AIR EMISSIONS GUIDE FOR AIR FORCE STATIONARY SOURCES

METHODS FOR ESTIMATING EMISSIONS OF AIR POLLUTANTS FOR STATIONARY SOURCES AT UNITED STATES AIR FORCE INSTALLATIONS

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Based on information and belief formed after reasonable inquiry, the statements and information in the document are true, accurate, and complete.

Signed:

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ACRONYMS

(Word formed from the initial letters of a name or parts of a series of words.)

AAFES	Army & Air Force Exchange Service
AFCEC	Air Force Civil Engineer Center
AGE	Aerospace Ground Equipment
APIMS	Air Program Information Management System
ARAR	Applicable or Relevant and Appropriate Requirements
BEE	Bioenvironmental Engineer
CALMIM	California Landfill Methane Inventory Model
CARB	California Air Resources Board
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
DODIC	Department of Defense Identification Codes
ECOM	External Combustion Engine
EESOH-MIS	Enterprise Environmental, Safety and Occupational Health Management Information System
EIAP	Environmental Impact Analysis Process
EPCRA	Emergency Planning and Community Right-to-Know Act
HAP	Hazardous Air Pollutant
HAZMART	Hazardous Materials Pharmacy
HEPA	High Efficiency Particulate Air
HVAC	Heating, Ventilating, and Air Conditioning
ICOM	Internal Combustion Engine
LAER	Lowest Achievable Emissions Rate
LandGEM	Landfill Gas Emissions Model
MIDAS	Munitions Items Disposition Action System
NAAQS	National Ambient Air Quality Standards
NEPA	National Environmental Policy Act
NESHAP	National Emission Standards for Hazardous Air Pollutants
NEW	Net Explosive Weight
RCRA	Resource Conservation and Recovery Act
SAW	Submerged Arc Welding
SIC	Standard Industrial Classification
SIP	State Implementation Plan
SMAW	Shielded Metal Arc Welding
USAF	United States Air Force

BREVITY CODES

(Shortened form of a frequently used group of words, phrases, or sentences consisting of entirely upper-case letters. Each letter is spoken individually.)

AEI	Air Emissions Inventory
AERR	Air Emissions Reporting Requirements
AFB	Air Force Base
AFI	Air Force Instruction
AFPMB	Armed Forces Post Management Board
BFB	Bubbling Fluidized Bed
BMP	Best Management Practices
BSFC	Brake-Specific Fuel Consumption
CAA	Clean Air Act
CAAA	Clean Air Act Amendments (of 1990)
CE	Civil Engineering
CEV	Civil Engineering Environmental
CFB	Circulating Fluidized Bed
CFC	Chlorofluorocarbon
CFR	Code of Federal Regulations
CI	Compression Ignition
DLA	Defense Logistics Agency
DoD	Department of Defense
EA	Environmental Assessment
EF	Emission Factor
EIIP	Emissions Inventory Improvement Program
EIP	Emissions Inventory Plan
EIR	Emissions Inventory Report
EIS	Environmental Impact Statement
EOD	Explosive Ordnance Disposal
EPA	Environmental Protection Agency
ERP	Environmental Restoration Program
ESP	Electrostatic Precipitator
FAA	Federal Aviation Administration
FBC	Fluidized Bed Combustor
FCAW	Flux-Cored Arc Welding
FF	Fabric Filter
FFR	Fuel Flow Rates
FGD	Flue Gas Desulphurization
FGR	Flue Gas Recirculation
GHG	Greenhouse Gases

GMAW	Gas Metal Arc Welding
GSA	General Services Administration
GSE	Ground Support Equipment
GWP	Global Warming Potential
HCFC	Hydrochlorofluorocarbons
HMA	Hot Mix Asphalt
HVLP	High Volume Low Pressure
HVOF	High Velocity Oxy-Fuel
IPCT	Industrial Process Cooling Towers
IRP	Installation Restoration Program
LEL	Lower Explosive Limit
LNB	Low NO_X Burner
LPG	Liquefied Petroleum Gas
MSW	Municipal Solid Waste
NC	Nameplate Capacity
NDI	Non-destructive Inspection
NMHC	Non-Methane Hydrocarbons
NMOC	Non-Methane Organic Compounds
NMTOC	Non-Methane Total Organic Compounds
NSPS	New Source Performance Standards
NSR	New Source Review
OBOD	Open Burning/Open Detonation
OCA	Off-Site Consequences Analysis
ODC	Ozone Depleting Chemicals
ODP	Ozone Depletion Potential
P2	Pollution Prevention
PM	Particulate Matter – Aerodynamic diameter unspecified
PM_{10}	Particulate Matter – Aerodynamic diameter < 10 micrometers
$PM_{2.5}$	Particulate Matter – Aerodynamic diameter < 2.5 micrometers
POL	Petroleum, Oil, and Lubricant
POTW	Publicly Owned Treatment Works
PSD	Prevention of Significant Deterioration
PTE	Potential-To-Emit
RMP	Risk Management Plan
SCC	Source Classification Code
SDS	Safety Data Sheets
SCR	Selective Catalytic Reduction
SF	Spillage Factor
SI	Spark Ignition
SME	Subject Matter Expert

SNCR	Selective Non-Catalytic Reduction
TCLP	Toxicity Characteristics Leaching Procedure
TDS	Total Dissolved Solids
THC	Total Hydrocarbons
TNMOC	Total Non-Methane Organic Compounds
TOC	Total Organic Compounds
TOG	Total Organic Gas
TRI	Toxic Release Inventory
ULSD	Ultra Low Sulfur Diesel
U.S.	United States
USDA	United States Department of Agriculture
VMT	Vehicle Miles Traveled
VOC	Volatile Organic Compound

