	64675	Diethyl sulfate
75252	Bromoform	119904	3,3-Dimethoxybenzidine
106990	1,3-Butadiene	60117	Dimethyl aminoazobenzene
	Cadmium Compounds	119937	3,3'-Dimethyl benzidine
156627	Calcium cyanamide	79447	Dimethyl carbamoyl chloride
133062	Captan	68122	Dimethyl formamide
63252	Carbaryl	57147	1,1-Dimethyl hydrazine
75150	Carbon disulfide	131113	Dimethyl phthalate
56235	Carbon tetrachloride	77781	Dimethyl sulfate
463581	Carbonyl sulfide	534521	4,6-Dinitro-o-cresol, and salts
120809	Catechol	51285	2,4-Dinitrophenol
133904	Chloramben	121142	2,4-Dinitrotoluene
57749	Chlordane	123911	1,4-Dioxane (1,4-Diethyleneoxide)
7782505	Chlorine	122667	1,2-Diphenylhydrazine
79118	Chloroacetic acid	106898	Epichlorohydrin (1-Chloro-2,3-epoxypropane)
532274	2-Chloroacetophenone	106887	1,2-Epoxybutane
108907	Chlorobenzene	140885	Ethyl acrylate
510156	Chlorobenzilate	100414	Ethyl benzene
67663	Chloroform	51796	Ethyl carbamate (Urethane)
107302	Chloromethyl methyl ether	75003	Ethyl chloride (Chloroethane)
		106934	Ethylene dibromide (Dibromoethane)

Table A-1. HAPs (Alphabetical Order – Continued)

CAS No.	Chemical Name	CAS No.	Chemical Name
107062	Ethylene dichloride (1,2-Dichloroethane)	98953	Nitrobenzene
107211	Ethylene glycol	92933	4-Nitrobiphenyl
151564	Ethylene imine (Aziridine)	100027	4-Nitrophenol
75218	Ethylene oxide	79469	2-Nitropropane
96457	Ethylene thiourea	684935	N-Nitroso-N-methylurea
75343	Ethylidene dichloride (1,1-Dichloroethane)	62759	N-Nitrosodimethylamine
50000	Formaldehyde	59892	N-Nitrosomorpholine
	Glycol ethers ²	56382	Parathion
76448	Heptachlor	82688	Pentachloronitrobenzene (Quintobenzene)
118741	Hexachlorobenzene	87865	Pentachlorophenol
87683	Hexachlorobutadiene	108952	Phenol
77474	Hexachlorocyclopentadiene	106503	p-Phenylenediamine
67721	Hexachloroethane	75445	Phosgene
822060	Hexamethylene-1,6-diisocyanate	7803512	Phosphine
680319	Hexamethylphosphoramide	7723140	Phosphorus
110543	Hexane	85449	Phthalic anhydride
302012	Hydrazine	1336363	Polychlorinated biphenyls (Aroclors)
7647010	Hydrochloric acid		Polycyclic Organic Matter ⁴
7664393	Hydrogen fluoride (Hydrofluoric acid)	1120714	1,3-Propane sultone
123319	Hydroquinone	57578	beta-Propiolactone
78591	Isophorone	123386	Propionaldehyde
58899	Lindane (all isomers)	114261	Propoxur (Baygon)
	Lead Compounds	78875	Propylene dichloride (1,2-Dichloropropane)
108316	Maleic anhydride	75569	Propylene oxide
	Manganese Compounds	75558	1,2-Propylenimine (2-Methyl aziridine)
	Mercury Compounds	91225	Quinoline
67561	Methanol	106514	Quinone
72435	Methoxychlor		Radionuclides (including radon) ⁵
74839	Methyl bromide (Bromomethane)		Selenium Compounds
74873	Methyl chloride (Chloromethane)	100425	Styrene
71556	Methyl chloroform (1,1,1-Trichloroethane)	96093	Styrene oxide
60344	Methyl hydrazine	1746016	2,3,7,8-Tetrachlorodibenzo-p-dioxin
74884	Methyl iodide (Iodomethane)	79345	1,1,2,2-Tetrachloroethane
108101	Methyl isobutyl ketone (Hexone)	127184	Tetrachloroethylene (Perchloroethylene)
624839	Methyl isocyanate	7550450	Titanium tetrachloride
80626	Methyl methacrylate	108883	Toluene
1634044	Methyl tert butyl ether	95807	2,4-Toluene diamine
101144	4,4-Methylene bis(2-chloroaniline)	584849	2,4-Toluene diisocyanate
75092	Methylene chloride (Dichloromethane)	95534	o-Toluidine
101688	Methylene diphenyl diisocyanate (MDI)	8001352	Toxaphene (chlorinated camphene)
101779	4,4'-Methylenedianiline	120821	1,2,4-Trichlorobenzene
	Mineral fibers (fine particles) ³	79005	1,1,2-Trichloroethane
91203	Naphthalene	79016	Trichloroethylene
	Nickel Compounds	95954	2,4,5-Trichlorophenol

Table A-1. HAPs (Alphabetical Order – Continued)

CAS No.	Chemical Name	CAS No.	Chemical Name
88062	2,4,6-Trichlorophenol	75014	Vinyl chloride
121448	Triethylamine	75354	Vinylidene chloride (1,1-Dichloroethylene)
1582098	Trifluralin	1330207	Xylenes (isomers and mixture)
540841	2,2,4-Trimethylpentane	95476	o-Xylenes
108054	Vinyl acetate	108383	m-Xylenes
593602	Vinyl bromide	106423	p-Xylenes
<p>NOTE: 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., antimon</p> <ol style="list-style-type: none"> 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 <ul style="list-style-type: none"> - 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. 			

Table A-2. HAPs (CAS Number Order)

CAS No.	Chemical Name	CAS No.	Chemical Name
50000	Formaldehyde	77781	Dimethyl sulfate
51285	2,4-Dinitrophenol	78591	Isophorone
51796	Ethyl carbamate (Urethane)	78875	Propylene dichloride (1,2-Dichloropropane)
53963	2-Acetylaminofluorene	79005	1,1,2-Trichloroethane
56235	Carbon tetrachloride	79016	Trichloroethylene
56382	Parathion	79061	Acrylamide
57147	1,1-Dimethyl hydrazine	79107	Acrylic acid
57578	beta-Propiolactone	79118	Chloroacetic acid
57749	Chlordane	79345	1,1,2,2-Tetrachloroethane
58899	Lindane (all isomers)	79447	Dimethyl carbamoyl chloride
59892	N-Nitrosomorpholine	79469	2-Nitropropane
60117	Dimethyl aminoazobenzene	80626	Methyl methacrylate
60344	Methyl hydrazine	82688	Pentachloronitrobenzene (Quintobenzene)
60355	Acetamide	84742	Dibutylphthalate
62533	Aniline	85449	Phthalic anhydride
62737	Dichlorvos	87683	Hexachlorobutadiene
62759	N-Nitrosodimethylamine	87865	Pentachlorophenol
63252	Carbaryl	88062	2,4,6-Trichlorophenol
64675	Diethyl sulfate	90040	o-Anisidine
67561	Methanol	91203	Naphthalene
67663	Chloroform	91225	Quinoline
67721	Hexachloroethane	91941	3,3-Dichlorobenzidene
68122	Dimethyl formamide	92524	Biphenyl
71432	Benzene (including benzene from gasoline)	92671	4-Aminobiphenyl
71556	Methyl chloroform (1,1,1-Trichloroethane)	92875	Benzidine
72435	Methoxychlor	92933	4-Nitrobiphenyl
74839	Methyl bromide (Bromomethane)	94757	2,4-D, salts and esters
74873	Methyl chloride (Chloromethane)	95476	o-Xylenes
74884	Methyl iodide (Iodomethane)	95487	o-Cresol
75003	Ethyl chloride (Chloroethane)	95534	o-Toluidine
75014	Vinyl chloride	95807	2,4-Toluene diamine
75058	Acetonitrile	95954	2,4,5-Trichlorophenol
75070	Acetaldehyde	96093	Styrene oxide
75092	Methylene chloride (Dichloromethane)	96128	1,2-Dibromo-3-chloropropane
75150	Carbon disulfide	96457	Ethylene thiourea
75218	Ethylene oxide	98077	Benzotrithloride
75252	Bromoform	98828	Cumene
75343	Ethylidene dichloride (1,1-Dichloroethane)	98862	Acetophenone
75354	Vinylidene chloride (1,1-Dichloroethylene)	98953	Nitrobenzene
75445	Phosgene	100027	4-Nitrophenol
75558	1,2-Propylenimine (2-Methyl aziridine)	100414	Ethyl benzene
75569	Propylene oxide	100425	Styrene
76448	Heptachlor	100447	Benzyl chloride
77474	Hexachlorocyclopentadiene	101144	4,4-Methylene bis(2-chloroaniline)

Table A-2. HAPs (CAS Number Order – Continued)

CAS No.	Chemical Name	CAS No.	Chemical Name
101688	Methylene diphenyl diisocyanate (MDI)	131113	Dimethyl phthalate
101779	4,4'-Methylenedianiline	132649	Dibenzofurans
106423	p-Xylenes	133062	Captan
106445	p-Cresol	133904	Chloramben
106467	1,4-Dichlorobenzene(p)	140885	Ethyl acrylate
106503	p-Phenylenediamine	151564	Ethylene imine (Aziridine)
106514	Quinone	156627	Calcium cyanamide
106887	1,2-Epoxybutane	302012	Hydrazine
106898	Epichlorohydrin (1-Chloro-2,3-epoxypropane)	334883	Diazomethane
106934	Ethylene dibromide (Dibromoethane)	463581	Carbonyl sulfide
106990	1,3-Butadiene	510156	Chlorobenzilate
107028	Acrolein	532274	2-Chloroacetophenone
107051	Allyl chloride	534521	4,6-Dinitro-o-cresol, and salts
107062	Ethylene dichloride (1,2-Dichloroethane)	540841	2,2,4-Trimethylpentane
107131	Acrylonitrile	542756	1,3-Dichloropropene
107211	Ethylene glycol	542881	Bis(chloromethyl)ether
107302	Chloromethyl methyl ether	584849	2,4-Toluene diisocyanate
108054	Vinyl acetate	593602	Vinyl bromide
108101	Methyl isobutyl ketone (Hexone)	624839	Methyl isocyanate
108316	Maleic anhydride	680319	Hexamethylphosphoramide
108383	m-Xylenes	684935	N-Nitroso-N-methylurea
108394	m-Cresol	822060	Hexamethylene-1,6-diisocyanate
108883	Toluene	1120714	1,3-Propane sultone
108907	Chlorobenzene	1319773	Cresols/Cresylic acid (isomers and mixture)
108952	Phenol	1330207	Xylenes (isomers and mixture)
110543	Hexane	1332214	Asbestos
111422	Diethanolamine	1336363	Polychlorinated biphenyls (Aroclors)
111444	Dichloroethyl ether (Bis(2-chloroethyl)ether)	1582098	Trifluralin
114261	Propoxur (Baygon)	1634044	Methyl tert butyl ether
117817	Bis(2-ethylhexyl)phthalate (DEHP)	1746016	2,3,7,8-Tetrachlorodibenzo-p-dioxin
118741	Hexachlorobenzene	3547044	DDE
119904	3,3-Dimethoxybenzidine	7550450	Titanium tetrachloride
119937	3,3'-Dimethyl benzidine	7647010	Hydrochloric acid
120809	Catechol	7664393	Hydrogen fluoride (Hydrofluoric acid)
120821	1,2,4-Trichlorobenzene	7723140	Phosphorus
121142	2,4-Dinitrotoluene	7782505	Chlorine
121448	Triethylamine	7803512	Phosphine
121697	N,N-Diethyl aniline (N,N-Dimethylaniline)	8001352	Toxaphene (chlorinated camphene)
122667	1,2-Diphenylhydrazine		Antimony Compounds
123319	Hydroquinone		Arsenic Compounds
123386	Propionaldehyde		(inorganic including arsine)
123911	1,4-Dioxane (1,4-Diethyleneoxide)		Beryllium Compounds
126998	Chloroprene		Cadmium Compounds
127184	Tetrachloroethylene (Perchloroethylene)		Chromium Compounds

Table A-2. HAPs (CAS Number Order – Continued)

CAS No.	Chemical Name	CAS No.	Chemical Name
	Cobalt Compounds		Mercury Compounds
	Coke Oven Emissions		Fine mineral fibers ³
	Cyanide Compounds ¹		Nickel Compounds
	Glycol ethers ²		Polycyclic Organic Matter ⁴
	Lead Compounds		Radionuclides (including radon) ⁵
	Manganese Compounds		Selenium Compounds
NOTE: NOTE: For all listings above which contain the word "compounds" and for glycol ethers, the following			
1.	X'CN where X = H' or any other group where a formal dissociation may occur. For example KCN or		
2.	Includes mono- and di- ethers of ethylene glycol, diethylene glycol, and triethylene glycol R-		
	- 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-(OCH ₂ CH) _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		
4.	Includes organic compounds with more than one benzene ring, and which have a boiling point greater		
5.	A type of atom which spontaneously undergoes radioactive decay.		

APPENDIX B - EPA DEFINITION OF VOCS, NATIONAL AMBIENT AIR QUALITY STANDARDS (NAAQS), AND MAJOR SOURCE CATEGORIES**40 CFR 51.100(s) - Definition - VOCs¹**

(s) VOC means any compound of carbon, excluding CO, CO₂, carbonic acid, metallic carbides or carbonates, and ammonium carbonate, which participates in atmospheric photochemical reactions.

(1) This includes any such organic compound other than the following, which have been determined to have negligible photochemical reactivity:

- CH₄
- ethane
- methylene chloride (dichloromethane)
- 1,1,1-trichloroethane (methyl chloroform)
- 1,1,2-trichloro-1,2,2-trifluoroethane (CFC-113)
- trichlorofluoromethane (CFC-11)
- dichlorodifluoromethane (CFC-12)
- chlorodifluoromethane (HCFC-22)
- trifluoromethane (HFC-23)
- 1,2-dichloro 1,1,2,2-tetrafluoroethane (CFC-114)
- chloropentafluoroethane (CFC-115)
- 1,1,1-trifluoro 2,2-dichloroethane (HCFC-123)
- 1,1,1,2-tetrafluoroethane (HFC-134a)
- 1,1-dichloro 1-fluoroethane (HCFC-141b)
- 1-chloro 1,1-difluoroethane (HCFC-142b)
- 2-chloro-1,1,1,2-tetrafluoroethane (HCFC-124)
- pentafluoroethane (HFC-125)
- 1,1,2,2-tetrafluoroethane (HFC-134)
- 1,1,1-trifluoroethane (HFC-143a)
- 1,1-difluoroethane (HFC-152a)
- parachlorobenzotrifluoride (PCBTF)
- cyclic, branched, or linear completely methylated siloxanes
- acetone
- perchloroethylene (tetrachloroethylene)
- 3,3-dichloro-1,1,1,2,2-pentafluoropropane (HCFC-225ca)
- 1,3-dichloro-1,1,2,2,3-pentafluoropropane (HCFC-225cb)
- 1,1,1,2,3,4,4,5,5,5-decafluoropentane (HFC 43-10mee)
- difluoromethane (HFC-32)
- ethylfluoride (HFC-161)
- 1,1,1,3,3,3-hexafluoropropane (HFC-236fa)
- 1,1,2,2,3-pentafluoropropane (HFC-245ca)
- 1,1,2,3,3-pentafluoropropane (HFC-245ea)
- 1,1,1,2,3-pentafluoropropane (HFC-245eb)
- 1,1,1,3,3-pentafluoropropane (HFC-245fa)
- 1,1,1,2,3,3-hexafluoropropane (HFC-236ea)
- 1,1,1,3,3-pentafluorobutane (HFC-365mfc)
- chlorofluoromethane (HCFC-31)
- 1-chloro-1-fluoroethane (HCFC-151a)
- 1,2-dichloro-1,1,2-trifluoroethane (HCFC-123a)
- 1,1,1,2,2,3,3,4,4-nonafluoro-4-methoxy-butane (C₄F₉OCH₃ or HFE-7100)

- 2-(difluoromethoxymethyl)-1,1,1,2,3,3,3-heptafluoropropane ((CF₃)₂CF₂OCH₃)
- 1-ethoxy-1,1,2,2,3,3,4,4,4-nonafluorobutane (C₄F₉OC₂H₅ or HFE-7200)
- 2-(ethoxydifluoromethyl)-1,1,1,2,3,3,3-heptafluoropropane ((CF₃)₂CF₂OC₂H₅)
- methyl acetate
- 1,1,1,2,2,3,3-heptafluoro-3-methoxy-propane (n-C₃F₇OCH₃ or HFE-7000)
- 3-ethoxy-1,1,1,2,3,4,4,5,5,6,6,6-dodecafluoro-2-(trifluoromethyl) hexane (HFE-7500)
- 1,1,1,2,3,3,3-heptafluoropropane (HFC 227ea)
- methyl formate (HCOOCH₃)
- 1,1,1,2,2,3,4,5,5,5-decafluoro-3-methoxy-4-trifluoromethyl-pentane (HFE-7300)
- perfluorocarbon compounds which fall into these classes:
 - (i) cyclic, branched, or linear, completely fluorinated alkanes,
 - (ii) cyclic, branched, or linear, completely fluorinated ethers with no unsaturations,
 - (iii) cyclic, branched, or linear, completely fluorinated tertiary amines with no unsaturations, and
 - (iv) sulfur containing perfluorocarbons with no unsaturations and with sulfur bonds only to carbon and fluorine.

(2) For purposes of determining compliance with emissions limits, VOC will be measured by the test methods in the approved State implementation plan (SIP) or 40 CFR Part 60, Appendix A, as applicable. Where such a method also measures compounds with negligible photochemical reactivity, these negligibly-reactive compounds may be excluded as VOC if the amount of such compounds is accurately quantified, and such exclusion is approved by the enforcement authority.

(3) As a precondition to excluding these compounds as VOC or at any time thereafter, the enforcement authority may require an owner or operator to provide monitoring or testing methods and results demonstrating, to the satisfaction of the enforcement authority, the amount of negligibly-reactive compounds in the source's emissions.

(4) For purposes of Federal enforcement for a specific source, the EPA shall use the test methods specified in the applicable EPA-approved SIP, in a permit issued pursuant to a program approved or promulgated under Title V of the Act, or under 40 CFR Part 51, Subpart I or Appendix S, or under 40 CFR Parts 52 or 60. The EPA shall not be bound by any State determination as to appropriate methods for testing or monitoring negligibly-reactive compounds if such determination is not reflected in any of the above provisions.

(5) The following compound(s) are VOC for purposes of all recordkeeping, emissions reporting, photochemical dispersion modeling and inventory requirements which apply to VOC and shall be uniquely identified in emission reports, but are not VOC for purposes of VOC emissions limitations or VOC content requirements: t-butyl acetate.

(6) For the purposes of determining compliance with California's aerosol coatings reactivity-based regulation, (as described in the California code of Regulations, Title 17, Division 3, Chapter 1, Subchapter 8.5, Article 3), any organic compound in the volatile portion of an aerosol coating is counted towards that product's reactivity-based limit. Therefore, the compounds identified in paragraph (s) of this section as negligibly reactive and excluded from EPA's definition of VOCs are to be counted towards a product's reactivity limit for the purposes of determining compliance with California's aerosol coatings reactivity-based regulation.

¹ Definition as of February 9, 2007, as posted on U.S. EPA Web site.

Table B-1. NAAQS

Pollutant	Standard Value		Standard Type
Carbon Monoxide (CO)			
8-hour Average	9 ppm	10 mg/m ³	Primary
1-hour Average	35 ppm	40 mg/m ³	Primary
Lead (Pb)			
Quarterly Average		1.5 µg/m ³	Primary & Secondary
Nitrogen Dioxide (NO₂)			
Annual Arithmetic Mean	0.053 ppm	100 µg/m ³	Primary & Secondary
Ozone (O₃)			
1-hour Average ^a	0.12 ppm	235 µg/m ³	Primary & Secondary
8-hour Average	0.08 ppm	157 µg/m ³	Primary & Secondary
Particulate < 10 micrometers			
Annual Arithmetic Mean	(Revoked Dec. 17, 2006)		Primary & Secondary
24-hour Average		150 µg/m ³	Primary & Secondary
Particulate < 2.5 micrometers			
Annual Arithmetic Mean		15 µg/m ³	Primary & Secondary
24-hour Average		35 µg/m ³	Primary & Secondary
Sulfur Dioxide (SO₂)			
Annual Arithmetic Mean	0.03 ppm	80 µg/m ³	Primary
24-hour Average	0.14 ppm	365 µg/m ³	Primary
3-hour Average	0.50 ppm	1,300 µg/m ³	Secondary

^a The ozone 1-hour standard applies only to areas that were designated non-attainment when the ozone 8-hour standard was adopted in July 1997.

Major Stationary Source or Major Source

The default major source threshold for each criteria pollutants *in attainment and unclassifiable areas* is 250 tons per year except the threshold is 100 tons per year for 28 specific source categories. Fugitive emissions from these source categories must be included in the emissions estimate. [[40 CFR 51.166\(b\)\(1\)](#), [40 CFR 52.21\(b\)\(1\)](#)]

The 28 source categories are:

- 1) Carbon black plants (furnace process)
- 2) Charcoal production plants
- 3) Chemical process plants
- 4) Coal cleaning plants (with thermal dryers)
- 5) Coke oven batteries

- 6) Fossil fuel-fired steam electric plants of more than 250 million British thermal units per hour heat input
- 7) Fossil-fuel boilers (or combination thereof) totaling more than 250 million British thermal units per hour heat input
- 8) Fuel conversion plants
- 9) Glass fiber processing plants
- 10) Hydrofluoric acid plants
- 11) Iron and steel mills
- 12) Kraft pulp mills
- 13) Lime plants
- 14) Municipal incinerators capable of charging >250 tons of refuse per day
- 15) Nitric acid plants
- 16) Petroleum refineries
- 17) Petroleum storage and transfer units with a total storage capacity exceeding 300,000 barrels
- 18) Phosphate rock processing plants
- 19) Portland cement plants
- 20) Primary aluminum ore reduction plants
- 21) Primary copper smelters
- 22) Primary lead smelters
- 23) Primary zinc smelters
- 24) Secondary metal production plants
- 25) Sintering plants
- 26) Sulfur recovery plants
- 27) Sulfuric acid plants
- 28) Taconite ore processing plants

APPENDIX C - SOURCE CLASSIFICATION CODES (SCC)

EPA's current listing of all source classification codes (SCCs) and their descriptions is found at http://www.epa.gov/ttn/chief/codes/readme_scc.txt. These codes are used as a primary identifying data element in EPA's National Emission Inventory (NEI) and many state agency emissions data systems. The current file contains 9,865 SCCs. This file also contains a "Sector" identifier for each SCC, which identifies the file sector within the NEI where sources with that SCC should be reported. The sectors are AREA, BIOGENIC, NONROAD, ON-ROAD, and POINT.