ABBREVIATIONS

(Shortened form of a word or phrase)

µg	Microgram(s)
A-hr	Ampere-hours
A/ft^2	Ampere per square foot
Btu	British Thermal Unit
ºC	Degrees Celsius
CH_4	Methane
CO	Carbon Monoxide
CO_2	Carbon Dioxide
Co	Cobalt
Cr	Chromium
Cr^{+6}	Hexavalent Chromium
Cr_2O_3	Chromium Oxide
EtO	Ethylene Oxide
ºF	Degrees Fahrenheit
ft	Foot (Feet)
g	Grams
g/L	Grams per Liter
gal	Gallon(s)
hp	Horse Power
hr	Hour(s)
kg	Kilogram
L	Liter
lb	Pound(s)
Mg	Megagram(s) [i.e., metric ton]
mg	Milligram(s)
MMBtu	Million British Thermal Units
Mn	Manganese
NH_3	Ammonia
Ni	Nickel
N_2O	Nitrous Oxide
NO_2	Nitrogen Dioxide
NO_X	Nitrogen Oxides
O_3	Ozone
PERC	Perchloroethylene
PFC	Perfluorocarbon
Pb	Lead
ppm	Parts per Million

ppmv	Parts per Million by Volume
ppmwt	Parts per Million by Weight
psi	Pounds per Square Inch
psia	Pounds per Square Inch Absolute
ºR	Degrees Rankin
scf	Standard Cubic Foot
SF_6	Sulfur Hexafluoride
SO_2	Sulfur Dioxide
SO_X	Sulfur Oxides
TNT	Trinitrotoluene
tpy	Tons per Year
UV	Ultraviolet
yr	Year(s)

1 INTRODUCTION

1.1 Background and Purpose

As awareness of the health hazards posed by air pollution increased, the need for further research and regulation gave rise to the Clean Air Act (CAA). The CAA, with its subsequent amendments, and other federal, state, and local programs, has expanded the requirements to quantify and report the amount of air pollutant emissions released into the atmosphere. These rules require compliance assurance and self-reporting so that facility managers will always know if their facility operates in accordance with air regulations.

The quantification of air pollutant emissions from a typical United States Air Force (USAF) base is accomplished by conducting an **Air Emissions Inventory (AEI)**. An AEI must be periodically updated as required by federal, state, and local regulations and each installation must record the collected data and calculations in the **Air Program Information Management System (APIMS)**. If there is not a periodic emission inventory requirement, APIMS must be updated no less than every three years to accurately reflect the current emissions. Installations located in a foreign territory must also abide by the requirements of the host government.

This Guide was prepared by the Air Force Civil Engineer Center (AFCEC) as a means of providing a uniform approach to estimating pollutant emissions from the most common types of **stationary sources** found at USAF installations. Provided in the following chapters are recommended methodologies for calculating **actual** pollutant emissions from these sources. Included in this Guide are most air emission sources that might be found on a USAF installation. Also included are brief discussions regarding emissions sources which have historically been regarded as stationary, but have since been deemed as either: **mobile**, **transitory**, or **insignificant**.

Any questions concerning this Guide, calculation methodologies for sources not provided here, or requests for additional information pertaining to USAF AEIs, should be directed to the Air Quality Subject Matter Expert; AFCEC, Compliance Technical Support Branch; 250 Donald Goodrich Drive; Building #1650 San Antonio, TX 78226.

1.2 Stationary, Mobile, and Transitory Sources

Emission sources may be regarded as mobile, stationary, or transitory. It is imperative that, when performing an air emissions inventory, every emissions source is correctly categorized because of the potential ramifications of determining if a facility is a "**major source**" (defined in a subsequent section – 1.5.3.3 Title V - Permits) of air pollutants. This Guide is concerned only with emissions from stationary sources likely to be found at an USAF base. For emissions calculation methodologies pertaining to mobile or transitory sources, refer to the latest versions of the *Air Emissions Guide for Air Force Mobile Sources* or *Air Emissions Guide for Air Force Transitory Sources*.

A stationary source is any building, structure, piece of equipment, facility, or installation that emits or may emit an air pollutant subject to regulation by the CAA. According to the Code of Federal Regulations (CFR), a “Building, structure, facility, or installation means all pollutant-emitting activities that belong to the same industrial grouping, are located on one or more contiguous or adjacent properties, and are under the control of the same person (or persons under common control) except the activities of any vessel” (40 CFR 51.165). Regarding air permits, “stationary source” typically refers to the collection of all emission units within a contiguous area under common control (e.g., fence line to fence line on a typical base).

A mobile source is any non-stationary equipment which may emit an air pollutant subject to regulation by the CAA. Mobile sources include a variety of vehicles, engines, and equipment. Mobile vehicle sources may be designated as either “on-road” or “non-road”. They are further subdivided based on engine size, vehicle weight, equipment type, and/or horsepower (hp). On-road vehicles include automobiles used for the transport of passengers or freight. Non-road sources include a multitude of equipment used for construction, agriculture, recreation, and many other purposes. It should be noted that certain districts may classify non-road engines as a stationary source, therefore, it is important to consult with the local air quality district for clarification as needed.

Transitory sources are non-routine and/or seasonal sources (may be stationary or mobile) that are short-term in nature. Historically, transitory sources have been erroneously included as stationary or mobile sources in AEIs. Transitory source emissions generally should only be accounted for when evaluating potential air quality impacts of proposed actions under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), National Environmental Policy Act (NEPA), General Conformity, and other federal regulations.

Non-routine – Non-routine sources are irregular, non-continuous, and/or infrequent sources of emissions. Air quality concerns for non-routine sources are generally addressed as Applicable or Relevant and Appropriate Requirements (ARARs) under other environmental laws (e.g., CERCLA for all sources associated with site restoration/remediation). Examples of non-routine sources typically associated with USAF installations include: bulk storage tank cleaning, fuel spills, prescribed burning, wild fires, and all sources associated with site restoration/remediation.