SCCs for Point sources are 8-characters; SCCs for Area, Biogenic, Nonroad and On-Road sectors are 10-characters. For each SCC, the file contains four levels of the description for that code. An SCC is labeled based on four description levels (i.e., SCC_L1, SCC_L2, SCC_L3, and SCC_L4) in order to reduce confusion with the 10-character SCCs used for Area, Biogenics, On-Road, and Nonroad sectors. EPA's current version of the SCC list has added fields to show the date the SCC was created or revised, and what was revised. Most SCCs will have null for created date, indicating that they are "older than dirt."

This version of the file also has added an indication of whether the SCC is "Active." Data reporters are requested not to use SCCs which have a "No" in this field. Some of the inactive SCCs have been assigned an Active "Map To" SCC. If an SCC had not been used in previous NEIs, EPA did not attempt to try to map it to one of the current SCCs.

Organization of SCCs.

The four levels of source descriptions for SCCs are associated with the first 1, 3, 6, and 8 characters of the point source codes, or the first 2, 4, 7, and 10 characters of the codes used for the other four NEI sectors. The first level uses only the first character and provides only the most general information on the category of the emissions.

The second level of description is associated with the first three characters, and subdivides the five major categories above into major industry groups. For example, 1-01 indicates External Combustion in Utility Boilers, and 1-02 indicates External Combustion in Industrial Boilers. The Manufacturing Processes category (3-) is currently divided into 21 industry classes, such as Chemical Manufacturing (3-01), Food and Agriculture (3-02), and Primary Metal Production (3-03).

The third level of description requires the first six characters to be specified, and it identifies a specific industry or emission source category, for example Cotton Ginning (3-02-004), or Primary Copper Smelting (3-03-005). The three characters which have been added to the industry class description (the first three characters) usually indicate the major product, raw material, or fuel used.

The fourth level of description is associated with the full eight character code. The addition of two more characters beyond the third level specifies the particular emitting process within the third-level source category. For example, SCC 3-03-005-06 specifies the Ore Concentrate Dryer emission source at a Primary Copper Smelting facility (3-03-005).

An eight-character code may correspond to a particular boiler type, process heater, process vent, or fuel. A single emission point may have two or more SCCs if it uses more than one material or burns more than one type of fuel, but most emission points will be described by one SCC.

As an example, “2-75-010-14” is an SCC an Air Force base might use to report exhaust emissions from landing and take-offs. The SCC is listed as a “Point” sector. Since this a point category, the SCC consists of eight digits. The first digit defines the general category of emissions (SCC_L1). In this example, “2” is “IC engines.” The second description level (SCC_L2) subdivides the five general categories above into major industry groups. In this example, the “2-75” (first three digits of the SCC) further defines the emissions source as “IC engines, Fixed Wing aircraft Landing and Takeoff Exhaust.” The third description level (SCC_L3) in the SCC refers to a specific industry or emission source category. In this example, “2-75-010” defines this as “IC engines, Fixed Wing aircraft Landing and Takeoff Exhaust, from a “military” emission source. Finally, the fourth description level (SCC_L4), in connection with the complete SCC specifies the particular emitting process in the source category described by SCC_L3. In the case of the sample SCC, the “2-75-010-14” refers to “IC engines, Fixed Wing aircraft Landing and Takeoff Exhaust, from a “military” emission source, specifically Jet Engines burning/using JP-4.”

APPENDIX D - DATA ELEMENTS FROM AIR EMISSION INVENTORIES (STATIONARY)

Source Type	Data Elements
Abrasive Blasting	<ol style="list-style-type: none"> 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) 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 <u>collects</u> 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	<ol style="list-style-type: none"> 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) 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	<ol style="list-style-type: none"> 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

Source Type	Data Elements
Chromium Electroplating and Chromic Acid Anodizing	<p><u>Chromium Electroplating</u></p> <ol style="list-style-type: none"> 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) 6. Make, model #, and manufacturer of each control device <p><u>Chromic Acid Anodizing</u></p> <ol style="list-style-type: none"> 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) 5. Make, model #, and manufacturer of each control device
Dry Cleaning Operations	<ol style="list-style-type: none"> 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 mass of solvent which is captured by the carbon adsorption system and not reintroduced back in to the process is required
Equipment Leaks	<ol style="list-style-type: none"> 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

Source Type	Data Elements
Ethylene Oxide Sterilizers	<ol style="list-style-type: none"> 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) 5. Make, model number, and manufacturer of each control device 6. The manufacturer's rated efficiency for each control device
External Combustion Sources	<ol style="list-style-type: none"> 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; LPG [propane or butane]) 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) 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) 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., LNB, FGR, low excess air, burners out of service, selective noncatalytic reduction, selective catalytic reduction, overfire air)
Fire Fighter Training	<ol style="list-style-type: none"> 1. Types of fuels burned (e.g., JP-8, propane) 2. Approximate quantity of each fuel type burned during the year

Source Type	Data Elements
Fuel Cell Maintenance	<p>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</p> <ol style="list-style-type: none"> 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: <ul style="list-style-type: none"> • 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)
Fuel Spills	<ol style="list-style-type: none"> 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

Source Type	Data Elements
Fuel Storage - Vertical Fixed Roof Tanks	<p>Data elements are based on EPA's TANKS program. The following information is required for each tank:</p> <ol style="list-style-type: none"> 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: <ul style="list-style-type: none"> • 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)	<p>Data elements are based on EPA's TANKS program. The following information is required for each tank:</p> <ol style="list-style-type: none"> 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: <ul style="list-style-type: none"> • 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	<p>Data elements are based on EPA's TANKS program. The following information is required for each tank:</p> <ol style="list-style-type: none"> 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	<p>Data elements are based on EPA's TANKS program. The following information is required for each tank:</p> <ol style="list-style-type: none"> 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	<ol style="list-style-type: none"> 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) 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: <ul style="list-style-type: none"> • <u>Capture</u> efficiency of vapor control system • <u>Control</u> 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	<ol style="list-style-type: none"> 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	<ol style="list-style-type: none"> 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	<ol style="list-style-type: none"> 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) [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	<ol style="list-style-type: none"> 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	<p><u>Gaseous Emissions</u></p> <ol style="list-style-type: none"> 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) 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? <p><u>Particulate Emissions</u></p> <ol style="list-style-type: none"> 1. Type of heavy duty equipment used to cover the waste with soil (e.g., bulldozer, graders) 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	<ol style="list-style-type: none"> 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	<ol style="list-style-type: none"> 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
OB/OD of Energetic Materials	<ol style="list-style-type: none"> 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: <ul style="list-style-type: none"> • Total mass of energetic material which is OB/OD during the year (lb/yr) 4. For open burning of assembled energetic materials (i.e., munitions), the following information is required: <ul style="list-style-type: none"> • 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: <ul style="list-style-type: none"> • 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 Section 23.2) instead of the EPA’s emission factor database: <ul style="list-style-type: none"> • 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	<ol style="list-style-type: none"> 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
ODSs	<ol style="list-style-type: none"> 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	<ol style="list-style-type: none"> 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: <ul style="list-style-type: none"> • 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	<p><u>Soil Vapor Extraction</u></p> <ol style="list-style-type: none"> 1. Flow rate of the extracted air (ft³/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 <p><u>Pump and Treat Utilizing Air Stripping</u></p> <ol style="list-style-type: none"> 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	<ol style="list-style-type: none"> 1. Types of rounds used during the year (e.g., 5.56 mm, 9 mm, 7.62 mm, 40 mm, 12 gauge) 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 Pb 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 Pb 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	<ol style="list-style-type: none"> 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 IC Engine Equipment	<ol style="list-style-type: none"> 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 <u>engine</u> (hp) 6. The loading factor (% of maximum power) the engine is typically operated at [Note: If unknown, use typical values listed in the “Stationary IC 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	<ol style="list-style-type: none"> 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) 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) 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	<ol style="list-style-type: none"> 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	<p><u>Wastewater Emissions</u></p> <ol style="list-style-type: none"> 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 ($\mu\text{g/l}$) 3. Average concentration of contaminants (e.g., VOC, organic HAPs) in the Effluent ($\mu\text{g/l}$) 4. Quantity (pounds) of chlorine added to the wastewater during the year <p><u>Sludge Digester Gas Flare Emissions</u></p> <ol style="list-style-type: none"> 1. Average daily quantity of gas combusted 2. Number of days during the year in which the flare was in operation
Welding	<ol style="list-style-type: none"> 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	<ol style="list-style-type: none"> 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 TSD content in the cooling water, if available
Woodworking	<ol style="list-style-type: none"> 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: <ul style="list-style-type: none"> • 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 E - RECOMMENDED AEI REPORT 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]
- SIC 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]
- SIC 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., AEI for ___ base for calendar year __)
 - Identity (name and office symbol) of the government organizations involved (e.g., base organization(s), Major Command (MAJCOM) organization, contracting organization)
 - Overall purpose of the inventory
 - General description of the base (e.g., size, location, primary mission)
- 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), types of sources addressed (e.g., stationary point, stationary fugitive, mobile), types of emissions addressed (i.e., actual only, actual and potential)
 - Attainment/non-attainment status of the base with respect to the NAAQS
 - 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)
- 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)? 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).

Sections 2 through ? – Specific Source Types

- 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 is 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.”
- SIC Code – As mentioned in Section 1.5.1 of this document, on 2 August 1996 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 August 1996 memo, or if there is not a more applicable SIC code for the source type].
- 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 be downloaded from the 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). For those source types with many emission units (e.g., boilers, generators, storage tanks), 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 following information should be included:
 - description of the methodology used
 - algorithms/equations used to calculate the emissions [Note: If an approved computer program (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)
 - 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 AEIs 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)
- Excerpts from reference documents
- Copies of (or excerpts from) applicable rules/regulations

EXAMPLE
Summary of Criteria Pollutant and Total HAP Emissions

SOURCE CATEGORY	CO		Pb		NO _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						
OB/OD of Energetic Materials						
Open/Prescribed Burning						
ODSs						
Pesticide Application						
Site Restoration						
Small Arms Firing						
Solvent Cleaning Machines						
Stationary IC 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						
OB/OD of Energetic Materials						
Open/Prescribed Burning						
ODSs						
Pesticide Application						
Site Restoration						
Small Arms Firing						
Solvent Cleaning Machines						
Stationary IC 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				
OB/OD of Energetic Materials				
Open/Prescribed Burning				
ODSs				
Pesticide Application				
Site Restoration				
Small Arms Firing				
Solvent Cleaning Machines				
Stationary IC 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									
NDI Operations									
OB/OD of Energetic Materials									
Open/Prescribed Burning									
ODSs									
Pesticide Application									
Site Restoration									
Small Arms Firing									
Solvent Cleaning Machines									
Stationary IC 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									
NDI Operations									
OB/OD of Energetic Materials									
Open/Prescribed Burning									
ODSs									
Pesticide Application									
Site Restoration									
Small Arms Firing									
Solvent Cleaning Machines									
Stationary IC 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	Ethy/ene glycol	Ethy/ene 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									
NDI Operations									
OB/OD of Energetic Materials									
Open/Prescribed Burning									
ODSs									
Pesticide Application									
Site Restoration									
Small Arms Firing									
Solvent Cleaning Machines									
Stationary IC 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	Pb 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									
NDI Operations									
OB/OD of Energetic Materials									
Open/Prescribed Burning									
ODSs									
Pesticide Application									
Site Restoration									
Small Arms Firing									
Solvent Cleaning Machines									
Stationary IC 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									
NDI Operations									
OB/OD of Energetic Materials									
Open/Prescribed Burning									
ODSs									
Pesticide Application									
Site Restoration									
Small Arms Firing									
Solvent Cleaning Machines									
Stationary IC 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									
NDI Operations									
OB/OD of Energetic Materials									
Open/Prescribed Burning									
ODSs									
Pesticide Application									
Site Restoration									
Small Arms Firing									
Solvent Cleaning Machines									
Stationary IC 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 F - AIRCRAFT ENGINE EMISSION FACTORS

Table F-1. List of Aircraft Engines and Emission Factor Tables

Aircraft or APU	Engine Designation	Emission Factor Table	Reference
C-130	T56-A-7	F-2 and F-3	(AFIERA, Nov 1998)
C-5A/B	TF39-GE-1C	F-4 and F-5	(AFIERA, Nov 1998)
F-16 C/D/N	F110-GE-100	F-6 and F-7	(AFIERA, Nov 1998)
B-1B	F101-GE-102	F-8 and F-9	(AFIERA, Nov 1998)
C/EC/RC-135E	TF33-P-102	F-10 and F-11	(AFIERA, Nov 1998)
C141	TF33-P-7/7A	F-12 and F-13	(AFIERA, Nov 1998)
T-37	J69-T-25	F-14 and F-15	(AFIERA, Nov 1998)
T-38	J85-GE-5M	F-16 and F-17	(AFIERA, Sep 2002)
C-17	F117-PW-100	F-18 and F-19	(AFIERA, Nov 1998)
B-2	F118-GE-100	F-20 and F-21	(AFIERA, Nov 1998)
F-117A and F/A-18C/D	F404-GE-F1D2/400	F-22 and F-23	(AFIERA, Nov 1998)
F-16C/D	F110-GE-129	F-24	(AFIERA, Nov 1998)
F-15	F100-PW-100	F-25	(AFIERA, Nov 1998)
F-15 and F-16	F100-PW-229	F-26	(AFIERA, Nov 1998)
MH53J (helicopter)	T64-GE-100	F-27 and F-28	(AFIERA, Nov 1998)
A-10	TF34-GE-100A	F-29 and F-30	(AFIERA, Nov 1998)
F-22	F119-PW-100	F-31 and F-32	(AFIERA, Jun 2002)
T-6A	PT6A-68	F-33 and F-34	(Pratt & Whitney, 2002)
UH60A, UH60G (helicopter)	T700-GE-700	F-35 and F-36	(AFIERA, Nov 1998)
C-130H (APU)	GTCP85-180	F-37 and F-38	(AFIERA, Nov 1998)
C-5A/B (APU)	GTCP165-1	F-39 and F-40	(AFIERA, Nov 1998)
KC-135R	F108-CF-100	F-41 and F-42	(AFIERA, Nov 1998)
	F100-PW-200	F-43 and F-44	
	TF30-P109	F-45 and F-46	
	T58-GE-16	F-47	
	T406-AD-400	F-48	

Table F-2. Criteria Pollutant Emission Factors for T56-A-7 Engine

Power Setting	Idle		Approach		Intermediate		Military	
Fuel Flow, lb/hr	724		880		1,742		2,262	
Pollutant	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel
NO _x	5.48	7.58	6.64	7.54	15.93	9.14	28.19	12.48
CO	3.66	5.05	3.42	3.89	3.37	1.93	5.2	2.31
THC	2.6	3.59	0.79	0.9	1.14	0.65	1	0.44

Source: Aircraft Engine and Auxiliary Power Unit (APU) Emissions Testing Final Report, Volume 1, December 1998, USAF/AFIERA

Table F-3. HAP Emission Factors for T56-A-7 Engine

Power Setting	Idle		Approach		Intermediate		Military	
Fuel Flow, lb/hr	724		880		1,742		2,262	
HAPs	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel
Acetaldehyde	7.54E-03	1.04E-02	ND	ND	9.46E-04	5.43E-04	3.72E-04	1.64E-04
Acrolein	ND	ND	ND	ND	ND	ND	ND	ND
Benzene	3.45E-03	4.76E-03	3.91E-03	4.45E-03	2.34E-03	1.34E-03	1.78E-03	7.86E-04
Ethylbenzene	ND	ND	5.45E-04	6.19E-04	5.46E-04	3.12E-04	4.06E-04	1.80E-04
Formaldehyde	2.97E-02	4.11E-02	2.94E-02	3.34E-02	1.62E-02	9.27E-03	8.62E-04	3.81E-04
MEK	9.60E-05	1.33E-04	6.16E-05	7.00E-05	ND	ND	1.40E-04	6.18E-05
Naphthalene	8.40E-04	1.60E-03	9.11E-04	1.04E-03	3.08E-04	1.77E-04	3.02E-04	1.34E-04
Styrene	ND	ND	3.22E-04	3.66E-04	ND	ND	ND	ND
Toluene	1.96E-03	2.71E-03	2.02E-03	2.29E-03	1.67E-03	9.60E-04	5.74E-05	2.52E-05
o-Xylene	ND	ND	2.84E-04	3.23E-04	2.92E-04	1.68E-04	5.62E-04	2.49E-04
m,p-Xylene	2.24E-04	3.11E-04	6.44E-04	7.32E-04	7.22E-04	4.15E-04	1.42E-03	6.28E-04

Source: Aircraft Engine and APU Emissions Testing Final Report, Volume 1, December 1998, USAF/AFIERA

Table F-4. Criteria Pollutant Emission Factors for TF39-GE-1C Engine

Power Setting	Idle		Approach		Intermediate		Takeoff	
Fuel Flow, lb/hr	1,448		10,477		12,541		13,862	
Pollutant	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel
NO _x	4.89	3.36	260.95	24.72	353.18	28.16	452.79	32.66
CO	84.63	58.21	8.1	0.77	19.17	1.53	17.18	1.28
THC	23.9	16.43	6.96	0.67	ND	ND	ND	ND

Source: Aircraft Engine and APU Emissions Testing Final Report, Volume 1, December 1998, USAF/AFIERA.

Table F-5. HAP Emission Factors for TF39-GE-1C Engine

Power Setting	Idle		Approach		Intermediate		Takeoff	
Fuel Flow, lb/hr	1,448.00		10,477.00		12,541		13,862	
HAPs	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel
Acetaldehyde	3.07E-01	2.12E-01	3.31E-02	3.16E-03	3.27E-03	2.61E-04	8.55E-03	6.17E-04
Acrolein	2.99E-01	2.06E-01	ND	ND	ND	ND	ND	ND
Benzene	5.18E-01	3.57E-01	1.63E-02	1.56E-03	1.76E-02	1.41E-03	2.99E-02	2.16E-03
Ethylbenzene	2.91E-02	2.00E-02	1.86E-02	1.78E-03	6.26E-03	4.99E-04	0.00E+00	0.00E+00
Formaldehyde	2.06E+00	1.42E+00	8.54E-02	8.15E-03	6.14E-02	4.90E-03	1.46E-01	1.06E-02
MEK	5.35E-02	3.69E-02	ND	ND	2.95E-03	2.35E-04	3.41E-03	2.46E-04
Naphthalene	1.41E-01	9.71E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Styrene	6.51E-02	4.48E-02	ND	ND	ND	ND	1.28E-02	9.26E-04
Toluene	1.86E-01	1.28E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
o-Xylene	2.90E-02	2.00E-02	1.62E-02	1.57E-03	8.57E-03	6.83E-04	0.00E+00	0.00E+00
m,p-Xylene	5.52E-02	3.80E-02	0.00E+00	0.00E+00	2.38E-02	1.90E-03	0.00E+00	0.00E+00

Source: Aircraft Engine and APU Emissions Testing Final Report, Volume 1, December 1998, USAF/AFIERA.

Table F-6. Criteria Pollutant Emission Factors for F110-GE-100 Engine

Power Setting	Idle		Approach		Intermediate		Military		Afterburner	
Fuel Flow, lb/hr	1,111		5,080		7,332		11,358		18,088	
Pollutant	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel
NO _x	4.18	3.77	49.69	9.78	124.02	16.84	329.41	29.02	257.94	14.25
CO	26.79	24.16	29.33	5.78	25.42	3.46	38.39	3.38	1219.25	67.27
THC	1.14	1.03	1.30	0.26	2.04	0.28	1.89	0.17	459.02	25.33

Source: Aircraft Engine and APU Emissions Testing Final Report, Volume 1, December 1998, USAF/AFIERA.

Table F-7. HAP Emission Factors for F110-GE-100 Engine

Power Setting	Idle		Approach		Intermediate		Military		Afterburner	
Fuel Flow, lb/hr	1,111		5,080		7,332		11,358		18,088	
HAPs	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel
Acetaldehyde	7.36E-03	6.64E-03	ND	ND	1.21E-03	1.65E-04	1.64E-03	1.45E-04	2.24E-01	1.24E-02
Acrolein	ND	ND	ND	ND	ND	ND	ND	ND	7.06E-01	3.90E-02
Benzene	3.26E-02	2.94E-02	9.00E-03	1.77E-03	1.16E-02	1.59E-03	1.83E-02	1.61E-03	3.39E+00	1.88E-01
Ethylbenzene	2.22E-03	2.00E-03	2.34E-03	4.60E-04	3.60E-03	4.91E-04	2.84E-03	2.50E-04	8.10E-01	4.46E-02
Formaldehyde	1.12E-01	1.01E-01	5.09E-02	1.00E-02	1.42E-01	1.94E-02	1.74E-01	1.53E-02	2.76E-01	1.52E-02
Naphthalene	2.68E-03	2.42E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.76E-03	3.31E-04	1.76E+00	9.72E-02
Styrene	4.10E-03	3.70E-03	2.20E-03	4.33E-04	4.51E-03	6.14E-04	3.47E-03	3.06E-04	1.03E-01	5.69E-03
Toluene	1.22E-02	1.10E-02	6.82E-03	1.34E-03	1.39E-02	1.90E-03	8.43E-03	7.44E-04	2.54E+00	1.40E-01
o-Xylene	1.53E-03	1.38E-03	2.20E-03	4.33E-04	1.82E-03	2.45E-04	2.84E-03	2.50E-04	5.14E-01	2.83E-02
m,p-Xylene	3.16E-03	2.85E-03	4.20E-03	8.27E-04	7.13E-03	9.71E-04	3.85E-03	3.39E-04	1.10E+00	6.03E-02

Source: Aircraft Engine and APU Emissions Testing Final Report, Volume 1, December 1998, USAF/AFIERA.

Table F-8. Criteria Pollutant Emission Factors for F101-GE-102 Engine

Power Setting	Idle		Approach		Intermediate		Military		Afterburner	
Fuel Flow, lb/hr	1,117		4,533		6,557		7,828		15,314	
Pollutant	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel
NO _x	4.58	4.10	41.51	9.16	86.22	13.15	100.43	12.83	259.11	16.91
CO	27.32	24.47	4.65	1.03	5.58	0.85	6.50	0.83	665.98	43.47
THC	ND	ND	2.09	0.46	2.60	0.40	2.91	0.37	947.21	61.82

Source: Aircraft Engine and APU Emissions Testing Final Report, Volume 1, December 1998, USAF/AFIERA.

Table F-9. HAP Emission Factors for F101-GE-102 Engine

Power Setting	Idle		Approach		Intermediate		Military		Afterburner	
Fuel Flow, lb/hr	1,117		4,533		6,557		7,828		15,314	
HAPs	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel
Acetaldehyde	ND	ND	ND	ND	ND	ND	ND	ND	2.71E-01	1.77E-02
Acrolein	ND	ND	ND	ND	ND	ND	ND	ND	1.26E+00	8.24E-02
Benzene	1.32E-02	1.18E-02	3.58E-03	7.91E-04	8.67E-03	1.32E-03	4.29E-02	5.49E-03	3.49E+00	2.27E-01
Ethylbenzene	ND	ND	ND	ND	ND	ND	ND	ND	1.32E+00	8.60E-02
Formaldehyde	1.16E-01	1.04E-01	2.32E-02	5.12E-03	3.04E-02	4.64E-03	3.47E-02	4.44E-03	5.96E-01	3.89E-02
Naphthalene	2.00E-03	1.79E-03	0.00E+00	0.00E+00	ND	ND	ND	ND	1.94E+00	1.27E-01
Styrene	1.21E-03	1.08E-03	ND	ND	3.58E-03	5.45E-04	ND	ND	1.86E-01	1.21E-02
Toluene	6.20E-03	5.55E-03	6.79E-03	1.50E-03	1.11E-02	1.69E-03	1.45E-02	1.85E-03	1.94E+00	1.26E-01
o-Xylene	ND	ND	ND	ND	ND	ND	ND	ND	1.06E+00	6.91E-02
m,p-Xylene	1.03E-03	9.22E-04	2.67E-03	5.90E-04	4.80E-03	7.31E-04	1.92E-02	2.46E-03	2.38E+00	1.55E-01

Source: Aircraft Engine and APU Emissions Testing Final Report, Volume 1, December 1998, USAF/AFIERA.

Table F-10. Criteria Pollutant Emission Factors for TF33-P-102 Engine

Power Setting	Idle		Approach		Intermediate		Military	
Fuel Flow, lb/hr	1,114		4,737		5,782		7,561	
Pollutant	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel
NO _x	1.55	1.39	30.16	6.37	45.56	7.88	91.35	12.08
CO	105.85	95.06	24.81	5.24	12.21	2.11	0.00	0.00
THC	101.21	90.91	6.51	1.37	8.67	1.50	4.19	0.55

Source: Aircraft Engine and APU Emissions Testing Final Report, Volume 1, December 1998, USAF/AFIERA.

Table F-11. HAP Emission Factors for TF33-P-102 Engine

Power Setting	Idle		Approach		Intermediate		Military	
Fuel Flow, lb/hr	1,114		4,737		5,782		7,561	
HAPs	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel
Acetaldehyde	7.54E-03	1.04E-02	0.00E+00	0.00E+00	ND	ND	ND	ND
Acrolein	ND	ND	ND	ND	ND	ND	ND	ND
Benzene	7.90E-01	7.10E-01	5.40E-02	1.14E-02	2.34E-02	4.05E-03	7.22E-03	9.55E-04
Ethylbenzene	9.63E-02	8.65E-02	3.90E-03	8.23E-04	3.56E-03	6.16E-04	ND	ND
Formaldehyde	1.05E+00	9.40E-01	3.15E-01	6.66E-02	1.31E-01	2.26E-02	ND	ND
Naphthalene	2.39E-01	2.14E-01	5.22E-03	1.10E-03	4.25E-03	7.36E-04	9.82E-04	1.30E-04
Styrene	1.21E-01	1.09E-01	5.61E-03	1.18E-03	3.32E-03	5.75E-04	ND	ND
Toluene	2.95E-01	2.65E-01	1.08E-02	2.28E-03	1.53E-02	2.65E-03	7.19E-03	9.51E-04
o-Xylene	6.79E-02	6.10E-02	0.00E+00	0.00E+00	1.59E-03	2.74E-04	2.85E-03	3.77E-04
m,p-Xylene	1.53E-01	1.37E-01	1.14E-02	2.41E-03	6.40E-03	1.11E-03	6.31E-03	8.34E-04

Source: Aircraft Engine and APU Emissions Testing Final Report, Volume 1, December 1998, USAF/AFIERA.

Table F-12. Criteria Pollutant Emission Factors for TF33-P-7 Engine

Power Setting	Idle		Approach		Intermediate		Military	
Fuel Flow, lb/hr	1,093		4,884		6,356		8,264	
Pollutant	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel
NO _x	0.87	0.8	34.77	7.13	51.48	8.1	85.05	10.29
CO	147.51	134.51	47.25	9.69	26.45	4.16	12.33	1.49
THC	152.39	139.27	24.95	5.14	3.50	0.55	ND	ND

Source: Aircraft Engine and APU Emissions Testing Final Report, Volume 1, December 1998, USAF/AFIERA.

Table F-13. HAP Emission Factors for TF33-P-7 Engine

Power Setting	Idle		Approach		Intermediate		Military	
Fuel Flow, lb/hr	1,093		4,884		6,356		8,264	
HAPs	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel
Acetaldehyde	ND	ND	4.26E-02	8.73E-03	ND	ND	ND	ND
Acrolein	ND	ND	ND	ND	ND	ND	ND	ND
Benzene	5.72E-01	5.20E-01	1.38E-01	2.85E-02	4.13E-02	6.49E-03	1.21E-02	1.47E-03
Ethylbenzene	2.19 E-01	2.00 E-01	9.97 E-03	2.06 E-03	3.25 E-03	5.11 E-04	3.64 E-03	4.42 E-04
Formaldehyde	2.52E+00	2.31E+00	6.41E-01	1.26E-01	1.78E-01	2.80E-02	4.36E-02	5.28E-03
Naphthalene	4.06E-01	3.71E-01	1.53E-02	3.14E-03	2.25E-03	3.55E-04	0.00 E+00	0.00 E+00
Styrene	2.65E-01	2.42E-01	1.68E-02	3.45E-03	4.74E-03	7.46E-04	ND	ND
Toluene	4.08E-01	3.73E-01	4.94E-02	1.02E-02	1.61E-02	2.54E-03	1.87E-02	2.27E-03
o-Xylene	1.39E-01	1.27E-01	6.93E-03	1.43E-03	2.81E-03	4.42E-04	3.99E-03	4.84E-04
m,p-Xylene	3.66E-01	3.35E-01	1.66E-02	3.42E-03	6.61E-03	1.04E-03	1.00E-02	1.21E-03

Source: Aircraft Engine and APU Emissions Testing Final Report, Volume 1, December 1998, USAF/AFIERA.

Table F-14. Criteria Pollutant Emission Factors for J69-T-25 Engine

Power Setting	Idle		Intermediate		Military	
Fuel Flow, lb/hr	167		872		1085	
Pollutant	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel
NO _x	0.13	0.80	2.55	2.92	4.91	4.52
CO	26.73	159.84	33.37	38.25	35.65	32.85
THC	2.51	15.00	0.06	0.07	0.21	0.20

Source: Aircraft Engine and APU Emissions Testing Final Report, Volume 1, December 1998, USAF/AFIERA.

Table F-15. HAP Emission Factors for J69-T-25 Engine

Power Setting	Idle		Intermediate		Military	
Fuel Flow, lb/hr	167		872		1,085	
HAPs	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel
Acetaldehyde	1.63E-02	9.77E-02	1.86E-03	2.14E-03	ND	ND
Acrolein	3.27E-02	1.96E-01	ND	ND	ND	ND
Benzene	3.16E-02	1.89E-01	3.03E-03	3.47E-03	2.02E-03	1.86E-03
Ethylbenzene	3.39E-03	2.03E-02	ND	ND	ND	ND
Formaldehyde	1.53E-01	9.12E-01	2.37E-02	2.71E-02	1.26E-02	1.16E-02
Naphthalene	5.92E-03	3.54E-02	2.97E-04	3.41E-04	2.41E-04	2.22E-04
Styrene	4.54E-03	2.71E-02	ND	ND	ND	ND
Toluene	1.87E-02	1.12E-01	1.36E-03	1.56E-03	9.00E-04	8.29E-04
o-Xylene	4.19E-03	2.51E-02	1.04E-03	1.19E-03	ND	ND
m,p-Xylene	1.08E-02	6.43E-02	6.23E-04	7.14E-04	6.33E-04	5.83E-04

Source: Aircraft Engine and APU Emissions Testing Final Report, Volume 1, December 1998, USAF/AFIERA.

Table F-16. Criteria Pollutant Emission Factors for J85-GE-5M Engine

Power Setting	Idle		Intermediate		Military		Afterburner	
Fuel Flow, lb/hr	525		1,045		2,550		7,695	
Pollutant	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel
NO _x	0.42	0.79	1.89	1.81	4.21	1.65	9.31	1.21
CO	100.49	191.41	51.10	48.90	64.64	25.35	78.41	10.19
SO ₂	0.47	0.90	0.94	0.90	2.30	0.90	6.93	0.90
THC	11.08	21.11	1.69	1.62	1.15	0.45	5.00	0.65
PM ₁₀	3.31	6.30	11.20	10.72	9.33	3.66	ND	ND

Source: Clean Air Act Testing of the T-38C Aircraft Engines, September 2002.

Table F-17. HAP Emission Factors for J85-GE-5M Engine

Power Setting	Idle		Intermediate		Military		Afterburner	
Fuel Flow, lb/hr	525		1,045		2,550		7,695	
HAPs	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel
Acetaldehyde	1.26E-01	2.40E-01	1.05E-02	2.00E-02	1.05E-03	2.00E-03	ND	ND
Acrolein	1.63E-01	3.10E-01	5.25E-03	1.00E-02	5.25E-04	1.00E-03	ND	ND
Benzene	1.58E-02	3.00E-02	1.05E-02	2.00E-02	1.58E-03	3.00E-03	ND	ND
Ethylbenzene	3.68E-04	7.00E-04	1.05E-03	2.00E-03	2.63E-05	5.00E-05	ND	ND
Formaldehyde	1.19E+00	2.26 +00	1.84E-01	3.50E-01	1.26E-02	2.40E-02	ND	ND
Naphthalene	4.35E-02	8.29E-02	3.12E-03	5.95E-03	2.45E-03	4.66E-03	ND	ND
Styrene	4.20E-03	8.00E-03	1.05E-03	2.00E-03	3.68E-05	7.00E-05	ND	ND
Toluene	1.58E-02	3.00E-02	5.25E-03	1.00E-02	4.73E-04	9.00E-04	ND	ND
m,p-Xylene	1.05E-02	2.00E-02	4.20E-03	8.00E-03	2.10E-04	4.00E-04	ND	ND

Source: Clean Air Act Testing of the T-38C Aircraft Engines, September 2002.

Table F-18. Criteria Pollutant Emission Factors for F117-PW-100 Engine

Power Setting	Idle		Approach		Intermediate	
Fuel Flow, lb/hr	978		4645		10,408	
Pollutant	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel
NO _x	3.68	3.72	71.94	15.47	340.51	32.74
CO	22.20	22.43	2.36	0.51	3.32	0.32
THC	2.03	2.05	2.01	0.43	4.02	0.39

Source: Aircraft Engine and APU Emissions Testing Final Report, Volume 1, December 1998, USAF/AFIERA.

Table F-19. HAP Emission Factors for F117-PW-100 Engine

Power Setting	Idle		Approach		Intermediate	
Fuel Flow, lb/hr	978		4,645		10,408	
HAPs	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel
Acetaldehyde	1.17E-02	1.18E-02	ND	ND	ND	ND
Acrolein	ND	ND	ND	ND	ND	ND
Benzene	2.20E-02	2.22E-02	4.13E-03	8.89E-04	6.51E-03	6.26E-04
Ethylbenzene	2.99E-03	3.02E-03	ND	ND	ND	ND
Formaldehyde	2.31E-01	2.33E-01	7.68E-02	1.65E-02	9.89E-02	9.51E-03
Naphthalene	2.34E-03	2.37E-03	ND	ND	ND	ND
Styrene	1.52E-03	1.53E-03	ND	ND	ND	ND
Toluene	6.54E-03	6.60E-03	6.55E-03	1.41E-03	1.17E-02	1.12E-03
o-Xylene	9.57E-04	9.66E-04	ND	ND	ND	ND
m,p-Xylene	2.24E-03	2.26E-03	3.28E-03	7.04E-04	5.69E-03	5.47E-04

Source: Aircraft Engine and APU Emissions Testing Final Report, Volume 1, December 1998, USAF/AFIERA.

Table F-20. Criteria Pollutant Emission Factors for F118-GE-100 Engine

Power Setting	Idle		Approach		Intermediate		Military	
Fuel Flow, lb/hr	1,097		3,773		6,350		10,887	
Pollutant	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel
NO _x	4.72	4.3	41.85	11.09	114.38	18.01	360.59	33.12
CO	23.02	20.98	7.62	2.02	5.36	0.84	7.07	0.65
THC	0.65	0.59	3.28	0.87	ND	ND	ND	ND

Source: Aircraft Engine and APU Emissions Testing Final Report, Volume 1, December 1998, USAF/AFIERA.

Table F-21. HAP Emission Factors for F118-GE-100 Engine

Power Setting	Idle		Approach		Intermediate		Military	
Fuel Flow, lb/hr	1,097		3,773		6,350		10,887	
HAPs	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel
Acetaldehyde	8.62E-03	7.85E-03	ND	ND	ND	ND	ND	ND
Acrolein	ND	ND	ND	ND	ND	ND	ND	ND
Benzene	2.96E-02	2.70E-02	3.24E-03	8.57E-04	2.35E-03	3.71E-04	3.68E-03	3.38E-04
Ethylbenzene	1.35E-03	1.23E-03	1.90E-03	5.03E-04	ND	ND	ND	ND
Formaldehyde	1.97E-01	1.80E-01	4.60E-02	1.22E-02	7.43E-02	1.17E-02	7.13E-02	6.55E-03
Naphthalene	0.00E+00	0.00E+00	ND	ND	ND	ND	ND	ND
Styrene	2.47E-03	2.26E-03	ND	ND	ND	ND	ND	ND
Toluene	1.08E-02	9.87E-03	5.08E-03	1.34E-03	1.89E-03	2.97E-04	4.19E-03	3.84E-04
o-Xylene	1.57E-03	1.43E-03	2.38E-03	6.28E-04	ND	ND	ND	ND
m,p-Xylene	4.20E-03	3.83E-03	5.53E-03	1.46E-03	2.11E-03	3.32E-04	2.60E-03	2.38E-04

Source: Aircraft Engine and APU Emissions Testing Final Report, Volume 1, December 1998, USAF/AFIERA.

Table F-22. Criteria Pollutant Emission Factors for F404-GE-F1D2 Engine

Power Setting	Idle		Approach		Intermediate		Military		Afterburner	
Fuel Flow, lb/hr	685		3,111		6,464		7,739		15,851	
Pollutant	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel
NO _x	1.17	1.71	24.46	7.86	110.1	17.04	199.91	25.83	86.05	5.43
CO	75.47	110.51	6.27	2.02	9.94	1.54	11.47	1.48	797.48	50.29
THC	35.14	51.46	3.76	1.21	1.18	0.18	0.91	0.12	425.55	26.83

Source: Aircraft Engine and APU Emissions Testing Final Report, Volume 1, December 1998, USAF/AFIERA.

Table F-23. HAP Emission Factors for F404-GE-F1D2 Engine

Power Setting	Idle		Approach		Intermediate		Military		Afterburner	
Fuel Flow, lb/hr	685		3,111		6,464		7,739		15,851	
HAPs	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel
Acetaldehyde	3.90E-02	5.71E-02	ND	ND	ND	ND	ND	ND	5.36E-01	3.38E-02
Acrolein	1.17E-01	1.71E-01	ND	ND	ND	ND	ND	ND	2.29E+00	1.45E-01
Benzene	3.52E-01	5.15E-01	2.35E-03	7.56E-04	4.17E-03	6.43E-04	5.70E-03	7.37E-04	5.86E+00	3.69E-01
Ethylbenzene	5.13E-02	7.51E-02	1.51E-03	4.84E-04	2.58E-03	3.99E-04	ND	ND	7.70E-01	4.85E-02
Formaldehyde	7.82E-01	1.14E+00	5.20E-02	1.67E-02	1.46E-01	2.26E-02	6.98E-02	9.02E-03	5.93E-01	3.74E-02
Naphthalene	8.95E-02	1.31E-01	9.65E-04	3.10E-04	4.55E-04	7.03E-05	7.99E-04	1.03E-04	1.16E+00	7.32E-02
Styrene	5.93E-02	8.69E-02	ND	ND	ND	ND	ND	ND	9.28E-02	5.85E-03
Toluene	1.78E-01	2.60E-01	2.72E-03	8.73E-04	6.91E-03	1.06E-03	5.13E-03	6.62E-04	2.83E+00	1.78E-01
o-Xylene	5.53E-02	8.10E-02	2.72E-03	8.75E-04	3.81E-03	5.88E-04	2.59E-03	3.35E-04	7.71E-01	4.86E-02
m,p-Xylene	1.15E-01	1.68E-01	5.48E-03	1.76E-03	8.91E-03	1.37E-03	5.76E-03	7.45E-04	1.47E+00	9.30E-02

Source: Aircraft Engine and APU Emissions Testing Final Report, Volume 1, December 1998, USAF/AFIERA.

Table F-24. Criteria Pollutant Emission Factors for F110-GE-129 Engine

Power Setting	Idle		Approach		Intermediate		Military		Afterburner	
Fuel Flow, lb/hr	961		4,832		6,939		8,611		15,564	
Pollutant	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel
NO _x	2.52	2.62	64.84	13.42	123.67	17.82	175.13	25.24	110.39	15.91
CO	43.28	45.01	9.34	1.93	10.61	1.53	10.11	1.46	984.82	141.93
THC	4.09	4.25	ND	ND	ND	ND	7.00	1.01	723.51	104.27

Source: Aircraft Engine and APU Emissions Testing Final Report, Volume 1, December 1998, USAF/AFIERA.

Table F-25. Criteria Pollutant Emission Factors for F100-PW-100 Engine

Power Setting	Idle		Approach		Intermediate		Military		Afterburner	
Fuel Flow, lb/hr	1,067		2,726		7,549		9,211		12,198	
Pollutant	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel
NO _x	4.40	4.12	33.13	12.15	261.83	34.69	331.25	43.88	279.19	36.98
CO	22.41	21.00	8.18	3	8.27	1.10	8.27	1.10	262.30	34.75
THC	3.60	3.37	0.52	0.19	ND	ND	2.78	0.37	48.41	6.41

Source: Aircraft Engine and APU Emissions Testing Final Report, Volume 1, December 1998, USAF/AFIERA.

Table F-26. Criteria Pollutant Emission Factors for F100-PW-229 Engine

Power Setting	Idle		Approach		Intermediate		Military		Afterburner	
Fuel Flow, lb/hr	1,087		3,098		5,838		11,490		20,793	
Pollutant	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel
NO _x	4.13	3.80	46.71	15.08	102.37	17.53	336.55	57.65	297.28	50.92
CO	11.05	10.16	3.62	1.17	0.85	0.15	3.84	0.66	447.33	76.62
THC	0.42	0.38	0.65	0.21	1.74	0.3	3.14	0.54	94.95	16.26

Source: Aircraft Engine and APU Emissions Testing Final Report, Volume 1, December 1998, USAF/AFIERA.

Table F-27. Criteria Pollutant Emission Factors for T64-GE-100 Engine (MH53J)

Power Setting	Ground Idle		75% Normal		Normal		Military	
Fuel Flow, lb/hr	298		941		1,698		1,848	
Pollutant	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel
NO _x	0.33	1.11	6.44	6.84	16.06	9.46	20.87	11.29
CO	22.79	76.60	7.39	7.85	3.75	2.21	4.01	2.17
THC	8.24	27.70	0.21	0.23	0.05	0.03	0.05	0.03

Source: Aircraft Engine and APU Emissions Testing Final Report, Volume 1, December 1998, USAF/AFIERA.

Table F-28. HAP Emission Factors for T64-GE-100 Engine (MH53J)

Power Setting	Ground Idle		75% Normal		Normal		Military	
Fuel Flow, lb/hr	298		941		1,698		1,848	
HAPs	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel
Acetaldehyde	1.51E-02	5.05E-02	1.13E-03	1.20E-03	ND	ND	ND	ND
Acrolein	3.39E-02	1.14E-01	1.29E-03	1.37E-03	ND	ND	ND	ND
Benzene	6.43E-02	2.16E-01	1.19E-02	1.27E-02	6.79E-03	3.98E-03	7.16E-03	3.88E-03
Ethylbenzene	6.68E-03	2.25E-02	2.89E-04	3.07E-04	ND	ND	ND	ND
Formaldehyde	2.13E-02	7.16E-02	1.10E-02	1.17E-02	5.40E-04	3.18E-04	3.39E-04	1.84E-04
Naphthalene	1.62E-02	5.44E-02	1.43E-03	1.52E-03	8.24E-06	4.96E-06	4.62E-03	2.50E-03
Styrene	1.22E-02	4.11E-02	4.81E-04	5.11E-04	ND	ND	ND	ND
Toluene	3.04E-02	1.02E-01	2.71E-03	2.88E-03	2.26E-04	1.33E-04	2.35E-04	1.27E-04
o-Xylene	6.16E-03	2.07E-02	2.68E-04	2.85E-04	ND	ND	ND	ND
m,p-Xylene	1.31E-02	4.39E-02	6.43E-04	6.83E-04	ND	ND	ND	ND

Source: Aircraft Engine and APU Emissions Testing Final Report, Volume 1, December 1998, USAF/AFIERA.