Non-routine sources should only be considered stationary sources if they are fixed at one location for one (1) year or greater, operational/occurring on a repetitive basis, and declared stationary by an applicable regulatory authority.

Seasonal - Seasonal sources are portable or semi-portable sources that are set up at a site for a specific temporary purpose before being re-located and used at another site. Seasonal sources typically associated with USAF installations include: seasonal equipment, hot mix asphalt plants, and all sources associated with construction.

Seasonal sources should only be considered stationary sources if they are fixed at one location on a permanent basis for at least two (2) years and operated at that single location for three (3) or more months each year.

This guide addresses stationary emissions sources typically found on USAF installations. Sources of emissions may be further subdivided as either being:

- **Point Sources** – not naturally occurring, discrete sources of emissions which emit through a stack, chimney, vent, or other functionally equivalent opening. Examples include stationary engines, boilers, and paint booths.
- **Area (Fugitive/Non-Point) Sources** – not naturally occurring sources of emissions which could not reasonably pass through a stack, chimney, vent or other functionally equivalent opening. Examples include open burns, firefighter training, and pesticide application.
- **Biogenic Sources** – naturally occurring sources of emissions. Examples include emissions from soil and vegetation, lightning, and volcanic emissions.

The term "area source" may be confusing since the definition of this term varies by pollutant group and regulation, such as criteria pollutants versus Hazardous Air Pollutants (HAPs). To reduce confusion, the term "fugitive source" is used throughout this guide to describe area/non-point sources of emissions. Since only point and fugitive source emissions are applicable to USAF installations because of their direct bearing on the determination of major source status, biogenic sources are not addressed within this Guide.

1.3 Actual vs. Potential to Emit (PTE)

This Guide describes calculation methodologies to determine "actual emissions." This does not imply that the emissions values were specifically measured and can be accurately quantified. Rather, actual emissions refer to emissions based on actual, measurable operational parameters such as 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 as annual or semi-annual demonstrations of compliance and emissions fee determination for holders of a Title V Permit.

A source's Potential to Emit (PTE) is a theoretical calculation used to determine if a source is a major or minor source for criteria pollutants, or a major or area source for HAPs. According to 40 CFR 70.2, PTE is the annual maximum capacity of a **stationary** source to emit under its physical and operational design. Additionally, 40 CFR 70.2 also states that any **physical or operational limitation** on the source to emit an air pollutant shall be treated as part of its design **if the limitation is enforceable by the EPA.** Physical or operational limitations may include air pollution control equipment, restrictions on hours of operation, or restrictions on the type or amount of material combusted, stored, or processed. While avoiding major source status can save a facility manpower costs, equipment modifications, and fees, PTEs sometimes contain overly conservative (and often unrealistic) calculation methods. This will result in greatly inflated PTE estimates and an exaggerated major source classification.

1.4 Pollutants

The primary pollutants addressed in this Guide include: criteria pollutants, HAPs, Ozone Depleting Chemicals (ODCs), and Greenhouse Gases (GHGs). Depending on available data, several sections within this Guide describe the calculation of individual or *speciated* HAPs, which may be used for determining if the facility is a major source for HAPs. A description of each pollutant class is addressed below.

1.4.1 Criteria Pollutants

In 1971, the United States Environmental Protection Agency (EPA) established National Ambient Air Quality Standards (NAAQS) for six pollutants, collectively called criteria pollutants. The EPA designates these six pollutants as "criteria" air pollutants because it regulates them by developing human health-based and/or environmentally-based criteria for setting permissible levels. These criteria pollutants are:

Particle Pollution - often referred to as Particulate Matter (PM)*:*

- PM includes the very fine dust, soot, smoke, and droplets formed from chemical reactions and incomplete burning of fuels.
- The fine particles of PM can get deep into the lungs, causing increased respiratory illnesses and tens of thousands of deaths each year.
- PM is defined as any particle with an equivalent diameter of less than or equal to 10 microns (**PM_{10}**) and is further subdivided to include a separate standard for particles with an equivalent aerodynamic diameter of less than or equal to 2.5 microns (**$PM_{2.5}$**).

Ground-Level Ozone (O_3):

- O_3 is a primary component of smog that causes human health problems and damage to forests and agricultural crops.
- Repeated exposure to O_3 can make people more susceptible to respiratory infections and lung inflammation.
- Though there is a NAAQS, **O_3 is not emitted directly into the air.**
- Two types of compounds that are the main ingredients (precursors) in forming ground-level O_3 in the presence of ultraviolet (UV) light include:
  - **Volatile Organic Compounds (VOCs):** Defined as “any compound of carbon, excluding carbon monoxide (CO), carbon dioxide (CO_2), carbonic acid, metallic carbides or carbonates, and ammonium carbonate, which participates in atmospheric photochemical reactions” (40 CFR 51.100). Sources include gas and diesel-fueled automobiles, petroleum refineries, chemical manufacturing plants, industrial plants, solvents used in paints, and an assortment of consumer and business products containing VOC.
  - **Nitrogen oxides (NO_X):** Provides the reddish-brown tint in smog. These are produced from the burning of gasoline, coal, or oil.

Carbon Monoxide (CO):

- CO is produced when fossil fuel burns incompletely because of insufficient oxygen (O_2).
- Wood, coal, and charcoal fires and gasoline engines always produce CO.
- In the United States, particularly in urban areas, most CO air emissions are from mobile sources.
- CO can cause harmful health effects by reducing O_2 delivery to the body's organs (like the heart and brain) and tissues.