Table F-29. Criteria Pollutant Emission Factors for TF34-GE-100A Engine

Power Setting	Idle		Approach		Intermediate		Military	
Fuel Flow, lb/hr	498		933		1,512		2,628	
Pollutant	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel
NO _x	0.16	0.33	2.89	3.09	8.49	5.61	23.94	9.11
CO	32.68	66.46	26.05	27.93	13.45	8.88	10.35	3.94
THC	7.95	16.17	0.47	0.51	0.61	0.40	1.56	0.70

Source: Aircraft Engine and APU Emissions Testing Final Report, Volume 1, December 1998, USAF/AFIERA.

Table F-30. HAP Emission Factors for TF34-GE-100A Engine

Power Setting	Idle		Approach		Intermediate		Military	
Fuel Flow, lb/hr	498		933		1,512		2,628	
HAPs	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel
Acetaldehyde	6.34E-02	1.27E-01	2.87E-02	3.07E-02	ND	ND	ND	ND
Acrolein	3.04E-02	6.11E-02	1.27E-02	1.36E-02	8.19E-03	5.41E-03	7.77E-03	2.96E-03
Benzene	1.40E-01	2.86E-01	5.94E-02	6.37E-02	1.44E-02	9.55E-03	1.12E-03	4.25E-03
Ethylbenzene	1.30E-02	2.68E-02	3.28E-03	3.51E-03	ND	ND	2.51E-03	9.56E-04
Formaldehyde	6.09E-01	1.22E+00	4.95E-01	5.31E-01	1.00E-01	6.62E-02	7.42E-02	2.82E-02
Naphthalene	2.23E-02	4.47E-02	7.94E-03	8.51E-03	2.41E-03	1.59E-03	8.42E-05	3.20E-05
Styrene	2.20E-02	4.56E-02	6.27E-03	6.72E-03	ND	ND	ND	ND
Toluene	5.60E-02	1.15E-01	1.30E-02	1.40E-02	4.85E-03	3.21E-03	3.52E-04	1.33E-04
o-Xylene	1.33E-02	2.75E-02	3.40E-03	3.65E-03	ND	ND	2.66E-03	1.01E-03
m,p-Xylene	2.74E-02	5.64E-02	7.42E-03	7.95E-03	2.30E-03	1.52E-03	6.33E-03	2.41E-03

Source: Aircraft Engine and APU Emissions Testing Final Report, Volume 1, December 1998, USAF/AFIERA.

Table F-31. Criteria Pollutant Emission Factors for F119-PW-100 Engine

Power Setting	Idle		Approach		Intermediate		Military		Afterburner	
Fuel Flow, lb/hr	1,377		2,742		10,113		18,625		50,170	
Pollutant	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel
NO _x	4.14	3.01	18.06	6.59	125.36	12.4	368.76	19.81	369.8	7.37
CO	66.3	48.15	21.71	7.92	21.62	2.14	13.99	0.75	807.67	16.1
NMHC	9.41	6.83	0.94	0.34	5.36	0.53	ND	ND	9.30	0.20
PM ₁₀	3.43	2.49	5.49	2.00	14.23	1.41	20.92	1.12	ND	ND
SO _x	0.52	0.38	1.04	0.38	3.84	0.38	7.07	0.38	19.06	0.38

Source: Aircraft Engine and APU emissions Testing Final Report Addendum F119-PW-100 Engine Emissions Testing Report June 2002, USAF/AFIERA.

Table F-32. HAP Emission Factors for F119-PW-100 Engine

Power Setting	Idle		Approach		Intermediate		Military	
Fuel Flow, lb/hr	1,377		2,742		10,113		18,625	
HAPs	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel
Acetaldehyde	1.53E-01	1.11E-01	1.85E-02	6.80E-03	2.64E-02	2.60E-03	1.56E-02	8.00E-04
Acrolein	4.96E-02	3.60E-02	ND	ND	ND	ND	ND	ND
Benzene	1.45E-01	1.06E-01	9.10E-03	3.30E-03	6.90E-03	7.00E-04	9.10E-03	5.00E-04
Ethylbenzene	2.26E-02	1.64E-02	1.20E-03	4.00E-04	5.00E-03	5.00E-04	3.40E-03	2.00E-04
Formaldehyde	1.37E+00	9.98E-01	9.75E-02	3.56E-02	2.47E-01	2.45E-02	1.41E-01	7.60E-03
Naphthalene	ND	ND	ND	ND	ND	ND	ND	ND
Styrene	4.30E-02	3.12E-02	1.20E-03	4.00E-04	ND	ND	ND	ND
Toluene	8.77E-02	6.37E-02	7.00E-04	3.00E-04	ND	ND	ND	ND
o-Xylene	3.84E-02	2.79E-02	9.00E-04	3.00E-04	4.90E-03	5.00E-04	3.10E-03	2.00E-04
m,p-Xylene	5.39E-02	3.91E-02	1.50E-03	6.00E-04	ND	ND	5.70E-03	3.00E-04
HAP Total	2.06E+00	1.50E+00	1.31E-01	4.77E-02	2.91E-01	2.87E-02	1.78E-01	9.60E-03

Source: Aircraft Engine and APU emissions Testing Final Report Addendum F119-PW-100 Engine Emissions Testing Report June 2002, USAF/AFIERA.

Table F-33. Criteria Pollutant Emission Factors for PT6A-68 Engine

Power Setting	Idle		Descend		Approach		Max Continuous	
Fuel Flow, lb/hr	155		328		448		618	
Pollutant	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel
NO _x	0.32	2.08	1.65	5.03	2.88	6.44	4.94	7.99
CO	20.00	128.96	11.56	35.24	5.64	12.58	2.94	4.75
SO ₂	0.10	0.66	0.22	0.66	0.30	0.66	0.41	0.66
THC	6.42	41.43	1.12	3.40	0.12	0.28	0.04	0.07
PM ₁₀	0.62	3.95	1.10	3.35	1.50	3.35	2.35	3.80

Source: PT6A-68 Emissions Measurement Program Summary, September 2002.

Emission factors are the average of testing two PT6A-68 engines at the Pratt & Whitney Canada facility.

Table F-34. HAP Emission Factors for PT6A-68 Engine

Power Setting	Idle		Descend		Approach		Max Continuous	
Fuel Flow, lb/hr	155		328		448		618	
HAPs	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel
Acetaldehyde	4.63E-02	2.99E-01	1.36E-02	8.79E-02	1.61E-02	1.04E-01	3.36E-04	2.17E-03
Acrolein	1.11E-01	7.16E-01	7.83E-03	5.05E-02	ND	ND	ND	ND
Benzene	4.39E-02	2.83E-01	1.31E-02	8.48E-02	2.22E-04	1.43E-03	1.34E-04	8.62E-04
Ethylbenzene	7.38E-03	4.76E-02	3.91E-04	2.52E-03	3.66E-05	2.36E-04	2.00E-05	1.29E-04
Formaldehyde	7.44E-01	4.80E+00	4.54E-01	2.93E+00	1.04E-01	6.73E-01	2.02E-03	1.30E-02
Naphthalene	1.12E-03	7.24E-03	2.17E-03	1.40E-02	9.73E-04	6.28E-03	1.19E-02	7.69E-02
Styrene	7.25E-03	4.68E-02	3.43E-04	2.21E-03	ND	ND	ND	ND
Toluene	2.56E-02	1.65E-01	3.81E-03	2.46E-02	3.67E-04	2.37E-03	8.03E-05	5.18E-04
o-Xylene	9.27E-03	5.98E-02	4.53E-04	2.92E-03	4.43E-05	2.86E-04	2.50E-05	1.61E-04
m,p-Xylene	1.75E-02	1.13E-01	9.35E-04	6.03E-03	9.72E-05	6.27E-04	6.20E-05	4.00E-04

Source: PT6A-68 Emissions Measurement Program Summary, September 2002. Emission factors are the average of testing two PT6A-68 engines at the Pratt & Whitney Canada facility.

Table F-35. Criteria Pollutant Emission Factors for T700-GE-700 Engine (UH60A)

Power Setting	Ground Idle		Flight Idle		Flight Max		Overspeed	
Fuel Flow, lb/hr	134		469		626		725	
Pollutant	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel
NO _x	0.45	3.35	5.14	10.95	7.43	11.88	8.28	11.42
CO	6.19	46.22	2.40	5.12	2.20	3.51	2.04	2.81
THC	ND	ND	0.10	0.22	0.35	0.56	0.38	0.53

Source: Aircraft Engine and APU Emissions Testing Final Report, Volume 1, December 1998, USAF/AFIERA.

Table F-36. HAP Emission Factors for T700-GE-700 Engine (UH60A)

Power Setting	Idle		Flight Idle		Flight Max		Overspeed	
Fuel Flow, lb/hr	134		469		626		725	
HAPs	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel
Acetaldehyde	2.42E-03	1.81E-02	1.42E-04	3.02E-04	ND	ND	ND	ND
Acrolein	9.69E-04	7.23E-03	4.54E-05	9.67E-05	ND	ND	ND	ND
Benzene	6.52E-03	4.87E-02	1.39E-04	2.97E-04	1.96E-04	3.13E-04	2.18E-04	3.00E-04
Ethylbenzene	3.01E-04	2.25E-03	2.19E-04	4.66E-04	ND	ND	1.44E-04	1.98E-04
Formaldehyde	2.94E-02	2.19E-01	1.92E-03	4.09E-03	ND	ND	3.49E-04	4.82E-04
Naphthalene	9.82E-04	7.33E-03	7.32E-05	1.56E-04	4.21E-05	6.73E-05	2.11E-05	2.91E-05
Styrene	6.92E-04	5.16E-03	ND	ND	ND	ND	ND	ND
Toluene	1.71E-03	1.28E-02	1.57E-04	3.35E-04	0.00E+00	0.00E+00	2.12E-04	2.92E-04
o-Xylene	3.75E-04	2.80E-03	1.69E-04	3.60E-04	1.15E-04	1.84E-04	2.94E-04	4.05E-04
m,p-Xylene	5.83E-04	4.35E-03	1.49E-04	3.17E-04	2.02E-04	3.23E-04	6.06E-04	8.36E-04

Source: Aircraft Engine and APU Emissions Testing Final Report, Volume 1, December 1998, USAF/AFIERA.

Table F-37. Criteria Pollutant Emission Factors for GTCP85-180 Engine (APU)

Power Setting	Constant	
Fuel Flow, lb/hr	270	
Pollutant	lb/hr	lb/10³ lb fuel
NO _x	1.28	4.73
CO	2.04	7.57
THC	0.01	0.05

Source: Aircraft Engine and APU Emissions Testing Final Report, Volume 1, December 1998, USAF/AFIERA.

Table F-38. HAP Emission Factors for GTCP85-180 Engine (APU)

Power Setting	Constant	
Fuel Flow, lb/hr	270	
HAPs	lb/hr	lb/10³ lb fuel
Acetaldehyde	5.64E-04	2.09E-03
Acrolein	8.22E-05	3.04E-04
Benzene	4.05E-03	1.50E-02
Ethylbenzene	3.26E-05	1.21E-04
Formaldehyde	5.50E-03	2.03E-02
Naphthalene	0.00E-00	0.00E-00
Styrene	5.16E-05	1.91E-04
Toluene	1.18E-03	4.36E-03
m,p-Xylene	6.37E-04	2.36E-03
o-Xylene	8.85E-05	3.28E-04

Source: Aircraft Engine and APU Emissions Testing Final Report, Volume 1, December 1998, USAF/AFIERA.

Table F-39. Criteria Pollutant Emission Factors for GTCP165-1 Engine (APU)

Power Setting	Constant	
Fuel Flow, lb/hr	273	
Pollutant	lb/hr	lb/10³ lb fuel
NO _x	1.22	4.52
CO	3.76	13.93
THC	0.07	0.24

Source: Aircraft Engine and APU Emissions Testing Final Report, Volume 1, December 1998, USAF/AFIERA.

Table F-40. HAP Emission Factors for GTCP165-1 Engine (APU)

Power Setting	Constant	
Fuel Flow, lb/hr	273	
HAPs	lb/hr	lb/10³ lb fuel
Acetaldehyde	1.53E-03	5.62E-03
Acrolein	ND	ND
Benzene	1.03E-02	3.86E-02
Ethylbenzene	2.35E-04	8.78E-04
Formaldehyde	5.12E-03	1.88E-02
Naphthalene	1.51E-03	5.55E-03
Styrene	6.11E-04	2.26E-03
Toluene	5.10E-03	1.89E-02
m,p-Xylene	1.32E-03	4.91E-03
o-Xylene	3.19E-04	1.19E-03

Source: Aircraft Engine and APU Emissions Testing Final Report, Volume 1, December 1998, USAF/AFIERA.

Table F-41. Criteria Pollutant Emission Factors for F108-CF-100 Engine

Power Setting	Idle		Approach		Intermediate		Military	
Fuel Flow, lb/hr	1,136		2,547		5,650		6,458	
Pollutant	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel
NO _x	4.41	3.88	14.59	5.73	62.36	11.04	77.83	12.05
CO	26.87	23.65	21.84	8.57	13.09	2.32	2.30	0.36
THC	ND	ND	ND	ND	ND	ND	3.88	0.60

Source: Aircraft Engine and APU Emissions Testing Final Report, Volume 1, December 1998, USAF/AFIERA.

Table F-42. HAP Emission Factors for F108-CF-100 Engine

Power Setting	Idle		Approach		Intermediate		Military	
Fuel Flow, lb/hr	1,136		2,547		5,650		6,458	
HAPs	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel
Acetaldehyde	0.00 E+00	0.00 E+00	ND	ND	ND	ND	ND	ND
Acrolein	ND	ND	ND	ND	ND	ND	ND	ND
Benzene	1.58 E-02	1.39 E-02	8.62 E-03	3.38 E-03	4.69 E-03	8.30 E-04	3.83 E-03	5.94 E-04
Ethylbenzene	1.14 E-03	1.00 E-03	2.07 E-03	8.11 E-04	ND	ND	ND	ND
Formaldehyde	1.08 E-01	9.35 E-02	3.83 E-02	1.50 E-02	3.15 E-02	5.58 E-03	4.53 E-02	7.01 E-03
Naphthalene	3.30 E-03	2.91 E-03	0.00 E+00	0.00 E+00	ND	ND	ND	ND
Styrene	1.69 E-03	1.49 E-03	ND	ND	ND	ND	ND	ND
Toluene	1.02 E-02	8.97 E-03	1.59 E-02	6.23 E-03	8.02 E-03	1.42 E-03	7.17 E-03	1.11 E-03
o-Xylene	ND	ND	1.32 E-03	5.17 E-04	ND	ND	ND	ND
m,p-Xylene	1.87 E-03	1.65 E-03	4.10 E-03	1.61 E-03	3.45 E-03	6.27 E-04	3.23 E-03	5.00 E-04

Source: Aircraft Engine and APU Emissions Testing Final Report, Volume 1, December 1998, USAF/AFIERA.

Table F-43. Criteria Pollutant Emission Factors for F100-PW-200 Engine

Power Setting	Idle		Approach		Intermediate		Military		Afterburner	
Fuel Flow, lb/hr	1,006		3,251		5,651		8,888		40,123	
Pollutant	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel
NO _x	4.21	4.19	42.3	13.0	143	25.2	285	34.0	271	6.77
CO	22.7	22.6	2.78	1.16	3.63	0.642	5.28	0.630	408	10.2
THC	3.26	3.24	0.467	0.144	0.409	0.072	0.318	0.038	5.52	0.138
PM ₁₀	2.50	2.47	7.70	2.37	8.94	1.58	14.0	1.66	122	3.07

Source: Radian, Engine and Hush House Emissions from a F100-PW-200 Jet Engine Tested at Kelly AFB, Feb. 1997.

Table F-44. HAP Emission Factors for F100-PW-200 Engine

Power Setting	Idle		Approach		Intermediate		Military		Afterburner	
Fuel Flow, lb/hr	1,006		3,251		5,651		8,888		40,123	
HAPs	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel
Acetaldehyde	1.91E-01	1.88E-01								
Acrolein	8.00E-02	8.00E-02								
Benzene	4.38E-02	4.38E-02								
Ethylbenzene	2.97E-03	2.97E-03								
Formaldehyde	6.03E-01	5.97E-01								
Naphthalene	3.02E-02	3.00E-02								
Styrene	3.65E-03	3.65E-03								
Toluene	1.57E-02	1.58E-02								
o-Xylene	3.52E-03	3.53E-03								
m,p-Xylene	1.40E-02	1.40E-02								

Source: Radian, Engine and Hush House Emissions from a F100-PW-200 Jet Engine Tested at Kelly AFB, Feb. 1997.

Table F-45. Criteria Pollutant Emission Factors for TF30-P109 Engine

Power Setting	Idle		Approach		Intermediate		Military		Afterburner	
Fuel Flow, lb/hr	761		1,727		2,921		6,263		37,548	
Pollutant	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel
NO _x	2.07	2.72	22.0	8.91	50.4	26.3	199	154	188	4.88
CO	48.5	63.7	46.1	25.1	16.6	5.70	3.55	0.57	238	6.19
THC	19.9	26.1	6.00	3.26	0.35	0.12	1.29	0.05	5.81	0.15

Source: Radian, Engine and Hush House Emissions from a TF30-P109 Engine Tested at Cannon AFB, June 1996.

Table F-46. HAP Emission Factors for TF30-P109 Engine

Power Setting	Idle		Approach		Intermediate		Military		Afterburner	
Fuel Flow, lb/hr	761		1,727		2,921		6,263		37,548	
HAPs	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel
Acetaldehyde										
Acrolein										
Benzene										
Ethylbenzene										
Formaldehyde										
Naphthalene										
Styrene										
Toluene										
o-Xylene										
m,p-Xylene										

Source: Radian, Engine and Hush House Emissions from a TF30-P109 Engine Tested at Cannon AFB, June 1996.

Table F-47. Criteria Pollutant Emission Factors for T58-GE-16 Engine

Power Setting	Ground Idle (54%)		Flight Idle (64%)		80%		90%		Max Continuous (100%)	
Fuel Flow, lb/hr	167		190		310		530		970	
Pollutant	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel
NO _x	1.48	8.86	1.68	8.84	2.57	8.29	3.80	7.17	5.48	5.65
CO	121.3	726.3	107.9	567.9	59.31	191.3	22.18	41.85	7.34	7.57
THC	45.59	273.0	39.18	206.2	17.78	57.36	4.18	7.89	0.23	0.237
PM ₁₀	5.06	30.30	5.06	26.63	5.06	16.32	1.78	3.36	1.78	1.84

Source: Aircraft Environmental Support Office, T58-GE-16 Engine Using JP-5 Fuel, Engine Parameters and Emission Indexes, Naval Aviation Depot – North Island.

Table F-48. Criteria Pollutant Emission Factors for T406-AD-400 Engine

Power Setting	Ground Idle (72%)		Flight Idle (83%)		88%		Max Continuous (100%)	
Fuel Flow, lb/hr	360		660		950		2,510	
Pollutant	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel	lb/hr	lb/10 ³ lb fuel
NO _x	4.09	ND	6.02	ND	7.90	ND	17.97	ND
CO	8.90	ND	3.33	ND	1.82	ND	0.29	ND
THC	<0.10	ND	<0.02	ND	<0.02	ND	<0.010	ND
PM ₁₀	1.58	ND	1.58	ND	1.58	ND	1.58	ND

Source: Aircraft Environmental Support Office, 406-AD-400 Engine Using JP-5 Fuel, Engine Parameters and Emission Indexes, Naval Aviation Depot – North Island.

APPENDIX G FUEL CHARACTERISTICS

Table G-1. Weight Percent Sulfur in Nonroad Fuels

Nonroad Fuel	Sulfur Content (wt %)
Highway diesel (ULSD)	0.0015 ^a
Nonroad Diesel	0.050 ^a
JP-8	0.071 ^b
Gasoline	0.0030 ^c
LPG	0.0010 ^d
CNG	Negligible

^a. Maximum sulfur content established under EPA Highway and Nonroad Diesel Fuel regulations.

^b. Defense Logistics Agency, Defense Energy Support Center, *Petroleum Quality Information System Fuels Data (2005)*, April 2006.

^c. Sulfur limits established under EPA Tier 2 Vehicle and Gasoline Sulfur regulation.

^d. World LP Gas Association, *Emissions, Test Methods, Standards and Technology*, 2002.

APPENDIX H – RECOMMENDED METHODS FOR CALCULATING POTENTIAL TO EMIT

Introduction

A source's PTE is an essential part of an AEI. Potential emissions are used to categorize a source as either "major" or "minor" for criteria air pollutants and either "major" or "area" for HAPs. Compliance costs vary greatly depending on the source's regulatory status. Under Titles III and V of the 1990 CAA 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 Air Force 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. 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 listing the operation as 24 hour-a-day process, 365 days a year (or 8,760 hrs/yr). Each facility would do well to actively pursue negotiations with their state and local regulators on alternative PTE calculation methods.

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 accept the default interpretation of the PTE definition to mean 8,760 hours. For most Air Force sources, this is an invalid assumption and results in an overestimation of potential emissions. As an example, South Dakota regulators have accepted the concept that some support shops are operational only during a "typical" work week (i.e., 40 hours per week/52 weeks per year) resulting in a work year of only 2,080 hours. In this example, the installation then uses 2,080 to determine its PTE. Several have gone one step further to accept ten holidays per year as more time a typical shop would not be emitting which then reduces the available hours to 2,000 per year. Obviously, this could have a significant impact on "major source" determinations.

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, EPA issued a 6 September 1995 policy memorandum on acceptable limits. This memo is detailed in Section 16 below. More recently, on 14 April 1998, the EPA published a policy memorandum which provides PTE guidance on eight different source categories, seven of which may be found at Air Force installations: gasoline service stations; gasoline bulk plants; boilers; coating sources; printing, publishing, and packaging operations; degreasers using volatile organic solvents; and 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 (T.O.s) 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 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) 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 are 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 is important to remember that all PTE limitations must be "federally enforceable." Federal enforceability ensures the conditions placed to limit a source's PTE 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.²⁰

- Title V permits
- Federally enforceable state operating permits (FESOPs)
- Construction permits
- General permits
- Limitations established by rules

²⁰ 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)."

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. As stated earlier, however, it is important that installation staff engage state and/or local regulators to ensure acceptability of each methodology. The PTE methodologies presented here can be used as a starting point for such negotiations.

Finally, this section ends with a “quick reference” table extracted from DoD’s environmental network and information exchange website. It is an excellent starting point for developing PTE for several emissions sources.

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, assume Base X has a wing with ten KC-135s. 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 ODSs, 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, 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 IC engine equipment, wastewater treatment plants, and wet cooling towers.

(1) ***Dry Cleaning Operations***

The 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, pump houses, hydrants) 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 PTE 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 PTE 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 BTUs per year which can be

divided by the heating value of the fuel (e.g., Btu/lb, Btu/gal, Btu/scf) 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, we assume Base X has a wing with ten KC-135s. 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, 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, assume Base X has a wing with ten KC-135s. 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 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) *OB/OD of Munitions*

Air Force bases do 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 Ordnance 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 IC Equipment

Several types of stationary IC 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 IC 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). 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 PTE for Emergency Generators" which allows sources to limit the potential hours of operation for emergency generators to 500 hr/yr. (When figuring PTE for emergency generators, operators must remember this is at 100% of the generator's capacity.) 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), if used for emergency purposes.

For all other stationary IC engine equipment not designated for emergencies, the PTE 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 IC 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 IC 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 flow rate 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.

Table H-1. Summary of Several Source Types and Emission Estimating Methods^b

Source Type	Pollutants	Emission Estimating Approach	Emission Factor References	PTE	Actual
Abrasive Blasting	PM, PM ₁₀ , HAPs (metals)	(EF) x (blast rate)	AP-42 Section 13.2.6	8,760 hours or less considering physical constraints of the operation	Actual # of hours of operation
Air Conditioning and Refrigeration Equipment	ODSs	Mass balance (make-up volume)	NA	Total ODS charge (ultraconservative)	ODS make up amount

Combustion Processes					
Boilers	Criteria pollutants, HAPs	(EF) x (hours of operation) x (heat input capacity)	AP-42 Sections: 1. Bituminous Coal 2. Anthracite Coal 3. Fuel Oil 4. Natural Gas 5. LPG	8,760 hours or less considering physical constraints of the operation	Actual # of hours of operation
Generators	Criteria pollutants, HAPs	(EF) x (hours of operation) x (bhp)	AP-42 Section 3.3	8,760 hours or less considering physical constraints of the operation 500 hours at 100% capacity for emergency generators	Actual # of hours of operation
Gas Turbines	Criteria pollutants, HAPs	(EF) x (hours of operation) x (bhp)	AP-42 Section 3.1	8,760 hours or less considering physical constraints of the operation	Actual # of hours of operation
Jet Engine Test Cells	Criteria pollutants, HAPs	(EF) x (pounds of fuel used or EF) x (hours of operation) x (bhp)	AESO Report No. 12-90; AP-42 Section 3.3	Maximum # of tests that can be conducted per year and the associated amount of fuel or time	Actual amount of fuel used or number of hours of operation
Fire Training	Criteria pollutants, HAPs	(EF) x (amount of fuel used)	AP-42 Sections: 1.3 Fuel Oil Wood 1.11 Waste Oil	Fuel used in maximum # of tests that can be conducted per year	Actual amount of fuel used
Incinerators	Criteria pollutants, HAPs	(EF) x (amount of waste destroyed)	AP-42 Section 2.1	8,760 hours x incinerator destruction capacity or less considering physical constraints of the operation	Actual # of hours of operation x destruction capacity

Table H-1. Summary of Several Source Types and Emission Estimating Methods^b (con't)

Fuel Handling					
Fuel Loading	VOCs, HAPs	(EF) x (fuel loaded)	AP-42 Section 5.2	Maximum loading rate x 8,760 hours	Actual amount of fuel loaded
Fuel Storage	VOCs, HAPs	Breathing and working losses (see Tanks ³ equation)	AP-42 Section 7.1.3.1	Maximum throughput rate x 8,760 hours or assume a potential rate of 3-5 turnovers per month (36-60 per year)	Actual amount of fuel throughput
Fuel Dispensing	VOCs, HAPs	(EF) x (fuel dispensed)	AP-42 Section 5.2	Maximum dispensing rate x 8,760 hours	Actual amount of fuel dispensed

Miscellaneous Processes that Generate PM					
Ash Handling	PM, PM ₁₀ , HAPs (metals)	(EF) x (amount of coal used)	AP-42 Section 13.2.4	8,760 hours	Actual amount of coal used
Coal Piles	PM, PM ₁₀ , HAPs (metals)	(EF) x (amount of coal stored)	Power Magazine article, June 1987	Maximum amount of coal stored at any one time	Average amount of coal stored at any one time
Coal Handling	PM, PM ₁₀ , HAPs (metals)	(EF) x (amount of coal transferred)	AP-42 Section 13.2.4	Maximum amount of coal transferred	Actual amount of coal transferred
Welding and Soldering	PM, PM ₁₀ , HAPs (metals)	(EF) x (amount of welding rod/solder used)	AP-42 Section 12.19	Maximum amount of welding rod/solder that can be used in a year	Actual amount of welding rod/solder used
Woodworking	PM, PM ₁₀	(EF) x (amount of wood processed)	See Section 7.6.4	Maximum amount of wood that can be processed in a year	Actual amount of wood processed
Ordnance Destruction	PM, PM ₁₀ , HAPs	(EF) x (amount of explosives detonated)	US Army OB/OD report, January 1992	Maximum amount of ordnance that can be detonated in a year based on the number of destruction events that can be held in a year	Actual amount of ordnance destroyed

Table H-1. Summary of Several Source Types and Emission Estimating Methods^b (con't)

Solvent Usage					
Degreasers	VOCs, HAPs	Amount of solvent added – Amount of solvent disposed	NA	Estimated scale up from actual emissions (assume 3 times actual usage)	Actual amounts of solvent used and disposed
Paint Stripping	VOCs, HAPs	Amount of solvent added – Amount of solvent disposed	NA	Estimated scale up from actual emissions or based on maximum number of stripping exercises that can be performed in a year	Actual amounts of solvent used and disposed
Metal Inspection/Fracture Detection	VOCs, HAPs	Amount of solvent added – Amount of solvent disposed	NA	Estimated scale up from actual emissions (assume 3 times actual usage)	Actual amounts of material used
Hand Wipe Cleaning	VOCs, HAPs	Amount of solvent added – Amount of solvent disposed	NA	Estimated scale up from actual emissions or based on maximum number of stripping exercises that can be performed in a year	Actual amounts of material used
Parts Cleaners	VOCs, HAPs	Amount of solvent added – Amount of solvent disposed	NA	Estimated scale up from actual emissions (assume 3 times actual usage)	Actual amounts of solvent used and disposed
Paint Gun Cleaners	VOCs, HAPs	Amount of solvent added – Amount of solvent disposed	NA	Estimated scale up from actual emissions (assume 3 times actual usage)	Actual amounts of solvent used and disposed
Solvent Distillation Units	VOCs, HAPs	(Amount of solvent distilled) x (VOC content)	NA	Maximum amount of solvent that can be distilled in a year based on still capacity	Actual amount of solvent distilled
Surface Coating					
Paint Booths	VOCs, PM, HAPs	(Paint usage) x (pollutant content)	NA	8,760 hours or less considering physical constraints of the operation ^c	Actual amount of paint used
Hand Applied/Touch-Up Painting	VOCs, HAPs	(Paint usage) x (pollutant content)	NA	Maximum amount of paint that can be applied in a year or a scale-up of actual paint usage	Actual amount of paint used

Table H-1. Summary of Several Source Types and Emission Estimating Methods^b (con't)

Treatment and Remediation Processes					
Wastewater Treatment Plants	Negligible	NA	NA	NA	NA
Site Remediation Systems	VOCs, PM, HAPs	(Treated stream pollutant concentration) x (hours of operation AND/OR combustion emissions if a thermal unit or IC engine are used for treatment)	AP-42 Sections for combustion units (if used)	8,760 hours	Actual # of hours of operation

^a U.S. Environmental Protection Agency, Compilation of Air Pollutant Emission Factors AP-42, Fifth Edition, Volume I: Stationary Point and Area Sources, Emission Factor And Inventory Group (MD-14), Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC, February 1996. AP-42 can be accessed on-line at www.epa.gov/ttn/chief/ap42.

^b This table was extracted from the Defense Environmental Network and Information Exchange (DENIX) website: <https://www.denix.osd.mil/denix/DOD/Policy/Navy/Air-Program/Tables/Table7-1.html>.

^c PTE can also be calculated using a scale-up from actual emissions. A factor of 2 to 3 times the actual usage can be used in lieu of the 8,760 hours or less. The factor should be consistent with guidance from the state/local air quality regulatory agency

APPENDIX I EMISSION FACTORS FOR MUNITIONS, EXPLOSIVES, AND PROPELLANTS

Table I-1a. Criteria Pollutant and Gasses Emission Factors for Munitions (lbs/item)^a

	Item	Energetic Material	Net Explosive Material (NEM)	CO (124-38-9)	NOx	PM10	PM2.5	TSP (12789-66-1)	Methane (74-82-8)
DODIC	Units:	gr/round	lbs/item	lbs/ item	lbs/ item	lbs/ item	lbs/ item	lbs/ item	lbs/ item
A059/A062/A064/AA33	5.56-mm Ball Cartridge (M855)	27.4	3.91E-03	1.6E-03	8.5E-05	3.9E-05	2.8E-05	3.8E-05	9.7E-06
A066/A071	5.56-mm Ball Cartridge (M193)	28.9	4.13E-03	1.8E-03	5.6E-05	3.8E-05	3.2E-05	4.2E-05	1.3E-05
A068	5.56-mm Tracer Cartridge (M196)	26.9	3.84E-03	1.6E-03	1.7E-05	6.7E-05	5.1E-05	7.0E-05	6.2E-06
A086	.22 Caliber Long Rifle Ball Cartridge	2.8	4.06E-04	8.0E-05	5.0E-06	3.4E-06	2.6E-06	3.3E-06	5.2E-07
A143/A255/A257/A131	7.62-mm Ball Cartridge (M80)	44.1	6.30E-03	2.3E-03	9.7E-05	5.1E-05	3.8E-05	5.1E-05	1.0E-05
A363	9-mm Ball Cartridge (M882)	5.5	7.89E-04	3.1E-04	1.5E-05	2.4E-05	2.0E-05	2.1E-05	1.4E-06
A475	.45 Caliber Ball Cartridge (M1911)	5.5	7.80E-04	2.6E-04	8.1E-06	3.7E-05	3.1E-05	3.2E-05	7.8E-07
A557/A555	.50 Caliber Ball Cartridge (M33)	235.2	3.36E-02	1.1E-02	1.2E-03	3.1E-04	1.9E-04	3.2E-04	1.3E-04
A598	.50 Caliber Blank Cartridge (M1A1)	48.2	6.89E-03	1.8E-03	2.8E-05	9.8E-05	8.8E-05	8.7E-05	3.4E-06
B571	40-mm High Explosive Cartridge (M383)	819.0	1.17E-01	7.0E-03	1.6E-03	1.3E-02	6.6E-03	1.6E-02	1.4E-04
B519	40-mm Practice Cartridge (M781)	5.6	8.00E-04	3.5E-04	3.6E-05	2.6E-05	2.3E-05	2.3E-05	3.7E-06
A011/A017	12-Gage Shotgun	28.9	4.13E-03	1.6E-04	ND	ND	ND	ND	ND

^a U.S. Environmental Protection Agency, Compilation of Air Pollutant Emission Factors AP-42, Fifth Edition, Volume I: Chapter 15: Ordnance Detonation, Emission Factor And Inventory Group (MD-14), Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC, February 1996. AP-42 can be accessed online at www.epa.gov/ttn/chief/ap42.

Table I-1b. Criteria Pollutant and Gasses Emission Factors for Munitions (lbs/NEW)^a

	Item	Energetic Material	Net Explosive Material (NEM)	CO (124-38-9)	NOx	PM10	PM2.5	TSP (12789-66-1)	Methane (74-82-8)
DODIC	Units:	gr/round	lbs/item	lb/lb NEW	lbs/ lb NEW	lbs/ lb NEW	lbs/ NEW	lbs/ NEW	lbs/ NEW
A059/A062/A064/AA33	5.56-mm Ball Cartridge (M855)	27.4	3.91E-03	2.2E-01	2.20E-02	1.0E-02	7.2E-03	9.8E-03	2.5E-03
A066/A071	5.56-mm Ball Cartridge (M193)	28.9	4.13E-03	4.4E-01	1.3E-02	9.2E-03	7.6E-03	1.0E-02	3.2E-03
A068	5.56-mm Tracer Cartridge (M196)	26.9	3.84E-03	4.2E-01	4.5E-03	1.7E-02	1.3E-02	1.8E-02	1.6E-03
A086	.22 Caliber Long Rifle Ball Cartridge	2.8	4.06E-04	2.0E-01	1.2E-02	8.3E-03	6.3E-03	8.2E-03	1.3E-03
A143/A255/A257/A131	7.62-mm Ball Cartridge (M80)	44.1	6.30E-03	3.6E-01	1.5E-02	8.1E-03	6.1E-03	8.0E-03	1.7E-03
A363	9-mm Ball Cartridge (M882)	5.5	7.89E-04	3.9E-01	1.9E-02	3.0E-02	2.6E-02	2.7E-02	1.8E-03
A475	.45 Caliber Ball Cartridge (M1911)	5.5	7.80E-04	3.4E-01	1.0E-02	4.7E-02	4.0E-02	4.2E-02	1.0E-03
A557/A555	.50 Caliber Ball Cartridge (M33)	235.2	3.36E-02	3.3E-01	3.6E-02	9.3E-03	5.6E-03	9.6E-03	3.8E-03
A598	.50 Caliber Blank Cartridge (M1A1)	48.2	6.89E-03	2.7E-01	4.1E-03	1.4E-02	1.3E-02	1.3E-02	5.0E-04
B571	40-mm High Explosive Cartridge (M383)	819.0	1.17E-01	6.00E-02	1.30E-02	1.10E-01	5.60E-02	1.40E-01	1.20E-03
B519	40-mm Practice Cartridge (M781)	5.6	8.00E-04	4.4E+00	4.5E-02	3.3E-02	2.9E-02	2.9E-02	4.6E-03
A011/A017	12-Gage Shotgun	28.9	4.13E-03	ND	ND	ND	ND	ND	ND

^a U.S. Environmental Protection Agency, Compilation of Air Pollutant Emission Factors AP-42, Fifth Edition, Volume I: Chapter 15: Ordnance Detonation, Emission Factor And Inventory Group (MD-14), Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC, February 1996. AP-42 can be accessed on-line at www.epa.gov/ttn/chief/ap42.

Table I-2a. Organic HAP Emission Factors for Munitions^a

	Item	Energetic Material	Net Explosive Material (NEM)	Acenaphthene (83-32-9)	Acetaldehyde (75-07-0)	Acetaldehyde (75-07-0)	Acetonitrile (75-05-8)	Acetophenone (98-86-2)	Acrolein (107-02-8)	Acrylonitrile (107-13-1)	Anthracene (120-12-7)	Benzene (71-43-2)	Benzo[a]anthracene (56-55-3)	Benzo[b]fluoranthene (205-99-2)	Benzo[k]fluoranthene (207-08-9)
DODIC	Units:	gr/round	lbs/item	lb/item	lb/item	lb/item	lb/item	lb/item	lb/item	lb/item	lb/item	lb/item	lb/item	lb/item	lb/item
A059/A062/A064/AA33	5.56-mm Ball Cartridge (M855)	27.4	3.91E-03	7.2 E-11	4.2 E-10	2.4 E-07	3.3 E-07	ND	2.6 E-08	5.2 E-08	5.2 E-11	6.3 E-07	1.9 E-10	3.1 E-10	1.5 E-10
A066/A071	5.56-mm Ball Cartridge (M193)	28.9	4.13E-03	2.1 E-10	1.6 E-09	3.1 E-07	7.3 E-07	ND	6.6 E-08	5.8 E-08	6.6 E-11	6.2 E-07	ND	ND	ND
A068	5.56-mm Tracer Cartridge (M196)	26.9	3.84E-03	1.7 E-10	1.2 E-07	1.2 E-07	2.3 E-07	3.3 E-08	ND	2.0 E-08	9.1 E-11	1.9 E-07	ND	1.2 E-10	ND
A086	.22 Caliber Long Rifle Ball Cartridge	2.8	4.06E-04	1.8 E-11	1.9 E-08	1.9 E-08	8.1 E-09	ND	ND	7.1 E-09	9.7 E-12	6.0 E-08	8.0 E-12	1.8 E-11	1.5 E-11
A143/A255/A257/A131	7.62-mm Ball Cartridge (M80)	44.1	6.30E-03	4.3 E-11	5.8 E-10	ND	2.4 E-07	ND	ND	7.1 E-08	6.8 E-11	7.1 E-07	7.1 E-07	3.5 E-10	1.7 E-10
A363	9-mm Ball Cartridge (M882)	5.5	7.89E-04	3.6 E-11	ND	ND	4.5 E-08	ND	8.1 E-09	2.2 E-08	3.9 E-11	1.9 E-07	2.3 E-10	2.5 E-10	1.6 E-10
A475	.45 Caliber Ball Cartridge (M1911)	5.5	7.80E-04	2.2 E-11	ND	ND	1.6 E-08	ND	ND	9.1 E-09	ND	1.3 E-07	1.1 E-10	1.4 E-10	9.2 E-11
A557/A555	.50 Caliber Ball Cartridge (M33)	235.2	3.36E-02	1.5 E-09	6.9 E-09	ND	1.2 E-06	ND	ND	2.7 E-07	7.2 E-10	4.0 E-06	1.7 E-09	2.6 E-09	1.2 E-09
A598	.50 Caliber Blank Cartridge (M1A1)	48.2	6.89E-03	ND	5.1 E-10	ND	2.0 E-08	ND	ND	7.0 E-09	ND	2.4 E-07	ND	ND	ND
B571	40-mm High Explosive Cartridge (M383)	819.0	1.17E-01	6.8 E-09	1.4 E-07	ND	1.1 E-05	2.7 E-07	8.4 E-07	1.9 E-06	1.2 E-08	7.4 E-06	6.2 E-09	6.8 E-09	3.5 E-09
B519	40-mm Practice Cartridge (M781)	5.6	8.00E-04	1.1 E-10	2.1 E-09	6.8 E-08	6.0 E-08	4.4 E-08	ND	9.5 E-08	6.0 E-11	6.8 E-07	1.8 E-11	1.1 E-10	ND
A011/A017	12-Gage Shotgun	28.9	4.13E-03	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

^a U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors AP-42, Fifth Edition, Volume I: Chapter 15: Ordnance Detonation*, Emission Factor And Inventory Group (MD-14), Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC, February 1996. AP-42 can be accessed on-line at www.epa.gov/ttn/chief/ap42.