Sulfur Dioxide (SO_2):

- A group of highly reactive gases known as “oxides of sulfur”, of which SO_2 is the most common component and therefore recorded as SO_X emissions.
- SO_2 in the ambient air is just one of several oxides of sulfur that contribute to air quality issues.
- SO_2 emissions are produced from fossil fuel combustion at power plants (73 percent) and other industrial facilities (20 percent).
- SO_2 is linked to several adverse effects on the respiratory system.

Nitrogen Dioxide (NO_2):

- NO_2 is a subgroup of nitrogen oxides, and is the most environmentally concerning component. It also acts as an indicator for the presence of the larger group of NO_X.
- NO_X is the precursor of NO_2 and is, therefore, recorded as NOx emissions.
- NO_2 forms quickly from vehicle, power plant, and off-road equipment emissions.
- NO_2 contributes to the formation of ground-level O_3 and fine particle pollution.
- NO_2 is linked to several adverse effects on the respiratory system.

Lead (Pb):

- Pb is a metal found naturally in the environment as well as in manufactured products.
- Prior to 1980, the major sources of Pb were on-road vehicles. As a result, the EPA removed Pb from motor vehicle gasoline, resulting in a 95% decline in Pb emissions between 1980 and 1999.
- Today, the major sources of Pb are ore and metals processing (e.g. lead smelters).
- Depending on the level of exposure, Pb can adversely affect the nervous system, kidney function, immune system, reproductive and developmental systems and the cardiovascular system.

Note that lead is both a criteria pollutant and HAP, and an Emission Factor (EF) is commonly provided in both the criteria pollutant and speciated HAPs tables within this Guide. Care should be taken to avoid the overestimation of this pollutant caused by duplicating emissions estimates using the same Pb EFs from the criteria pollutant and speciated HAPs tables provided. For a current list of the NAAQS for the criteria pollutants, refer to 40 CFR 50.

Also, note that O_3 is not directly emitted into the air, but is created through photochemical reactions involving NO_X and VOCs, and PM may be the result of the release of primary pollutants or the formation of secondary pollutants. Therefore, this Guide provides EFs for a list of criteria pollutants which differ slightly from those regulated by the NAAQS. The list of "criteria pollutants" for emissions inventory purposes are reported as those shown below:

- CO
- NO_X
- PM_{10}
- $PM_{2.5}$
- SO_X
- VOCs
- Pb

1.4.2 Hazardous Air Pollutants (HAPs)

According to the 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.” Section 112(b) of the CAA provided an initial list of HAPs including specific chemical compounds and compound classes. The EPA is charged with the periodic review and revision of this list and has established procedures for both “listing” and “delisting” compounds. A total of 189 compounds were on the original HAP list, though four compounds have since been removed: Hydrogen Sulfide in December 1991, Caprolactam in June 1996 (61FR30816), Ethylene Glycol Monobutyl Ether (EGBE) in November 2004 (69FR69320), and Methyl Ethyl Ketone (MEK) in December 2005 (70FR75047). The most current list of HAPs available at the time of this writing is provided at the end of this Guide, in APPENDIX A - EPA HAP List.

1.4.3 Ozone Depleting Chemicals (ODC)

The ozone layer is responsible for absorbing much of the sun’s UV radiation. In the last few decades, the concern over the depletion of the ozone layer prompted an international treaty known as the Montreal Protocol. The Montreal Protocol banned the production of a class of compounds known as chlorofluorocarbons (CFCs), which are known to contribute to the depletion of the ozone layer. These compounds are known as Ozone Depleting Chemicals (ODCs). ODCs are assigned an Ozone Depletion Potential (ODP) which is a measure of the compound’s ability to degrade the ozone layer. Class I substances are those ODCs that have an ODP of 0.2 or higher and include CFCs, halons, carbon tetrachloride, methyl chloroform, methyl bromide, and hydrobromofluorocarbons (HBFCs). All hydrochlorofluorocarbons (HCFCs) are class II substances and have an ODP of less than 0.2. Appendix A and Appendix B of 40 CFR 82 lists the class I and class II ODCs, respectively. Despite their regulation, ODCs may still be found in, or used for, 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).

1.4.4 Greenhouse Gases (GHG)

Global climate change is becoming one of the most important issues of the 21st century. Some GHGs, such as CO_2, are emitted to the atmosphere through both naturally occurring processes and human activities. Other GHGs (e.g., fluorinated gases) are created and emitted solely through human activities. The principal GHGs emitted to the atmosphere through human actions are CO_2, methane (CH_4), nitrous oxide (N_2O), and fluorinated gases.

CO_2 is the primary GHG emitted through human activity, accounting for 82 percent of all GHG emissions from human actions in the United States. CO_2 enters the atmosphere primarily through the burning of fossil fuels and industrial processes. CO_2 is also removed from the atmosphere (or "sequestered") when it is absorbed by plants as part of the biological carbon cycle. CH_4 is emitted during the production and transport of coal, natural gas, and oil. CH_4 emissions also result from livestock and other agricultural practices and by the decay of organic waste in municipal solid waste landfills. N_2O is emitted during agricultural and industrial processes, as well as during combustion of fossil fuels and solid waste.