Table I-2a. [Con't] Organic HAP Emission Factors for Munitions^a

	Item	Benzo[ghi]perylene (191-24-2)	Benzo[a]pyrene (50-32-8)	Benzo[e]pyrene (192-97-2)	1,3-Butadiene (106-99-0)	Benzo[a]pyrene (50-32-8)	Benzo[a]pyrene (50-32-8)	Butylbenzylphthalate (85-68-7)	Carbon disulfide (75-15-0)	Carbon tetrachloride (56-23-5)	Chlorobenzene (108-90-7)	Chloromethane (74-87-3)	Chrysene (218-01-9)
DODIC	Units:	lb/item	lb/item	lb/item	lb/item	lb/item	lb/item	lb/item	lb/item	lb/item	lb/item	lb/item	lb/item
A059/A062/ A064/AA33	5.56-mm Ball Cartridge (M855)	1.1 E-09	2.9 E-10	4.4 E-10	1.2 E-08	2.8 E-09	ND	ND	ND	ND	ND	1.1 E-09	2.1 E-10
A066/A071	5.56-mm Ball Cartridge (M193)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.1 E-09	ND
A068	5.56-mm Tracer Cartridge (M196)	ND	1.2 E-10	1.2 E-10	ND	1.2 E-10	1.2 E-10	ND	ND	ND	ND	ND	ND
A086	.22 Caliber Long Rifle Ball Cartridge	1.3 E-10	3.2 E-11	3.3 E-11	ND	3.2 E-11	3.2 E-11	ND	ND	ND	ND	ND	9.3 E-12
A143/A255/ A257/A131	7.62-mm Ball Cartridge (M80)	2.4 E-09	4.4 E-10	7.2 E-10	3.0E-06	1.9 E-08	ND	ND	4.5 E-09	ND	ND	3.0 E-09	3.2 E-10
A363	9-mm Ball Cartridge (M882)	6.7 E-10	2.3 E-10	2.7 E-10	1.2 E-09	2.3 E-10	2.3 E-10	ND	1.6 E-09	ND	ND	ND	2.4 E-10
A475	.45 Caliber Ball Cartridge (M1911)	1.6 E-10	ND	1.1 E-10	2.5 E-09	ND	ND	ND	6.5 E-09	ND	ND	4.3 E-10	1.4 E-10
A557/A555	.50 Caliber Ball Cartridge (M33)	1.3 E-08	3.7 E-09	5.4 E-09	1.5 E-07	ND	ND	ND	ND	ND	ND	2.6 E-09	2.1 E-09
A598	.50 Caliber Blank Cartridge (M1A1)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.0 E-09	ND
B571	40-mm High Explosive Cartridge (M383)	8.2 E-09	6.4 E-09	ND	ND	ND	ND	3.4 E-07	ND	ND	1.6 E-07	2.2 E-07	9.3 E-09
B519	40-mm Practice Cartridge (M781)	2.2 E-10	8.0 E-11	ND	ND	ND	ND	ND	1.3 E-07	2.7 E-09	ND	ND	4.0 E-11
A011/A017	12-Gage Shotgun	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

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Table I-2a. [Con't] Organic HAP Emission Factors for Munitions^a

	Item	Dibenz[a,h]anthracene (53-70-3)	Dibutyl phthalate (84-74-2)	Dichlorodifluoromethane (75-71-8)	1,2-Dichloroethane (107-06-2)	Total dioxin / furan compounds	Ethylbenzene (100-41-4)	Ethylene (74-85-1)	bis(2-Ethylhexyl)phthalate (117-81-7)	Fluoranthene (206-44-0)	Fluorene (86-73-7)	Formaldehyde (50-00-0)	1,2,3,4,6,7,8- Heptachlorodibenzo-p- dioxin (35822-46-9)
DODIC	Units:	lb/item	lb/item	lb/item	lb/item	lb/item	lb/item	lb/item	lb/item	lb/item	lb/item	lb/item	lb/item
A059/A062/ A064/AA33	5.56-mm Ball Cartridge (M855)	4.0 E-11	ND	8.9 E-11	1.2 E-08	9.4 E-15	2.0 E-09	6.7 E-07	ND	3.9 E-10	2.3 E-10	1.8 E-07	8.2 E-15
A066/A071	5.56-mm Ball Cartridge (M193)	ND	ND	ND	1.5 E-08	6.7 E-15	ND	8.9 E-07	ND	ND	5.8 E-10	1.4 E-07	ND
A068	5.56-mm Tracer Cartridge (M196)	ND	ND	ND	3.8 E-09	1.7 E-13	1.6 E-09	3.8 E-07	3.0 E-08	ND	4.4 E-10	1.6 E-07	4.0 E-14
A086	.22 Caliber Long Rifle Ball Cartridge	ND	ND	ND	9.4 E-10	2.1 E-15	ND	3.9 E-07	ND	1.2 E-11	4.5 E-11	8.2 E-08	6.2 E-16
A143/A255/ A257/A131	7.62-mm Ball Cartridge (M80)	3.8 E-11	ND	ND	9.9 E-09	1.2 E-14	3.2 E-09	9.7 E-07	ND	6.4 E-10	1.9 E-10	8.4 E-08	9.6 E-15
A363	9-mm Ball Cartridge (M882)	3.0 E-11	ND	1.7 E-10	2.8 E-09	ND	1.5 E-09	5.2 E-07	ND	4.5 E-10	1.1 E-10	5.2 E-08	ND
A475	.45 Caliber Ball Cartridge (M1911)	1.6 E-11	ND	ND	2.3 E-09	2.9 E-15	1.3 E-09	3.9 E-07		2.6 E-10	9.8 E-11	2.5 E-08	ND
A557/A555	.50 Caliber Ball Cartridge (M33)	3.0 E-10	ND	ND	7.4 E-08	6.5 E-14	3.0 E-08	4.0 E-06	ND	3.1 E-09	3.4 E-09	E-07	ND
A598	.50 Caliber Blank Cartridge (M1A1)	ND	ND	ND	ND	1.4 E-14	3.8 E-07	ND	ND	1.7 E-10	1.6 E-10	7.8 E-08	7.8 E-08
B571	40-mm High Explosive Cartridge (M383)	4.3 E-10	3.7 E- 07	ND	ND	1.1 E-11	2.0 E-07	1.8 E-05	4.7 E-07	3.3 E-08	4.2 E-08	ND	1.0 E-12
B519	40-mm Practice Cartridge (M781)	ND	ND	ND	9.8 E-09	2.0 E-13	2.1 E-08	1.7 E-06	ND	1.0 E-10	2.7 E-10	9.2 E-08	2.4 E-14
A011/A017	12-Gage Shotgun	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

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Table I-2a. [Con't] Organic HAP Emission Factors for Munitions^a

	Item	1,2,3,4,6,7,8-Heptachlorodibenzofuran (67562-39-4)	1,2,3,4,7,8,9-Heptachlorodibenzofuran (55673-89-7)	1,2,3,4,7,8-Hexachlorodibenzo-p-dioxin (39227-28-6)	1,2,3,6,7,8-Hexachlorodibenzo-p-dioxin (57653-85-7)	1,2,3,7,8,9-Hexachlorodibenzo-p-dioxin (19408-74-3)	1,2,3,4,7,8-Hexachlorodibenzofuran (70648-26-9)	1,2,3,6,7,8-Hexachlorodibenzofuran (57117-44-9)	2,3,4,6,7,8-Hexachlorodibenzofuran (60851-34-5)	Hexane (110-54-3)	Hydrochloric acid (7647-01-0)	Hydrogen Cyanide (74-90-8)	Indeno[1,2,3-cd]pyrene (193-39-5)	Methyl methacrylate (80-62-6)
DODIC	Units:	lb/item	lb/item	lb/item	lb/item	lb/item	lb/item	lb/item	lb/item	lb/item	lb/item	lb/item	lb/item	lb/item
A059/A062/A064/AA33	5.56-mm Ball Cartridge (M855)	8.2 E-15	ND	ND	ND	ND	ND	ND	ND	3.4 E-07	ND	2.2 E-05	3.5 E-10	ND
A066/A071	5.56-mm Ball Cartridge (M193)	ND	ND	ND	ND	ND	5.0 E-16	ND	ND	ND	ND	2.4 E-05	ND	ND
A068	5.56-mm Tracer Cartridge (M196)	4.0 E-14	ND	ND	4.0 E-14	4.0 E-14	4.0 E-14	4.0 E-14	ND	ND	4.0 E-14	3.0 E-06	ND	ND
A086	.22 Caliber Long Rifle Ball Cartridge	6.2 E-16	ND	ND	6.2 E-16	6.2 E-16	6.2 E-16	6.2 E-16	ND	ND	6.2 E-16	8.3 E-08	3.5 E-11	ND
A143/A255/A257/A131	7.62-mm Ball Cartridge (M80)	2.5 E-15	ND	ND	ND	ND	ND	ND	ND	2.0 E-07	ND	4.5 E-06	4.6 E-10	ND
A363	9-mm Ball Cartridge (M882)	ND	ND	ND	ND	ND	ND	ND	ND	4.9 E-07	ND	1.8 E-06	3.0 E-10	ND
A475	.45 Caliber Ball Cartridge (M1911)	ND	ND	ND	ND	ND	8.5 E-16	ND	ND	6.3 E-08	ND	1.0 E-06	1.2 E-10	ND
A557/A555	.50 Caliber Ball Cartridge (M33)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.6 E-04	3.0 E-09	ND
A598	.50 Caliber Blank Cartridge (M1A1)	3.6 E-16	ND	ND	ND	ND	ND	ND	ND	2.3 E-07	ND	1.0 E-06	ND	ND
B571	40-mm High Explosive Cartridge (M383)	1.3 E-13	4.7 E-14	2.8 E-14	1.9 E-13	1.3 E-13	1.4 E-13	5.3 E-14	6.9 E-14	ND	ND	5.4 E-05	4.8 E-09	1.0 E-07
B519	40-mm Practice Cartridge (M781)	ND	ND	1.9 E-15	ND	ND	ND	ND	ND	ND	ND	6.1 E-07	1.2 E-10	ND
A011/A017	12-Gage Shotgun	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

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Table I-2a. [Con't] Organic HAP Emission Factors for Munitions^a

	Item	Methyl tert-butyl ether (1634-04-4)	Methylene Chloride (75-09-2)	Naphthalene (91-20-3)	Naphthalene (91-20-3)	Naphthalene (91-20-3)	Naphthalene (91-20-3)	Naphthalene (91-20-3)	1,2,3,4,6,7,8,9- Octachlorodibenzofuran (39001-02-0)	Phenanthrene (85-01-8)	Naphthalene (91-20-3)	Naphthalene (91-20-3)	Naphthalene (91-20-3)	Naphthalene (91-20-3)
DODIC	Units:	lb/item	lb/item	lb/item	lb/item	lb/item	lb/item	lb/item	lb/item	lb/item	lb/item	lb/item	lb/item	lb/item
A059/A062/ A064/AA33	5.56-mm Ball Cartridge (M855)	ND	1.0 E-07	9.3 E-09	9.3 E-09	4.4 E-07	ND	ND	ND	3.0 E-10	ND	ND	ND	1.0 E-08
A066/A071	5.56-mm Ball Cartridge (M193)	ND	ND	ND	2.2 E-08	ND	ND	ND	ND	ND	ND	1.8 E-15	1.1 E-16	2.1 E-08
A068	5.56-mm Tracer Cartridge (M196)	6.7 E-10	ND	1.3 E-08	1.3 E-08	1.3 E-08	1.3 E-08	1.3 E-08	ND	ND	1.3 E-08	1.3 E-08	1.3 E-08	1.3 E-08
A086	.22 Caliber Long Rifle Ball Cartridge	ND	1.8 E-07	3.3 E-09	3.3 E-09	3.3 E-09	3.3 E-09	3.3 E-09	ND	5.2 E-11	3.3 E-09	3.3 E-09	3.3 E-09	3.3 E-09
A143/A255/ A257/A131	7.62-mm Ball Cartridge (M80)	ND	1.0 E-07	ND	2.4 E-08	ND	ND	ND	ND	3.1 E-10	ND	ND	ND	ND
A363	9-mm Ball Cartridge (M882)	ND	2.3 E-07	4.5 E-09	4.5 E-09	4.5 E-09	4.5 E-09	4.5 E-09	ND	2.4 E-10	4.5 E-09	4.5 E-09	4.5 E-09	4.5 E-09
A475	.45 Caliber Ball Cartridge (M1911)	ND	5.0 E-08	ND	ND	ND	ND	ND	2.1 E-15	1.6 E-10	ND	ND	ND	ND
A557/A555	.50 Caliber Ball Cartridge (M33)	ND	8.0 E-07	ND	1.8 E-07	ND	ND	ND	6.5 E-14	3.5 E-09	ND	ND	ND	ND
A598	.50 Caliber Blank Cartridge (M1A1)	ND	1.8 E-07	ND	2.9 E-08	ND	ND	ND	1.1 E-14	ND	ND	ND	ND	ND
B571	40-mm High Explosive Cartridge (M383)	ND	ND	ND	2.0 E-07	1.2 E-05	ND	7.7 E-12	3.4 E-13	9.0 E-08	6.6 E-14	9.1 E-14	2.0 E-13	ND
B519	40-mm Practice Cartridge (M781)	ND	3.2 E-07	ND	1.2 E-08	4.0 E-07	ND	1.7 E-13	ND	3.2 E-10	ND	ND	ND	ND
A011/A017	12-Gage Shotgun	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

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Table I-2a. [Con't] Organic HAP Emission Factors for Munitions^a

	Item	Propylene (115-07-1)	Pyrene (129-00-0)	Styrene (100-42-5)	1,2,3,4,6,7,8,9-Octachlorodibenzo-p-dioxin (3268-87-9)	1,2,3,4,6,7,8,9-Octachlorodibenzo-p-dioxin (3268-87-9)	1,2,3,4,6,7,8,9-Octachlorodibenzo-p-dioxin (3268-87-9)	1,2,3,4,6,7,8,9-Octachlorodibenzo-p-dioxin (3268-87-9)	Toluene (108-88-3)	1,1,1-Trichloroethane (71-55-6)	Trichlorofluoromethane (75-69-4)	1,2,4-Trimethylbenzene (95-63-6)	2,2,4-Trimethylpentane (540-84-1)	Xylenes (106-42-3, 108-38-3, 95-47-6)
DODIC	Units:	lb/item	lb/item	lb/item	lb/item	lb/item	lb/item	lb/item	lb/item	lb/item	lb/item	lb/item	lb/item	lb/item
A059/A062/A064/AA33	5.56-mm Ball Cartridge (M855)	1.2 E-07	9.5 E-10	8.3 E-09	2.9 E-07	ND	ND	ND	3.0 E-08	1.6 E-09	ND	1.9 E-09	ND	6.3 E-09
A066/A071	5.56-mm Ball Cartridge (M193)	8.5 E-08	2.2 E-10	7.9 E-09	ND	ND	4.3 E-15	ND	2.7 E-08	ND	ND	ND	ND	ND
A068	5.56-mm Tracer Cartridge (M196)	5.3 E-08	ND	7.9 E-09	ND	ND	ND	ND	1.5 E-08	ND	ND	ND	ND	ND
A086	.22 Caliber Long Rifle Ball Cartridge	6.4 E-08	2.3 E-11	3.0 E-09	ND	ND	ND	ND	6.0 E-09	6.4 E-10	ND	ND	ND	ND
A143/A255/A257/A131	7.62-mm Ball Cartridge (M80)	1.8 E-07	2.2 E-09	9.3 E-09	ND	ND	ND	ND	4.4 E-08	ND	ND	ND	ND	9.5 E-09
A363	9-mm Ball Cartridge (M882)	1.5 E-07	1.0 E-09	2.1 E-09	6.4 E-08	6.4 E-08	6.4 E-08	6.4 E-08	3.9E-05	1.9 E-10	ND	8.5 E-10	ND	9.5E-06
A475	.45 Caliber Ball Cartridge (M1911)	1.2 E-07	3.9 E-10	3.2 E-09	ND	ND	ND	ND	2.5 E-08	ND	ND	3.1 E-10	ND	6.3E-06
A557/A555	.50 Caliber Ball Cartridge (M33)	1.1 E-06	8.2 E-09	1.3 E-07	ND	ND	ND	ND	4.0 E-07	ND	ND	2.1 E-07	ND	1.7E-06
A598	.50 Caliber Blank Cartridge (M1A1)	ND	1.6 E-10	1.7 E-09	3.1 E-06	ND	ND	ND	1.3 E-08	ND	ND	ND	ND	2.6E-07
B571	40-mm High Explosive Cartridge (M383)	6.8 E-06	4.6 E-08	2.2 E-07	ND	1.2 E-14	2.5 E-13	ND	1.6 E-06	ND	8.8 E-08	9.0 E-08	5.2 E-08	8.1 E-06
B519	40-mm Practice Cartridge (M781)	1.6 E-07	1.1 E-10	2.4 E-07	ND	ND	ND	ND	8.6 E-08	1.2 E-07	ND	5.1 E-08	ND	1.6E-04
A011/A017	12-Gage Shotgun	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

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Table I-2b. Organic HAP Emission Factors for Munitions (lbs/NEW)^a

	Item	Energetic Material	Net Explosive Material (NEM)	Acenaphthene (83-32-9)	Acenaphthylene (208-96-8)	Acetaldehyde (75-07-0)	Acetonitrile (75-05-8)	Acetophenone (98-86-2)	Acrolein (107-02-8)	Acrylonitrile (107-13-1)	Anthracene (120-12-7)	Benzene (71-43-2)	Benzo[a]anthracene (56-55-3)	Benzo[b]fluoranthene (205-99-2)
DODIC	Units:	gr/round	lbs/item	lb/NEW	lb/NEW	lb/NEW	lb/NEW	lb/NEW	lb/NEW	lb/NEW	lb/NEW	lb/NEW	lb/NEW	lb/NEW
A059/A062/A064/AA33	5.56-mm Ball Cartridge (M855)	27.4	3.91E-03	1.8 E-08	1.1 E-07	6.1 E-05	8.4 E-05	ND	6.5 E-06	1.3 E-05	1.3 E-08	1.6 E-04	5.0 E-08	8.0 E-08
A066/A071	5.56-mm Ball Cartridge (M193)	28.9	4.13E-03	5.1 E-08	3.8 E-07	7.6E-05	1.8E-04	ND	1.6 E-05	1.4 E-05	1.6 E-08	1.5E-04	ND	ND
A068	5.56-mm Tracer Cartridge (M196)	26.9	3.84E-03	4.5 E-08	3.1 E-07	3.2E-05	6.1E-05	8.5 E-06	ND	5.2 E-06	2.4 E-08	5.0E-05	ND	3.2 E-08
A086	.22 Caliber Long Rifle Ball Cartridge	2.8	4.06E-04	4.5 E-08	9.7 E-07	4.7E-05	2.0E-05	ND	ND	1.7 E-05	2.4 E-08	1.5E-04	2.0 E-08	4.4 E-08
A143/A255/A257/A131	7.62-mm Ball Cartridge (M80)	44.1	6.30E-03	6.9 E-09	9.2 E-08	ND	3.8E-05	ND	ND	1.1 E-05	1.1 E-08	1.1E-04	5.4 E-08	5.6 E-08
A363	9-mm Ball Cartridge (M882)	5.5	7.89E-04	4.6 E-08	3.1 E-07	ND	5.7E-05		1.0 E-05	2.8 E-05	4.9 E-08	2.4E-04	2.9 E-07	3.2 E-07
A475	.45 Caliber Ball Cartridge (M1911)	5.5	7.80E-04	2.8 E-08	ND	ND	2.0E-05	ND	ND	1.2 E-05	ND	1.6E-04	1.5 E-07	1.7 E-07
A557/A555	.50 Caliber Ball Cartridge (M33)	235.2	3.36E-02	4.5 E-08	2.1 E-07	ND	3.7E-05	ND	ND	8.1 E-06	2.2 E-08	1.2E-04	5.1 E-08	7.8 E-08
A598	.50 Caliber Blank Cartridge (M1A1)	48.2	6.89E-03	ND	7.3 E-08	ND	2.9E-06	ND	ND	1.0 E-06	ND	3.4E-05	ND	ND
B571	40-mm High Explosive Cartridge (M383)	819.0	1.17E-01	5.8 E-08	1.2 E-06	ND	9.4E-05	2.3 E-06	7.2 E-06	1.6 E-05	1.0 E-07	6.4E-05	5.3 E-08	5.8 E-08
B519	40-mm Practice Cartridge (M781)	5.6	8.00E-04	1.4 E-07	2.7 E-06	8.4E-05	7.5E-05	5.5 E-05	ND	1.2 E-04	7.5 E-08	8.5E-04	2.2 E-08	1.4 E-07
A011/A017	12-Gage Shotgun	28.9	4.13E-03	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

^a U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors AP-42, Fifth Edition, Volume I: Chapter 15: Ordnance Detonation, Emission Factor And Inventory Group (MD-14)*, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC, February 1996. AP-42 can be accessed on-line at www.epa.gov/ttn/chief/ap42.

Table I-2b. [Con't] Organic HAP Emission Factors for Munitions (lbs/NEW)^a

Item	Benzo[g,h,i]perylene (191-24-2)	Benzo[a]pyrene (50-32-8)	Benzo[e]pyrene (192-97-2)	1,3-Butadiene (106-99-0)	t-Butyl alcohol (75-65-0)	Butyraldehyde (123-72-8)	Butylbenzylphthalate (85-68-7)	Carbon disulfide (75-15-0)	Carbon tetrachloride (56-23-5)	Chlorobenzene (108-90-7)	Chloromethane (74-87-3)	Chrysene (218-01-9)	Dichlorodifluoromethane (75-71-8)	
DODIC	Units:	lb/NEW	lb/NEW	lb/NEW	lb/NEW	lb/NEW	lb/NEW	lb/NEW	lb/NEW	lb/NEW	lb/NEW	lb/NEW	lb/NEW	
A059/A062/ A064/AA33	5.56-mm Ball Cartridge (M855)	2.7 E-07	7.3 E-08	1.1 E-07	3.1 E-06	7.2 E-07	ND	ND	ND	ND	2.9 E-07	5.5 E-08	2.3 E-08	
A066/A071	5.56-mm Ball Cartridge (M193)	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.7 E-07	ND	ND	
A068	5.56-mm Tracer Cartridge (M196)	ND	3.1 E-08	3.2 E-08	ND	ND	ND	ND	ND	2.5 E-07	6.0 E-07	ND	ND	
A086	.22 Caliber Long Rifle Ball Cartridge	3.2 E-07	7.9 E-08	8.1 E-08	ND	ND	ND	ND	ND	ND	ND	2.3 E-08	ND	
A143/A255/ A257/A131	7.62-mm Ball Cartridge (M80)	3.8 E-07	7.0 E-08	1.1 E-07	3.0E-06	3.0 E-06	ND	ND	7.2 E-07	ND	ND	4.8 E-07	5.0 E-08	ND
A363	9-mm Ball Cartridge (M882)	8.5 E-07	2.9 E-07	3.4 E-07	1.5E-06	ND	ND	ND	2.0 E-06	ND	ND	3.0 E-07	2.1 E-07	
A475	.45 Caliber Ball Cartridge (M1911)	2.1 E-07	ND	1.5 E-07	3.2E-06	ND	ND	ND	8.4 E-06	ND	ND	5.5 E-07	1.8 E-07	ND
A557/A555	.50 Caliber Ball Cartridge (M33)	3.9 E-07	1.1 E-07	1.6 E-07	4.5E-06	ND	ND	ND	ND	ND	ND	7.8 E-08	6.3 E-08	ND
A598	.50 Caliber Blank Cartridge (M1A1)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.9 E-07	ND	ND
B571	40-mm High Explosive Cartridge (M383)	7.0 E-08	5.5 E-08	ND	ND	ND	ND	2.9 E-06	ND	ND	1.4 E-06	1.9 E-06	8.0 E-08	ND
B519	40-mm Practice Cartridge (M781)	2.7 E-07	1.0 E-07	ND	ND	ND	ND	ND	1.7 E-04	3.3 E-06	ND	ND	5.0 E-08	ND
A011/A017	12-Gage Shotgun	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

^a U.S. Environmental Protection Agency, Compilation of Air Pollutant Emission Factors AP-42, Fifth Edition, Volume I: Chapter 15: Ordnance Detonation, Emission Factor And Inventory Group (MD-14), Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC, February 1996. AP-42 can be accessed on-line at www.epa.gov/ttn/chief/ap42.

Table I-2b. [Con't] Organic HAP Emission Factors for Munitions (lbs/NEW)^a

	Item	1,2-Dichloroethane (107-06-2)	Total dioxin / furan compounds	Ethylbenzene (100-41-4)	Ethylene (74-85-1)	bis(2- Ethylhexyl)phthalate (117-81-7)	Fluoranthene (206-44-0)	Fluorene (86-73-7)	Formaldehyde (50-00-0)	1,2,3,4,6,7,8- Heptachlorodibenzo-p- dioxin (35822-46-9)	1,2,3,4,6,7,8- Heptachlorodibenzofuran (67562-39-4)	1,2,3,4,7,8,9- Heptachlorodibenzofuran (55673-89-7)	1,2,3,4,7,8- Hexachlorodibenzo-p- dioxin (39227-28-6)	1,2,3,6,7,8- Hexachlorodibenzo-p- dioxin (57653-85-7)
DODIC	Units:	lb/NEW	lb/NEW	lb/NEW	lb/NEW	lb/NEW	lb/NEW	lb/NEW	lb/NEW	lb/NEW	lb/NEW	lb/NEW	lb/NEW	lb/NEW
A059/A062/ A064/AA33	5.56-mm Ball Cartridge (M855)	3.2 E-06	2.4 E-12	5.0 E-07	1.7 E-04	ND	9.9 E-08	5.9 E-08	4.7 E-05	2.1 E-12	3.0 E-13	ND	ND	ND
A066/A071	5.56-mm Ball Cartridge (M193)	3.6 E-06	1.6 E-12	ND	2.2 E-04	ND	ND	1.4 E-07	1.1E-04	ND	ND	ND	ND	ND
A068	5.56-mm Tracer Cartridge (M196)	9.8 E-07	4.3 E-11	4.2E-07	9.8 E-05	7.8 E-06	ND	1.1 E-07	4.0E-05	1.1 E-11	7.7 E-12	ND	ND	2.6 E-12
A086	.22 Caliber Long Rifle Ball Cartridge	2.3 E-06	5.3 E-12	ND	9.6 E-04	ND	2.8 E-08	1.1 E-07	2.0E-04	1.5 E-12	4.0 E-13	ND	ND	ND
A143/A255/ A257/A131	7.62-mm Ball Cartridge (M80)	1.6 E-06	1.9 E-12	5.0E-07	1.5 E-04	ND	1.0 E-07	3.0 E-08	1.3E-05	1.5 E-12	4.0 E-13	ND	ND	ND
A363	9-mm Ball Cartridge (M882)	3.5 E-06	ND	1.9E-06	6.6 E-04	ND	5.6 E-07	1.3 E-07	6.6E-05	ND	ND	ND	ND	ND
A475	.45 Caliber Ball Cartridge (M1911)	3.0 E-06	3.7 E-12	1.7E-06	5.0 E-04		3.3 E-07	1.3 E-07	3.2E-05	ND	ND	ND	ND	ND
A557/A555	.50 Caliber Ball Cartridge (M33)	2.2 E-06	1.9 E-12	9.0E-07	1.2 E-04	ND	9.1 E-08	1.0 E-07	1.3E-05	ND	ND	ND	ND	ND
A598	.50 Caliber Blank Cartridge (M1A1)	ND	2.1 E-12	5.5 E-05	ND	ND	2.5 E-08	2.3 E-08	1.1E-05	4.2 E-13	5.2 E-14	ND	ND	ND
B571	40-mm High Explosive Cartridge (M383)	ND	9.0 E-11	1.7E-06	1.5 E-04	4.0 E-06	2.8 E-07	3.6 E-07	ND	8.8 E-12	1.1 E-12	4.0 E-13	2.4 E-13	1.6 E-12
B519	40-mm Practice Cartridge (M781)	1.2 E-05	2.5 E-10	2.6E-05	2.2 E-03	ND	1.3 E-07	3.3 E-07	1.2E-04	3.0 E-11	ND	ND	2.4 E-12	ND
A011/A017	12-Gage Shotgun	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

^a U.S. Environmental Protection Agency, Compilation of Air Pollutant Emission Factors AP-42, Fifth Edition, Volume I: Chapter 15: Ordnance Detonation, Emission Factor And Inventory Group (MD-14), Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC, February 1996. AP-42 can be accessed on-line at www.epa.gov/ttn/chief/ap42.

Table I-2b. [Con't] Organic HAP Emission Factors for Munitions (lbs/NEW)^a

Item	Hexane (110-54-3)	Hydrochloric acid (7647-01-0)	Hydrogen cyanide (74-90-8)	Indeno[1,2,3-cd]pyrene (193-39-5)	Methyl methacrylate (80-62-6)	Methyl tert-butyl ether (1634-04-4)	Methylene Chloride (75-09-2)	2-Methylacetonitrile (75-86-5)	Naphthalene (91-20-3)	Nitric acid (7697-37-2)	Nitroglycerin (55-63-0)	1,2,3,4,6,7,8,9-Octachlorodibenzo-p-dioxin (3268-87-9)	1,2,3,4,6,7,8,9-Octachlorodibenzofuran (39001-02-0)
DODIC	Units:	lb/NEW	lb/NEW	lb/NEW	lb/NEW	lb/NEW	lb/NEW	lb/NEW	lb/NEW	lb/NEW	lb/NEW	lb/NEW	lb/NEW
A059/A062/A064/AA33	5.56-mm Ball Cartridge (M855)	8.6 E-05	ND	5.6 E-03	8.9 E-08	ND	ND	2.6 E-05	7.8 E-06	2.4 E-06	1.1 E-04	ND	ND
A066/A071	5.56-mm Ball Cartridge (M193)	ND	ND	5.8E-03	ND	ND	ND	ND	ND	5.3E-06	ND	ND	ND
A068	5.56-mm Tracer Cartridge (M196)	ND	ND	7.7E-04	ND	ND	1.7 E-07	ND	ND	3.3E-06	6.5 E-05	ND	ND
A086	.22 Caliber Long Rifle Ball Cartridge	ND	ND	2.0E-04	8.7 E-08	ND	ND	4.4E-04	ND	8.3E-06	1.5 E-04	1.7 E-05	3.3 E-12
A143/A255/A257/A131	7.62-mm Ball Cartridge (M80)	3.1E-05	ND	7.1E-04	7.3 E-08	ND	ND	1.6 E-05	ND	3.8E-06	ND	ND	ND
A363	9-mm Ball Cartridge (M882)	6.3E-04	ND	2.3E-03	3.8 E-07	ND	ND	2.9E-04	ND	5.6E-06	2.4 E-04	ND	ND
A475	.45 Caliber Ball Cartridge (M1911)	8.0E-05	ND	1.3E-03	1.5 E-07	ND	ND	6.5E-05	ND	ND	ND	ND	2.6 E-12
A557/A555	.50 Caliber Ball Cartridge (M33)	ND	ND	4.8E-03	8.8 E-08	ND	ND	2.4E-05	ND	5.3E-06	ND	ND	1.9 E-12
A598	.50 Caliber Blank Cartridge (M1A1)	3.3E-05	ND	1.5E-04	ND	ND	ND	2.6E-05	ND	4.1E-06	ND	ND	1.6 E-12
B571	40-mm High Explosive Cartridge (M383)	ND	ND	4.6E-04	4.1 E-08	8.6 E-07	ND	ND	ND	1.7E-06	1.0 E-04	ND	6.6 E-11
B519	40-mm Practice Cartridge (M781)	ND	ND	7.6E-04	1.4 E-07	ND	ND	4.0E-04	ND	1.5E-05	5.0 E-04	ND	2.2 E-10
A011/A017	12-Gage Shotgun	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

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Table I-2b. [Con't] Organic HAP Emission Factors for Munitions (lbs/NEW)^a

Item	Units:	Phenanthrene (85-01-8)	1,2,3,7,8-Pentachlorodibenzo-p-dioxin (40321-76-4)	1,2,3,7,8-Pentachlorodibenzofuran (57117-41-6)	2,3,4,7,8-Pentachlorodibenzofuran (57117-31-4)	Propionaldehyde (123-38-6)	Propylene (115-07-1)	Pyrene (129-00-0)	Styrene (100-42-5)	Sulfuric acid (7664-93-9)	2,3,7,8-Tetrachlorodibenzo-p-dioxin (1746-01-6)	2,3,7,8-Tetrachlorodibenzofuran (51207-31-9)	1,1,2,2-Tetrachloroethane (79-34-5)
DODIC	Units:	lb/NEW	lb/NEW	lb/NEW	lb/NEW	lb/NEW	lb/NEW	lb/NEW	lb/NEW	lb/NEW	lb/NEW	lb/NEW	lb/NEW
A059/A062/A064/AA33	5.56-mm Ball Cartridge (M855)	7.6 E-08	ND	ND	ND	2.6 E-06	3.0 E-05	2.4 E-07	2.4 E-07	7.5 E-05	ND	ND	ND
A066/A071	5.56-mm Ball Cartridge (M193)	ND	ND	4.4 E-13	2.7 E-14	5.2 E-06	2.1 E-05	5.4 E-08	1.9E-06	ND	ND	1.0 E-12	ND
A068	5.56-mm Tracer Cartridge (M196)	ND	1.0 E-12	2.4 E-12	2.7 E-12	ND	1.4 E-05	ND	2.1E-06	9.1 E-05	7.6 E-12	5.6 E-12	ND
A086	.22 Caliber Long Rifle Ball Cartridge	1.3 E-07	ND	ND	ND	ND	1.6 E-04	5.6 E-08	7.3E-06	ND	ND	ND	ND
A143/A255/A257/A131	7.62-mm Ball Cartridge (M80)	4.9 E-08	ND	ND	ND	ND	2.9 E-05	3.5 E-07	1.5E-06	ND	ND	ND	ND
A363	9-mm Ball Cartridge (M882)	3.1 E-07	ND	ND	ND	ND	1.9 E-04	1.3 E-06	2.6E-06	8.1 E-05	ND	ND	ND
A475	.45 Caliber Ball Cartridge (M1911)	2.1 E-07	ND	ND	ND	ND	1.6 E-04	4.9 E-07	4.3E-06	ND	ND	ND	ND
A557/A555	.50 Caliber Ball Cartridge (M33)	1.0 E-07	ND	ND	ND	ND	3.1 E-05	2.4 E-07	4.0E-06	ND	ND	ND	ND
A598	.50 Caliber Blank Cartridge (M1A1)	ND	ND	ND	ND	ND	ND	2.3 E-08	2.4E-07	4.5 E-04	ND	ND	ND
B571	40-mm High Explosive Cartridge (M383)	7.7 E-07	5.6 E-13	7.8 E-13	1.7 E-12	ND	5.8 E-05	3.9 E-07	1.9E-06	ND	1.0 E-13	2.1 E-12	ND
B519	40-mm Practice Cartridge (M781)	4.0 E-07	ND	ND	ND	ND	2.0 E-04	1.3 E-07	3.0E-04	ND	ND	ND	ND
A011/A017	12-Gage Shotgun	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

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Table I-2b. [Con't] Organic HAP Emission Factors for Munitions (lbs/NEW)^a

	Item	Toluene (108-88-3)	1,1,1-Trichloroethane (71-55-6)	Trichlorofluoromethane (75-69-4)	1,2,4-Trimethylbenzene (95-63-6)	2,2,4-Trimethylpentane (540-84-1)	Xylenes (106-42-3, 108-38-3, 95-47-6)
DODIC	Units:	lb/NEW	lb/NEW	lb/NEW	lb/NEW	lb/NEW	lb/NEW
A059/A062/A064/AA33	5.56-mm Ball Cartridge (M855)	7.6 E-06	4.1 E-07	ND	4.8 E-07	ND	1.64 E-06
A066/A071	5.56-mm Ball Cartridge (M193)	6.6 E-06	ND	ND	ND	ND	ND
A068	5.56-mm Tracer Cartridge (M196)	4.0E-06	ND	ND	ND	ND	ND
A086	.22 Caliber Long Rifle Ball Cartridge	1.5E-05	1.6 E-06	ND	ND	ND	ND
A143/A255/A257/A131	7.62-mm Ball Cartridge (M80)	7.0E-06	ND	ND	ND	ND	1.5 E-06
A363	9-mm Ball Cartridge (M882)	3.9E-05	2.4 E-07	ND	1.1 E-06	ND	7.5 E-09
A475	.45 Caliber Ball Cartridge (M1911)	3.2E-05	ND	ND	3.9 E-07	ND	5.0 E-09
A557/A555	.50 Caliber Ball Cartridge (M33)	1.2E-05	ND	ND	7.1 E-09	ND	5.8 E-08
A598	.50 Caliber Blank Cartridge (M1A1)	1.9E-06	ND	ND	ND	ND	1.8 E-09
B571	40-mm High Explosive Cartridge (M383)	1.4 E-05	ND	7.6 E-07	7.7 E-07	4.4 E-07	9.5 E-07
B519	40-mm Practice Cartridge (M781)	1.1E-04	1.4 E-04	ND	6.3 E-05	ND	1.3E-07
A011/A017	12-Gage Shotgun	ND	ND	ND	ND	ND	ND

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Table I-3a. Inorganic HAP Emission Factors for Munitions

DODIC	Item	Antimony (7440-36-0)	Barium (7440-39-3)	Cadmium (7440-43-9)	Chromium (7440-47-3)	Copper (7440-50-8)	Lead (7439-92-1)	Selenium (7782-49-2)	Zinc (7440-66-6)
		lbs/ item	lbs/ item	lbs/ item	lbs/ item	lbs/ item	lbs/ item	lbs/ item	lbs/ item
	Units:								
A059/A062/A064/AA33	5.56-mm Ball Cartridge (M855)	1.5E-06	6.9E-07	ND	ND	1.5E-05	5.1E-06	9.9E-09	2.0E-06
A066/A071	5.56-mm Ball Cartridge (M193)	1.7E-06	4.4E-07	ND	ND	9.5E-06	1.3E-05	ND	1.2E-06
A068	5.56-mm Tracer Cartridge (M196)	1.3E-06	4.7E-07	ND	ND	2.1E-05	2.8E-06	ND	2.4E-06
A086	.22 Caliber Long Rifle Ball Cartridge	8.9E-09	ND	ND	ND	6.8E-09	1.9E-06	ND	1.6E-08
A143/A255/A257/A131	7.62-mm Ball Cartridge (M80)	2.0E-06	6.1E-07	ND	ND	1.0E-05	4.9E-06	ND	1.4E-06
A363	9-mm Ball Cartridge (M882)	2.0E-06	1.7E-06	ND	ND	9.8E-07	6.8E-06	ND	1.6E-07
A475	.45 Caliber Ball Cartridge (M1911)	2.9E-06	1.5E-06	ND	ND	1.5E-06	1.2E-05	ND	2.4E-07
A557/A555	.50 Caliber Ball Cartridge (M33)	3.3E-06	2.2E-06	ND	ND	4.6E-05	1.3E-05	ND	6.7E-06
A598	.50 Caliber Blank Cartridge (M1A1)	6.9E-06	4.3E-06	ND	ND	1.0E-06	1.2E-05	ND	4.6E-07
B571	40-mm High Explosive Cartridge (M383)	ND	3.3E-06	ND	5.3E-06	9.6E-04	7.3E-05	ND	1.1E-04
B519	40-mm Practice Cartridge (M781)	1.2E-06	6.7E-07	ND	1.5E-08	7.2E-08	6.7E-06	ND	4.2E-06
A011/A017	12-Gage Shotgun	ND	ND	ND	ND	ND	5.1E-05	ND	ND

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Table I-3b. Inorganic HAP Emission Factors for Munitions (lbs/NEW)^a

DODIC	Item	Antimony (7440-36-0)	Barium (7440-39-3)	Cadmium (7440-43-9)	Chromium (7440-47-3)	Copper (7440-50-8)	Lead (7439-92-1)	Selenium (7782-49-2)	Zinc (7440-66-6)
	Units:	lb/NEW	lb/NEW	lb/NEW	lb/NEW	lb/NEW	lb/NEW	lb/NEW	lb/NEW
A059/A062/ A064/AA33	5.56-mm Ball Cartridge (M855)	3.9E-04	1.8E-04	ND	ND	3.8E-03	1.3E-03	2.5E-06	5.0E-04
A066/A071	5.56-mm Ball Cartridge (M193)	4.1E-04	1.1E-04	ND	ND	2.3E-03	3.2E-03	ND	2.8E-04
A068	5.56-mm Tracer Cartridge (M196)	3.5E-04	1.2E-04	ND	ND	5.4E-03	7.2E-04	ND	6.2E-04
A086	.22 Caliber Long Rifle Ball Cartridge	2.2E-05	ND	ND	ND	1.7E-05	4.6E-03	ND	3.8E-05
A143/A255/ A257/A131	7.62-mm Ball Cartridge (M80)	3.2E-04	9.7E-05	ND	ND	1.6E-03	7.8E-04	ND	2.2E-04
A363	9-mm Ball Cartridge (M882)	2.6E-03	2.2E-03	ND	ND	1.2E-03	8.6E-03	ND	2.1E-04
A475	.45 Caliber Ball Cartridge (M1911)	3.7E-03	1.9E-03	ND	ND	2.0E-03	1.6E-02	ND	3.1E-04
A557/A555	.50 Caliber Ball Cartridge (M33)	1.0E-04	6.4E-05	ND	ND	1.4E-03	4.0E-04	ND	2.0E-04
A598	.50 Caliber Blank Cartridge (M1A1)	9.9E-04	6.2E-04	ND	ND	1.5E-04	1.7E-03	ND	6.7E-05
B571	40-mm High Explosive Cartridge (M383)	ND	2.8E-05	ND	4.6E-05	8.2E-03	6.2E-04	ND	9.2E-04
B519	40-mm Practice Cartridge (M781)	1.5E-03	8.3E-04	ND	1.8E-05	8.9E-05	8.3E-03	ND	5.2E-03
A011/A017	12-Gage Shotgun								

^a U.S. Environmental Protection Agency, Compilation of Air Pollutant Emission Factors AP-42, Fifth Edition, Volume I: Chapter 15: Ordnance Detonation, Emission Factor And Inventory Group (MD-14), Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC, February 1996. AP-42 can be accessed on-line at www.epa.gov/ttn/chief/ap42.

Table I-4a. Criteria Pollutant Emission Factors for Assembled Energetic Materials

DODIC	Item	CO (124-38-9)	NO _x	SO _x	PM ₁₀
		Units: lbs/lb	lbs/lb	lbs/lb	lbs/lb
L231	Signal, Illum, Aircraft, Red Star, AN-M43A2	2.2E-02	1.4E-02	1.3E-02	4.5E-01
L306	Ground Illum. Signal, Red Star, M158 (lb/lb)	1.2E-02	4.1E-03	1.1E-04	8.2E-02
L410	Flare, Countermeasure, Aircraft, M206 (lb/lb)	8.3E-03	8.1E-03	1.0E-03	5.5E-01
M187	Impulse Cartridge, ARD 446-1 (lb/lb)	1.3E-02	8.1E-03	2.4E-04	8.3E-02
NA	Impulse Cartridge, BBU-368 (lb/lb)	8.4E-03	5.5E-03	4.0E-04	1.8E-01
NA	Impulse Cartridge, MK107 MOD01 (lb/lb)	1.4E-02	1.6E-02	2.6E-04	2.5E-01
NA	Fuse, Inertia Tail, Bomb, FMU 54A/B (lb/lb)	1.8E-02	9.5E-03	4.1E-04	3.3E-01
NA	Fuse, Inertia Tail, Bomb, FMU 139A/B (lb/lb)	2.3E-02	2.7E-02	1.4E-03	6.0E-01

Table I-4b. Criteria Pollutant Emission Factors for Assembled Energetic Materials

DODIC	Item	CO (124-38-9)	NO _x	SO _x	PM ₁₀
		Units: lbs/NEW	lbs/NEW	lbs/NEW	lbs/NEW
L231	Signal, Illum, Aircraft, Red Star, AN-M43A2	2.2E-02	1.4E-02	1.3E-02	4.5E-01
L306	Ground Illum. Signal, Red Star, M158 (lb/lb)	1.2E-02	4.1E-03	1.1E-04	8.2E-02
L410	Flare, Countermeasure, Aircraft, M206 (lb/lb)	8.3E-03	8.1E-03	1.0E-03	5.5E-01
M187	Impulse Cartridge, ARD 446-1 (lb/lb)	1.3E-02	8.1E-03	2.4E-04	8.3E-02
NA	Impulse Cartridge, BBU-368 (lb/lb)	8.4E-03	5.5E-03	4.0E-04	1.8E-01
NA	Impulse Cartridge, MK107 MOD01 (lb/lb)	1.4E-02	1.6E-02	2.6E-04	2.5E-01
NA	Fuse, Inertia Tail, Bomb, FMU 54A/B (lb/lb)	1.8E-02	9.5E-03	4.1E-04	3.3E-01
NA	Fuse, Inertia Tail, Bomb, FMU 139A/B (lb/lb)	2.3E-02	2.7E-02	1.4E-03	6.0E-01

Table I-5a. Organic HAP Emission Factors for Assembled Energetic Materials

Item	Benzene (71-43-2)	1,3-Butadiene (106-99-0)	Ethylbenzene (100-41-4)	Hexane (110-54-3)	Methylene Chloride (75-09-2)	Styrene (100-42-5)	Toluene (108-88-3)	Vinyl Chloride (75-01-4)
	Units: lbs/lb	lbs/lb	lbs/lb	lbs/lb	lbs/lb	lbs/lb	lbs/lb	lbs/lb
Signal, Illum, Aircraft, Red Star, AN-M43A2	3.4E-05	1.9E-06	4.6E-07	8.1E-07	8.1E-06	4.5E-06	3.0E-05	2.3E-06
Ground Illum. Signal, Red Star, M158 (lb/lb)	3.0E-05	1.2E-05	7.0E-07	1.1E-06	1.0E-04	2.2E-06	2.5E-05	1.1E-06
Flare, Countermeasure, Aircraft, M206 (lb/lb)	4.5E-05	3.0E-06	2.4E-06	6.8E-07	4.1E-04	7.1E-06	2.8E-05	1.5E-06
Impulse Cartridge, ARD 446-1 (lb/lb)	6.7E-05	6.7E-06	1.9E-06	1.5E-07	5.0E-05	5.4E-06	1.7E-05	ND
Impulse Cartridge, BBU-368 (lb/lb)	2.1E-05	2.8E-06	2.4E-06	1.7E-06	1.7E-04	3.6E-06	9.1E-06	1.7E-06
Impulse Cartridge, MK107 MOD01 (lb/lb)	6.4E-05	2.0E-06	9.7E-07	5.3E-07	2.3E-04	9.4E-06	9.0E-06	2.4E-06
Fuse, Inertia Tail, Bomb, FMU 54A/B (lb/lb)	1.1E-04	4.5E-06	2.4E-06	4.4E-07	7.4E-04	7.8E-06	3.2E-05	6.8E-07
Fuse, Inertia Tail, Bomb, FMU 139A/B (lb/lb)	1.2E-04	2.1E-05	3.2E-06	6.5E-07	1.1E-04	2.9E-05	2.3E-05	1.8E-06