GHGs are assigned a Global Warming Potential (GWP), which is a measure of how much heat the gas traps in the atmosphere calculated over a specific time interval, typically 100 years. The higher the GWP, the greater the potential for the gas to trap heat, and the more harmful the gas is regarded. CO_2 is used as the baseline gas and assigned a GWP of 1. Emissions of GHGs may be converted into CO_2 equivalent (CO_2e) by taking the product of each GHG EF and its respective GWP. Table A-1 of 40 CFR 98 provides the GWPs for several GHGs. The GWP values given throughout this Guide are subject to change in the upcoming years due to new data becoming available, but are considered current as of June 6, 2016. The total GHG emissions are calculated by summing all emissions from each gas and is generally derived from the following equation:

$$EF_{GHG} = \sum_{i=1}^{n} (EF_i \times GWP_i)$$

Equation 1-1

Where,

EF_{GHG} = Greenhouse gas emission factor expressed as CO_2 equivalent (CO_2e)
EF_i = Emission factor for greenhouse gas species i
GWP_i = Global warming potential for greenhouse gas species i

1.5 Air Emission Inventories (AEI)

An AEI is a compilation of the air pollutant emissions in an area over a given period of time, typically one year. Some local agencies may have specific data reporting requirements or protocols which the installation must adhere to when conducting the AEI.

The law requires accurate records of sources of air pollutants to be maintained. 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. The regulatory requirements for conducting an AEI are listed in the following subsections.

1.5.1 Air Emissions Reporting Requirements Rule (AERR)

The Air Emissions Reporting Requirements (AERR) rule was developed to simplify the emissions reporting required of every state. This rule was created to update the reporting requirements as originally stipulated in the Consolidated Emissions Reporting Requirements (CERR) rule, which has been in place since 2002. The AERR rule provided in 40 CFR 51 Subpart A, states that emissions are to be reported 12 months from the end of the inventory year and biogenic emissions are no longer required to be estimated. In addition to the criteria pollutants, states must also report emissions of lead compounds and ammonia (NH_3), but not HAPs or GHGs, though reporting these emissions is encouraged.

1.5.2 Air Force Instruction (AFI) 32-7040 update

Air Force Instruction (AFI) 32-7040 states that installations shall:

> "Air Quality Compliance and Resource Management states the following in Air Force Instruction (AFI) 32-7040: "The CEIE must prepare and periodically update an AEI, using APIMS, of all installation stationary sources (stationary source AEI) and Air Force owned or operated mobile sources (mobile source AEI) IAW the current Air Force air emissions inventory guidance and applicable state or local requirements promulgated per 40 CFR Part 51 Subpart A, Air Emissions Reporting Requirements."
>
> "Comprehensive AEIs (i.e., includes both permitted and non-permitted sources) are performed at the frequency as required by federal, state and local regulations. Overseas installations conduct AEIs IAW Foreign Governing Standards and/or Host Nation agreements. At a minimum, the CEIE, will annually review/validate APIMS as current (i.e., sources and consumption data is representative of the current base conditions) and update (i.e., a comprehensive review of all sources and their consumption data) at least every three years (five years for overseas and remotely located facilities) to accurately reflect current emissions."
>
> "Stationary source AEIs include all criteria pollutants, HAPs, and GHGs and reflect the installation's current actual and PTE emissions. Annual regulatory emissions reports,
> a subset of the comprehensive AEI, are provided to federal, state and local (including Metropolitan Planning Organization or other regional) regulatory agencies as required. Mandatory pollutant emissions reporting is provided to AFCEC/CZ as part of the annual
> data call. GHG reporting mandated by E.O. 13693, is accomplished at the HAF level."
>
> "Affected installations that exceed the GHG reporting threshold shall accomplish GHG reporting mandated by Title 40 CFR Part 98, Mandatory Reporting of Greenhouse Gases. Other installations within 10% of the GHG reporting

threshold shall accomplish GHG estimates IAW Title 40 CFR Part 98 and only report the results to AFCEC/CZ via APIMS. Installation AEI data stored in APIMS are available for use as needed by AFCEC and higher headquarters." (4 November 2014, Certified Current 14 October 2016)

1.5.3 Clean Air Act (CAA)

The CAA was enacted to control air pollution by outlining the EPA's responsibility to develop and enforce regulations protecting the public from harmful air contaminants. The CAA identifies two types of air quality standards and designates these as primary and secondary standards. Primary standards are those that protect the public health and include "sensitive" population groups such as the young, the elderly, and asthmatics. Secondary standards are those that protect the public welfare and include protection against decreased visibility and damage to animals, crops, vegetation, or even buildings. Areas which meet the primary and secondary NAAQs for a pollutant are classified as being in *attainment* for that pollutant. Areas that do not meet the NAAQS are classified as *nonattainment* for that pollutant. An area historically classified as nonattainment, which later consistently meets the NAAQS, and any additional requirements, will be re-designated as a *maintenance* area.

1.5.3.1 Title I - Air Pollution Prevention and Control

The CAA requires states to develop State Implementation Plans (SIPs) for attaining and maintaining the NAAQS. Per Title I of the CAAA-90 (Clean Air Act Amendments), 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(c)(3) 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 that are in nonattainment for that pollutant.
- Section 182(a)(1) of the CAA requires each state to submit a current inventory of actual VOC and NO_X emissions (from sources in areas that are in nonattainment for O_3) and of actual CO emissions (from sources in areas that are in nonattainment for CO). After 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 O_3 nonattainment areas to report their actual VOC and NO_X emissions to the state annually. States may waive this requirement for sources that emit less than 25 tons per year (tpy) of VOC or NO_X.

1.5.3.2 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 (NESHAP) to regulate certain source categories that 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, and each regulation contains specific monitoring, recordkeeping, and reporting requirements. Also, some NESHAPs only apply to sources considered a major source for HAPs. **A major source for HAPs is defined as any stationary source or group of stationary sources located within a contiguous area and under common control that emits or has a PTE of 10 or more tpy of any single HAP or 25 or more tpy of any combination of HAPs.** For a source (e.g., military installation) to determine if it is a major source for HAPs, an inventory of HAP emissions must be performed.

It is important to note that fugitive emissions **must** be included when determining if a source is a major source for HAPs. Additionally, a May 16, 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, the facility must always comply with that NESHAP. This is required even if it later becomes a non-major source (area source) for HAPs. This is known as the "Once In, Always In" policy.

On August 14, 2000, the EPA issued a memorandum, "Subject: Guidance on the Major Source Determination for Certain HAPs" (Seitz 2000). The memo was meant to provide guidance on applying the major source threshold for compounds, salts and esters, and/or "plurals" (e.g. xylene isomers). It was unclear, at the time, if the 10 tpy threshold should apply to each chemical or to the aggregate group of HAPs. This memo directs facilities to consider polycyclic organic matter, 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. In other words, the **total emissions of the chemicals in these aggregate groups** must be less than 10 tpy or the source will be considered major for HAPs.

1.5.3.3 Title V - Permits

Under Title V of the CAAA-90, all stationary sources classified as a "major source" are required to obtain a Title V operating permit. A major source under Title V includes any stationary source or group of stationary sources within a contiguous area and under common control that emits or has the PTE:

- 10 tpy or more of any HAP **or** 25 tpy or more of any combination of HAPs.
- 100 tpy or more of any air pollutant subject to regulation. For some of the criteria pollutants, lower thresholds exist for certain nonattainment areas. These lower thresholds include the following:
    - 50 tpy of VOC and NO_X emissions in “serious” O_3 nonattainment areas and in O_3 transport regions.
    - 25 tpy of VOC and NO_X emissions in “severe” O_3 nonattainment areas.
    - 10 tpy of VOC and NO_X emissions in “extreme” O_3 nonattainment areas.
    - 50 tpy of CO emissions in “serious” CO nonattainment areas.
    - 70 tpy of PM_{10} emissions in “serious” PM_{10} nonattainment areas.

To determine if a USAF base is a major source under the provisions of Title V, an emissions inventory (of actual and potential emissions) must be completed. 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 source categories listed in 40 CFR 51.166.

1.5.3.4 New Source Review (NSR)

The New Source Review (NSR) permitting program was established as part of the 1977 CAA amendments to ensure that air quality is not significantly degraded because of new construction or modifications at existing facilities. The NSR permits establish how a source is to be operated, its emissions limits, and what construction is allowed for the modification of that source. NSR requires stationary sources of air pollution to obtain permits prior to construction. There are three types of NSR permitting requirements: Prevention of Significant Deterioration (PSD) permits, Nonattainment NSR permits, and minor source permits.

PSD permits are required for new major sources or major modifications at existing sources for pollution located in attainment areas. The PSD program requires that any new construction or modification must use the Best Available Control Technology (BACT) and perform air quality and environmental impact analysis. There are 28 source categories given in 40 CFR 51.166 which, if they emit 100 tpy, **including fugitive emissions**, are regarded as PSD major sources. Sources that do not fall into one of the 28 categories are regarded as PSD major sources if they emit 250 tpy, **excluding fugitive emissions**. Typically, there are only two sources that fall into one of these categories that may potentially be found on a USAF installation. These sources are fossil fuel boilers greater than 250 Million British Thermal Units per hour (MMBtu/hr) heat input and petroleum storage units with a capacity exceeding 300,000 barrels. The local air pollution control agency may provide additional information regarding the PSD permit application process, required for PSD major sources, as well as the typical length of time it takes before a permit is issued.

Nonattainment NSR permits are required for new major sources or major modifications at existing sources for pollution located in nonattainment areas. All nonattainment NSR programs require the installation of the Lowest Achievable Emission Rate (LAER). LAER is determined either by taking the most stringent emission limitation contained in a SIP for the category source or the most stringent emission limit achieved in practice by such class or category of source, whichever is more constraining. Additionally, since the construction is to take place in a nonattainment area, part of the nonattainment NSR program requires some form of emission offsets. These offsets are reductions in emissions from existing sources near the proposed construction that are greater than the emissions increase from the new source to provide a net air quality benefit.

Minor NSR permits are required for new construction that does not require PSD or nonattainment NSR permits. These permits contain requirements limiting the emissions to avoid PSD and nonattainment NSR, and to prevent the new construction from violating the control strategy in a nonattainment area.

1.5.3.5 General Conformity

Section 176(c) of the CAA prohibits federal activities from taking various actions in nonattainment or maintenance areas unless they first demonstrate conformance with their respective SIP. "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**" (40 CFR 93.150(b)). 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** first establishes if a full-scale conformity determination is required and, if it is, a **conformity determination** assesses whether the action conforms to the SIP. The general conformity program requires all federal actions in nonattainment and maintenance areas to comply with the appropriate SIP. An AEI is usually required as part of the conformity determination to identify/quantify air emissions from the proposed federal actions.

Note that the conformity process is separate from the National Environmental Policy Act (NEPA) analysis process, though the two may be integrated. There are certain requirements for NEPA that are not required under conformity. For example, NEPA requires the development of reasonable alternative actions, whereas conformity only requires analysis of the proposed action.

1.5.4 National Environmental Policy Act (NEPA)

NEPA requires federal agencies to evaluate the environmental impacts associated with proposed actions that they either fund, support, permit, or implement. There are three levels of analysis:

- **Categorical Exclusion Determination** – A proposed action may be categorically excluded from a detailed environmental analysis if the action meets certain criteria that a previous agency has determined to have no significant environmental impact.
- **Environmental Assessment (EA)** – A proposed action not categorically excluded must be evaluated to determine if undertaking would significantly affect the environment. If there is no impact, the agency issues a Finding of No Significant Impact (FONSI). If the EA concludes the action results in a significant environmental impact, an Environmental Impact Statement (EIS) must be prepared.
- **Environmental Impact Statement (EIS)** – An EIS is a detailed evaluation of the proposed action and its alternatives. A draft EIS is filed with the EPA who publishes a "Notice of Availability" in the Federal Register. Publication of the "Notice of Availability" begins a 45-day public comment period and mandatory 30 day waiting period before the agency can decide on the proposed action.