Table I-5b. Inorganic HAP Emission Factors for Assembled Energetic Materials

Item	Antimony (7440-36-0)	Barium (7440-39-3)	Cadmium (7440-43-9)	Chromium (7440-47-3)	Copper (7440-50-8)	Lead (7439-92-1)	Zinc (7440-66-6)
Units:	lbs/lb	lbs/lb	lbs/lb	lbs/lb	lbs/lb	lbs/lb	lbs/lb
Signal, Illum, Aircraft, Red Star, AN-M43A2	ND	1.1E-04	8.8E-05	5.7E-05	3.7E-04	7.0E-05	3.4E-04
Ground Illum. Signal, Red Star, M158 (lb/lb)	ND	1.7E-04	1.1E-03	1.5E-04	ND	ND	ND
Flare, Countermeasure, Aircraft, M206 (lb/lb)	ND	2.4E-04	3.4E-05	1.6E-04	ND	ND	ND
Impulse Cartridge, ARD 446-1 (lb/lb)	1.8E-04	ND	ND	ND	ND	3.1E-04	ND
Impulse Cartridge, BBU-368 (lb/lb)	ND	ND	ND	ND	1.2E-03	6.8E-05	ND
Impulse Cartridge, MK107 MOD01 (lb/lb)	ND	1.6E-05	1.4E-03	3.3E-05	1.4E-03	ND	ND
Fuse, Inertia Tail, Bomb, FMU 54A/B (lb/lb)	ND	ND	3.1E-04	3.9E-05	5.1E-04	ND	ND
Fuse, Inertia Tail, Bomb, FMU 139A/B (lb/lb)	2.2E-04	ND	2.3E-03	1.4E-04	6.8E-03	2.6E-03	6.2E-03

Table I-6. Criteria Pollutant and Gasses Emission Factors for Explosives

Item	CO (124-38-9)	NO _x	SO _x	PM ₁₀	PM _{2.5}	TSP (12789-66-1)	Methane (74-82-8)	VOC (NMOC)
Units:	lbs/lb	lbs/lb	lbs/lb	lbs/lb	lbs/lb	lbs/lb	lbs/lb	lbs/lb
Demolition Block Charge (M112)	2.6E-02	7.9E-03	ND	2.6E-02	1.9E-02	3.2E-02	1.6E-03	ND
1/4-Pound Demolition Block Charge	5.0E-03	3.0E-03	ND	1.2E-02	4.6E-03	1.7E-02	2.0E-05	ND
1-Pound Demolition Block Charge	4.8E-03	1.3E-02	4.0E-05	2.5E-02	1.4E-02	3.2E-02	ND	ND
Military Dynamite Demolition Block Charge	5.4E-03	2.4E-03	ND	8.9E-03	3.5E-03	1.6E-02	6.5E-05	ND
Linear Demolition Charge (M58A3) (per ft)	5.5E-02	9.0E-02	ND	2.3E-01	1.1E-01	2.4E-01	1.3E-03	ND
Smokeless Powder (lb/lb)	1.6E-03	ND	6.1E-04	1.8E-03	ND	ND	ND	ND
Detonating Train (lb/lb)	9.4E-03	9.3E-03	4.6E-04	3.6E-02	ND	ND	ND	8.5E-04
TNT (2,4,6-Trinitrotoluene) (lb/lb)	1.0E-02	1.0E-02	1.4E-04	9.3E-02	ND	ND	ND	ND
Explosive D (Ammonium Picrate) (lb/lb)	5.3E-02	2.0E-03	ND	ND	ND	ND	2.4E-03	2.0E-03
Composition B (lb/lb)	4.2E-03	9.5E-03	1.3E-04	1.2E-02	ND	ND	ND	1.1E-04
RDX (lb/lb)	3.1E-02	1.5E-03	ND	ND	ND	ND	2.0E-04	1.3E-03
M1 (85% Nitrocellulose) (lb/lb)	2.5E-04	1.7E-03	ND	ND	ND	ND	8.0E-03	4.6E-04
M6 (87.7% Nitrocellulose) (lb/lb)	9.5E-05	7.6E-03	ND	ND	ND	ND	4.6E-05	1.3E-05
Tritonal (79% TNT, 21% Aluminum) (lb/lb)	4.7E-03	8.4E-03	1.6E-04	3.7E-01	ND	ND	ND	2.8E-04
Tritonal with 2.5% Calcium Stearate (lb/lb)	2.7E-03	6.6E-03	1.2E-04	2.6E-01	ND	ND	ND	4.0E-05
Amatol (50% TNT, 50% Ammon. Nitrate) (lb/lb)	9.7E-03	1.8E-02	2.6E-04	1.9E-02	ND	ND	ND	4.5E-04
Diesel and Dunnage	6.0E-03	8.4E-04	1.9E-04	5.4E-03	ND	ND	ND	1.2E-02

Table I-7. Organic HAP Emission Factors for Explosives

Item	Acetaldehyde (75-07-0)	Acetonitrile (75-05-8)	Benzene (71-43-2)	Bis(2- Ethylhexyl) Phthalate (117-81-7)	1,3-Butadiene (106-99-0)	Ethylbenzene (100-41-4)	Formaldehyde (50-00-0)	Hexane (110-54-3)	Hydrogen Cyanide (1634-04-4)	Methylene Chloride (75-09-2)	Naphthalene (91-20-3)	Styrene (100-42-5)	Toluene (108-88-3)	Xylenes (106-42-3, 108-38-3, 95-47-6)
Units:	lbs/lb	lbs/lb	lbs/lb	lbs/lb	lbs/lb	lbs/lb	lbs/lb	lbs/lb	lbs/lb	lbs/lb	lbs/lb	lbs/lb	lbs/lb	lbs/lb
Demolition Block Charge (M112)	#####	#####	#####	1.5E-05	ND	ND	#####	#####	#####	1.9E-06	#####	ND	#####	ND
1/4-Pound Demolition Block Charge	ND	ND	#####	3.7E-06	ND	#####	ND	ND	#####	3.3E-07	#####	ND	#####	3.8E-06
1-Pound Demolition Block Charge	ND	ND	#####	9.9E-06	ND	ND	#####	ND	#####	ND	#####	ND	ND	ND
Military Dynamite Demolition Block Charge	#####	#####	#####	1.1E-05	ND	#####	ND	#####	#####	1.8E-06	#####	ND	#####	3.1E-06
Linear Demolition Charge (M58A3) (per ft)	#####	#####	#####	4.7E-05	ND	#####	ND	ND	#####	ND	#####	#####	#####	4.9E-06
Smokeless Powder (lb/lb)	ND	ND	#####	ND	ND	ND	ND	#####	ND	7.2E-07	ND	ND	#####	ND
Detonating Train (lb/lb)	ND	ND	#####	ND	#####	#####	ND	#####	ND	4.2E-05	ND	#####	#####	ND
TNT (2,4,6-Trinitrotoluene) (lb/lb)	ND	ND	#####	ND	ND	#####	ND	#####	ND	ND	ND	#####	#####	ND
Explosive D (Ammonium Picrate) (lb/lb)	ND	ND	#####	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Composition B (lb/lb)	ND	ND	#####	ND	ND	#####	ND	#####	ND	1.4E-04	ND	ND	#####	ND
RDX (lb/lb)	ND	ND	#####	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M1 (85% Nitrocellulose) (lb/lb)	ND	ND	#####	ND	ND	ND	ND	ND	ND	ND	#####	ND	ND	ND
M6 (87.7% Nitrocellulose) (lb/lb)	ND	ND	#####	ND	ND	ND	ND	ND	ND	ND	#####	ND	ND	ND
Tritonal (79% TNT, 21% Aluminum) (lb/lb)	ND	ND	#####	ND	ND	#####	ND	#####	ND	1.8E-05	ND	ND	#####	ND
Tritonal with 2.5% Calcium Stearate (lb/lb)	ND	ND	ND	ND	#####	#####	ND	ND	ND	1.6E-04	ND	ND	ND	ND
Amatol (50% TNT, 50% Ammon. Nitrate) (lb/lb)	ND	ND	#####	ND	ND	#####	ND	#####	ND	1.5E-04	ND	ND	#####	ND
Diesel and Dunnage	ND	ND	#####	ND	#####	#####	ND	#####	ND	ND	ND	ND	#####	ND

Table I-8. Inorganic HAP Emission Factors for Explosives

Item	Antimony (7440-36-0)	Barium (7440-39-3)	Cadmium (7440-43-9)	Chromium (7440-47-3)	Copper (7440-50-8)	Lead (7439-92-1)	Selenium (7782-49-2)	Zinc (7440-66-6)
	Units:	lbs/lb	lbs/lb	lbs/lb	lbs/lb	lbs/lb	lbs/lb	lbs/lb
Demolition Block Charge (M112)	2.9E-06	5.5E-06	ND	9.4E-06	1.2E-04	1.7E-04	ND	2.6E-05
1/4-Pound Demolition Block Charge	ND	1.5E-04	ND	5.4E-06	1.2E-04	1.4E-04	ND	1.4E-05
1-Pound Demolition Block Charge	ND	6.2E-04	ND	8.7E-06	5.3E-04	2.0E-04	3.8E-06	3.3E-04
Military Dynamite Demolition Block Charge	ND	1.1E-05	ND	2.3E-06	2.7E-05	1.5E-04	ND	1.6E-05
Linear Demolition Charge (M58A3) (per ft)	ND	3.2E-05	9.5E-04	5.0E-05	2.2E-03	1.7E-04	ND	7.5E-04
Smokeless Powder (lb/lb)	ND	ND	ND	ND	ND	ND	ND	ND
Detonating Train (lb/lb)	ND	ND	1.1E-05	ND	ND	1.8E-04	ND	ND
TNT (2,4,6-Trinitrotoluene) (lb/lb)	6.7E-07	8.2E-03	4.0E-05	2.3E-05	5.0E-04	9.0E-06	ND	1.0E-05
Explosive D (Ammonium Picrate) (lb/lb)	ND	ND	ND	ND	ND	ND	ND	ND
Composition B (lb/lb)	ND	ND	ND	ND	ND	ND	ND	ND
RDX (lb/lb)	ND	ND	ND	ND	ND	ND	ND	ND
M1 (85% Nitrocellulose) (lb/lb)	ND	ND	ND	ND	ND	ND	ND	ND
M6 (87.7% Nitrocellulose) (lb/lb)	ND	ND	ND	ND	ND	ND	ND	ND
Tritonal (79% TNT, 21% Aluminum) (lb/lb)	ND	1.6E-04	ND	ND	ND	1.1E-03	ND	ND
Tritonal with 2.5% Calcium Stearate (lb/lb)	ND	3.6E-04	ND	ND	5.0E-04	9.2E-04	ND	7.0E-05
Amatol (50% TNT, 50% Ammon. Nitrate) (lb/lb)	ND	6.0E-06	ND	ND	ND	3.3E-05	ND	ND
Diesel and Dunnage	ND	ND	ND	ND	ND	ND	ND	6.3E-05

Table I-9. Criteria Pollutant Emission Factors for Propellants

Item	CO (124-38-9)	NO _x	SO _x	PM ₁₀	VOC (NMOC)
Units:	lbs/lb	lbs/lb	lbs/lb	lbs/lb	lbs/lb
Propellant - Ammonium Perchlorate, Aluminum	2.0E-02	2.0E-03	5.0E-05	4.2E-01	5.0E-05
Propellant - Ammonium Perchlorate, Nonal	1.4E-04	6.4E-03	1.1E-04	1.5E-02	4.0E-05
Propellant - M-3	1.4E-02	ND	ND	8.6E-03	9.3E-05
Propellant - M-9	2.7E-03	ND	ND	1.6E-02	1.5E-05
Propellant - M-43	6.6E-04	6.8E-03	1.2E-04	1.2E-03	4.1E-05
Propellant - MK-23	2.7E-04	ND	ND	5.9E-02	ND
Propellant - M31A1E1	1.3E-04	1.3E-03	ND	9.1E-01	1.0E-04
Propellant - PBXN-110	1.2E-03	2.9E-03	3.5E-04	4.9E-01	5.1E-05
Propellant - Smokey Sam	7.2E-02	1.1E-02	1.5E-04	2.6E-01	1.1E-03
Propellant - Composite (MK-6)	4.2E-03	3.1E-03	1.1E-03	ND	ND

Table I-10. Organic HAP Emission Factors for Propellants

Item	Benzene (71-43-2)	1,3-Butadiene (106-99-0)	Ethylbenzene (100-41-4)	Hexane (110-54-3)	Methylene Chloride (75-09-2)	Styrene (100-42-5)	Toluene (108-88-3)	Vinyl Chloride (75-01-4)
Units:	lbs/lb	lbs/lb	lbs/lb	lbs/lb	lbs/lb	lbs/lb	lbs/lb	lbs/lb
Propellant - Ammonium Perchlorate, Aluminum	ND	ND	ND	ND	ND	ND	ND	ND
Propellant - Ammonium Perchlorate, Nonal	ND	ND	ND	ND	ND	ND	ND	ND
Propellant - M-3	1.0E-05	ND	2.6E-07	1.9E-05	2.3E-05	ND	1.8E-06	ND
Propellant - M-9	3.2E-06	ND	ND	ND	ND	4.7E-07	ND	ND
Propellant - M-43	1.7E-06	9.1E-08	ND	9.1E-08	ND	ND	5.4E-07	ND
Propellant - MK-23	ND	2.0E-07	ND	ND	6.0E-07	ND	ND	1.5E-06
Propellant - M31A1E1	ND	ND	ND	ND	ND	ND	ND	ND
Propellant - PBXN-110	4.9E-06	5.0E-07	8.0E-07	ND	ND	ND	ND	2.2E-07
Propellant - Smokey Sam	6.6E-05	1.2E-06	1.2E-06	2.7E-06	1.2E-06	ND	8.6E-06	8.8E-07
Propellant - Composite (MK-6)	5.7E-05	ND	ND	ND	ND	ND	ND	ND

Table I-11. Inorganic HAP Emission Factors for Propellants

Item	Barium (7440-39-3)	Chromium (7440-47-3)	Copper (7440-50-8)	Lead (7439-92-1)	Zinc (7440-66-6)
Units:	lbs/lb	lbs/lb	lbs/lb	lbs/lb	lbs/lb
Propellant - Ammonium Perchlorate, Aluminum	1.0E-05	1.0E-05	ND	4.0E-05	4.0E-05
Propellant - Ammonium Perchlorate, Nonal	ND	1.0E-05	8.0E-05	ND	ND
Propellant - M-3	ND	ND	4.4E-06	ND	ND
Propellant - M-9	ND	ND	6.5E-06	ND	ND
Propellant - M-43	ND	ND	ND	ND	ND
Propellant - MK-23	ND	ND	ND	ND	ND
Propellant - M31A1E1	ND	ND	1.0E-05	ND	ND
Propellant - PBXN-110	ND	ND	ND	ND	ND
Propellant - Smokey Sam	ND	ND	ND	ND	ND
Propellant - Composite (MK-6)	1.6E-06	4.8E-05	ND	ND	ND

APPENDIX J
LOAD FACTORS AND ANNUAL ACTIVITY FOR IC ENGINES

Table J-1. Load Factors and Annual Activity for IC Engines

SCC	Equipment Description	Load Factor (fraction of power)	Activity (hours/year)
2260001010	2-Stroke Motorcycles: Off-Road ^a	1.00	1600
2260001030	2-Stroke All Terrain Vehicles ^a	1.00	1608
2260004010	2-Stroke Lawn mowers (Residential)	0.33	25
2260004011	2-Stroke Lawn mowers (Commercial)	0.33	406
2260004021	2-Stroke Chain Saws < 6 HP (Commercial)	0.70	303
2260004026	2-Stroke Trimmers/Edgers/Brush Cutters	0.91	137
2260004030	2-Stroke Leafblowers/Vacuums (Residential)	0.94	10
2260004076	2-Stroke Other Lawn & Garden Equipment	0.58	61
2260005035	2-Stroke Sprayers	0.65	80
2260006005	2-Stroke Light Commercial Generator Set	0.68	115
2260006010	2-Stroke Light Commercial Pumps	0.69	221
2260006015	2-Stroke Light Commercial Air Compressors	0.56	484
2260006030	2-Stroke Light Commercial Pressure Wash	0.85	115
2260008005	2-Stroke Airport Support Equipment	0.56	681
2265001010	4-Stroke Motorcycles: Off-Road ^a	1.00	1600
2265001030	4-Stroke All Terrain Vehicles ^a	1.00	1608
2265002015	4-Stroke Rollers	0.62	621
2265002018	4-Stroke Scrapers	0.70	540
2265002021	4-Stroke Paving Equipment	0.59	175
2265002030	4-Stroke Trenchers	0.66	402
2265002033	4-Stroke Bore/Drill Rigs	0.79	107
2265002036	4-Stroke Excavators	0.53	378
2265002042	4-Stroke Cement & Mortar Mixers	0.59	84
2265002045	4-Stroke Cranes	0.47	415
2265002048	4-Stroke Graders	0.64	504
2265002063	4-Stroke Rubber Tire Dozers	0.75	900
2265002066	4-Stroke Tractors/Loaders/Backhoes	0.48	870
2265002069	4-Stroke Crawler Tractors	0.80	700
2265002072	4-Stroke Skid Steer Loaders	0.58	310
2265002081	4-Stroke Other Construction Equipment	0.48	371
2265003020	4-Stroke Forklifts	0.30	1800
2265003040	4-Stroke Other General Industrial Equipment	0.54	713
2265003050	4-Stroke Other Material Handling Equipment	0.53	386
2265003070	4-Stroke Terminal Tractors	0.78	827
2265004016	4-Stroke Rotary Tillers < 6 HP (Commercial)	0.40	472
2265004026	4-Stroke Trimmers/Edgers/Brush Cutters	0.91	137
2265004036	4-Stroke Snowblowers (Commercial)	0.35	136
2265004041	4-Stroke Rear Engine Riding Mowers (Comm)	0.38	569
2265004056	4-Stroke Lawn & Garden Tractors (Comm)	0.44	721
2265004071	4-Stroke Commercial Turf Equipment (Comm)	0.60	682
2265004076	4-Stroke Other Lawn & Garden Equipment	0.58	61
2265005015	4-Stroke Agricultural Tractors	0.62	550

Table J-1. [con't] Load Factors And Annual Activity For IC Engines

SCC	Equipment Description	Load Factor (fraction of power)	Activity (hours/year)
2265006005	4-Stroke Light Commercial Generator Sets	0.68	115
2265006010	4-Stroke Light Commercial Pumps	0.69	221
2265006015	4-Stroke Light Commercial Air Compressors	0.56	484
2265006025	4-Stroke Light Commercial Welders	0.68	408
2265006030	4-Stroke Light Commercial Pressure Washers	0.85	115
2265008005	4-Stroke Airport Support Equipment	0.56	681
2267002072	LPG Skid Steer Loaders	0.58	310
2267003020	LPG Forklifts	0.30	1800
2267003040	LPG Other General Industrial Equipment	0.54	713
2267003050	LPG Other Material Handling Equipment	0.53	386
2267003070	LPG Terminal Tractors	0.78	827
2267006005	LPG Light Commercial Generator Sets	0.68	115
2267006010	LPG Light Commercial Pumps	0.69	221
2267006015	LPG Light Commercial Air Compressors	0.56	484
2268002072	CNG Skid Steer Loaders	0.58	310
2268003020	CNG Forklifts	0.30	1800
2268003040	CNG Other General Industrial Equipment	0.54	713
2268003050	CNG Other Material Handling Equipment	0.53	386
2268003070	CNG Terminal Tractors	0.78	827
2268006005	CNG Light Commercial Generator Sets	0.68	115
2268006010	CNG Light Commercial Pumps	0.69	221
2268008005	CNG Airport Support Equipment	0.56	681
2270002015	Diesel Rollers	0.59	760
2270002018	Diesel Scrapers	0.59	914
2270002021	Diesel Paving Equipment	0.59	622
2270002024	Diesel Surfacing Equipment	0.59	561
2270002030	Diesel Trenchers	0.59	593
2270002036	Diesel Excavators	0.59	1092
2270002042	Diesel Cement & Mortar Mixers	0.43	275
2270002045	Diesel Cranes	0.43	990
2270002048	Diesel Graders	0.59	962
2270002051	Diesel Off-highway Trucks	0.59	1641
2270002057	Diesel Rough Terrain Forklifts	0.59	662
2270002060	Diesel Rubber Tire Loaders	0.59	761
2270002063	Diesel Rubber Tire Dozers	0.59	899
2270002069	Diesel Crawler Tractors	0.59	936
2270002081	Diesel Other Construction Equipment	0.59	606
2270003020	Diesel Forklifts	0.59	1700
2270003040	Diesel Other General Industrial Equipment	0.43	878
2270003050	Diesel Other Material Handling Equipment	0.21	421
2270003070	Diesel Terminal Tractors	0.59	1257

Table J-1. [con't] Load Factors And Annual Activity For IC Engines

SCC	Equipment Description	Load Factor (fraction of power)	Activity (hours/year)
2270005015	Diesel Agricultural Tractors	0.59	475
2270005030	Diesel Agricultural Mowers	0.59	363
2270005060	Diesel Irrigation Sets	0.43	749
2270006005	Diesel Light Commercial Generator Sets	0.43	338
2270006010	Diesel Light Commercial Pumps	0.43	403
2270006015	Diesel Light Commercial Air Compressors	0.43	815
2270006025	Diesel Light Commercial Welders	0.21	643
2270006030	Diesel Light Commercial Pressure Washer	0.43	145
2270008005	Diesel Airport Support Equipment	0.59	732
2282005010	2-Stroke Outboards	0.21	34.8
2282005015	2-Stroke Personal Watercraft	0.21	77.3
2282010005	4-Stroke Inboards	0.21	47.6
2282020005	Diesel Inboards	0.43	200

Data from: EPA, *Median Life, Annual Activity, and Load Factor Values for Nonroad Engine Emissions Modeling*, Appendix A, EPA420-P-04-005, April 2004.

^a Activities for off-road motorcycles and all terrain vehicles are in units of miles per year.