1.5.4.1 Environmental Impact Analysis Process (EIAP)

The Environmental Impact Analysis Process (EIAP) is the Air Force's tool for implementing procedures for environmental impact analysis within the United States and abroad. Within the United States, EIAP maintains compliance with NEPA and the Council on Environmental Quality (CEQ) Regulations for Implementing the Procedural Provisions of the NEPA (40 CFR Parts 1500 through 1508). USAF environmental impact analyses of actions outside the United States are to be in accordance with Executive Order 12114, Environmental Effects Abroad of Major Federal Actions and 32 CFR 187, Environmental Effects Abroad of Major Department of Defense Actions.

1.5.5 State/Local Programs

Some state and local regulatory agencies have unique programs that require an 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 that may pose chronic or acute health threats when present in the air. The "Hot Spots" Act requires applicable facilities to prepare and submit an Emissions Inventory Plan (EIP) to indicate how air toxic emissions will be measured or calculated. After the EIP is approved by the state or local regulatory agency, the facility is required to prepare and submit an Emissions Inventory Report quantifying the air toxic emissions.

1.5.6 Other Inventory Uses

An AEI can be a useful tool in helping industrial facilities to implement various environmental programs. The most common of these programs are discussed in the following sections of this Guide.

1.5.6.1 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, and the amount of pollutant emissions from each source. 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.

1.5.6.2 Risk Assessments

Section 112(r) of the CAA outlines the requirements for a Risk Management Plan (RMP) that covers the accidental release prevention requirements. The rule regulates 77 toxic and 63 flammable substances that 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 is to inform local communities of processes in their area that have the potential to present a catastrophic hazard release, and to require responsible parties (i.e. the respective USAF base) to develop a RMP.

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 RMP. The EPA and federal law enforcement agencies have become concerned that OCA descriptions in executive summaries may pose a security risk, so the 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.

1.5.6.3 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 that may be used to create surplus emissions. These surplus emissions may be traded within a source (e.g. within a facility, plant, or installation) or between different sources to meet applicable air pollution control requirements. Though most states have emissions trading programs, programs vary from state to state, as well as regionally or locally. For a facility to trade emissions, the emissions from its processes must be quantified. This information may be obtained from AEIs.

1.6 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 exceed threshold levels, the entire group is treated as a single major source. On August 2, 1996, the EPA published a memorandum, “Subject: Major Source

Determinations for Military Installations under the Air Toxics, New Source Review, and Title V Operating Permit Programs of the Clean Air Act (Act)" (Seitz 1996). This memo established several policies regarding major source determination at military installations. The following sections of this Guide provide a summary of these policies.

1.6.1 Common Control Determinations

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

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

For example, if a National Guard unit was located at an USAF base, the emissions associated with the National Guard activities would not be counted towards the USAF installation's emissions when making a major source determination for that USAF base. The National Guard unit would be required to perform a major source determination based on emissions from National Guard activities.

Additionally, 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. 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 non-military 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, a USAF 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 USAF aircraft). This hangar can therefore be considered 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 manages 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, these activities must be included in the major source determination.

1.6.2 Industrial Grouping and Support Facility Determinations

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, that 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, the EPA has determined that this procedure is inappropriate for major source determinations at some military installations. The recommended 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". Second, each activity is assigned the 2-digit SIC code that best describes it. SIC code 97 should be used if no other appropriate SIC code exists. Next, activities with the same 2-digit SIC code 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 making a major source determination, each support activity is part of the same source as the primary activity it supports.

Military installations include numerous emission sources such as 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. Though these sources may be located on military installations and used by on-base military personnel, they often are not essential activities related to the primary military activity of the base. Therefore, the EPA believes these types of activities may **not** be considered required support facilities. 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 USAF installations have been successful in "disaggregating" their AAFES gasoline stations, resulting in a change to their major source status.

1.7 Authoritative Algorithms and Emission Factors (EFs)

An EF 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 pollutant emitting activity. 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.

This Source Guide is the USAF single authoritative compilation of algorithms and EFs for stationary sources. No other algorithms or EFs shall be used unless mandated by a legally inferable regulatory requirement (e.g., permit stipulates) or approved by AFCEC/CZTQ on a case-by-case basis. Algorithms and EFs used by the USAF are generally from the *Compilation of Air Pollutant Emission Factors* (AP-42) and WebFIRE (EPA's online EF database). However, data in AP-42 is often obsolete due to equipment updates that occur more frequently than EF research and WebFIRE is known to contain errors and conflicting data. Additionally, EFs for Air Force-unique circumstances and sources have been developed by the USAF and are only available in this Source Guide. Therefore, the only algorithms and EFs authorized for use in estimating USAF emissions are those maintained within this and other official USAF source guides, unless a specific temporary exemption is approved by AFCEC/CZTQ.

APIMS is the Air Force-approved information system for air quality, which provides a standardized, integrated tool and methodology to track, manage, and report all data related to the Air Quality Program. In accordance with AFI 32-7040, APIMS is mandated for use in air quality permit management, air emission inventory, vehicle inspection & maintenance certification, and air emissions reporting. The Installation/Base Civil Engineer - Environmental Element must ensure the air quality compliance and resource management data are accurately maintained in APIMS in a timely manner.

APIMS is mandated by AFI 32-7040 for estimating USAF AEI. This Guide is the single authoritative compilation of algorithms and EFs, however, APIMS is periodically updated so that the EFs and algorithms agree with the current source guide. All algorithms and EFs within APIMS must be from within this and other official USAF source guides (unless specifically approved by AFCEC/CZTQ). Upon discovery of any unauthorized algorithms and/or EFs within APIMS, contact the APIMS Help Desk for removal or pursuing temporary authorization from AFCEC/CZTQ.

1.8 Emissions Inventory Methodologies

The purpose of this Guide is to provide a uniform approach to calculating AEIs. This effort is due to the common errors found in emissions inventories such as missing or duplicate facilities, missing operating or technical data, data entry and transcription errors, incorrect Safety Data Sheets (SDS), and calculation errors. Care should be made to reduce errors and improve the quality of the data. When conducting an AEI, several methods can be used to quantify air pollutants from emission sources. The methods listed below start at the most expensive and most reliable method for estimating emissions and progresses to the least expensive, least reliable method:

- Emissions monitoring/sampling (e.g., continuous emissions monitoring or stack sampling)
- Mass balances
- Source category emissions model
- State/industry factors
- Emission factors
- Engineering estimates

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

Many EFs found in this Guide were taken from AP-42 where they were assigned a data quality rating from "A" through "E," with "A" being the best quality. The factor's rating is a general indication of the reliability of that factor based on the quality of the test and how well the factor represents the emission source. Additional or alternative EFs may be available from other sources, most notably the California Air Resource Board (CARB). If an EF for a specific pollutant or process is not available, that does not mean the EPA believes the source should not be inventoried, but that there is insufficient data to provide guidance.

AFI 32-7040 states that AEIs should be prepared and updated via APIMS. The default EFs in APIMS are those found in this Guide. However, alternative EFs, such as those requested by state and local air regulators, may be used if the alternative EF is submitted and approved by AFCEC/CZTQ. The general equation for emissions estimation using an EF is:

$$\mathbf{E} = \mathbf{A} \times \mathbf{EF} \times \left(\mathbf{1} - \frac{\boldsymbol{ER}}{\mathbf{100}}\right)$$

Equation 1-2

Where,

E = Emissions of pollutant, typically on an annual basis
A = Activity rate
EF = Emission factor
ER = Overall emission reduction efficiency, if applicable (%)

The overall emission reduction efficiency is the product of the control device destruction or removal efficiency and the capture efficiency of the control system. When estimating emissions for an extended period, an average efficiency is used to account for routine operations. In some cases, a material balance approach may provide a better estimate of emissions than emission tests. In general, material balances are appropriate for use in situations where a high percentage of material is lost to the atmosphere. All the materials going into and coming out of the process must be considered to allow an emission estimation to be credible.

1.9 Guide Organization

This Guide is organized into chapters which are specifically related to facilities or processes typically found at USAF installations. Chapter topics may or may not correspond directly to source types identified in EPA, state, or local guidance documents. The intent is to consider sources usually associated with a facility, activity, or process. This Guide specifically addresses stationary sources of air emissions. Guidance for addressing mobile or transitory sources of air pollutants may be found in the latest versions of the *Air Emissions Guide for Air Force Mobile Sources* or *Air Emissions Guide for Air Force Transitory Sources* respectively.

1.10 References

32 CFR 187, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Subchapter L-Environment, Part 187-Environmental Effects Abroad of Major Department of Defense Actions," U.S. Environmental Protection Agency

40 CFR 51, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 51-Requirements for Preparation, Adoption, and Submittal of Implementation Plans," U.S. Environmental Protection Agency

40 CFR 68, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 68-Chemical Accident Prevention Provisions," U.S. Environmental Protection Agency

40 CFR 70.2, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 70.2-State Operating Permit Programs: Definitions," U.S. Environmental Protection Agency

40 CFR 82, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 82-Protection of Stratospheric Ozone," U.S. Environmental Protection Agency

40 CFR 93, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 93-Determining Conformity of Federal Actions to State or Federal Implementation Plans," U.S. Environmental Protection Agency

40 CFR 98, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 98-Mandatory Greenhouse Gas Reporting," U.S. Environmental Protection Agency

40 CFR Chapter V, “Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency Chapter 5-Council on Environmental Quality – part 1500 through 1508,” U. S. Environmental Protection Agency

AFI 2016, “Air Force Instruction (AFI) 32-7040,” Air Quality Compliance and Resource Management, October 14, 2016

CEPA 1987, “California’s Air Toxics “Hot Spots” Information and Assessment Act” Assembly Bill 2588, 1987

E.O. 1979, “Environmental Effects Abroad of Major Federal Actions,” Executive Order 12114, 4 January 1979

FR 1996, “Deletion of Caprolactam From the List of Hazardous Air Pollutants: Final Rule,” 61 FR 30816, June 1996

FR 2004, “List of Hazardous Air Pollutants, Petition Process, Lesser Quantity Designations, Source Category List; Petition To Delist of Ethylene Glycol Monobutyl Ether: Final Rule,” 69 FR 69320, November 2004

FR 2005, “List of Hazardous Air Pollutants, Petition Process, Lesser Quantity Designations, Source Category List-methyl ethyl ketone: Final Rule,” 70 FR 75047, December 2005

Seitz 1996, Seitz J. S., Memorandum titled “Major Source Determinations for Military Installations Under the Air Toxics, New Source Review, and Title V Operating Permit Programs of the Clean Air Act (Act),” U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, August 2, 1996

Seitz 2000, Seitz J. S., Memorandum titled “Guidance on the Major Source Determination for Certain Hazardous Air Pollutants,” U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, August 14, 2000

2 EXTERNAL COMBUSTION (ECOM)

- *Point Source*

2.1 Introduction

External combustion (ECOM) sources include furnaces and boilers. Furnaces heat an area by warming air while boilers utilize water and may produce enough steam to generate electricity. Larger, stationary external combustion engines are located at the base heat/power plant. Emissions from external combustion engines will vary depending on several factors including the boiler configuration, the size of the combustor, the firing configuration, the fuel type, the control devices used, and a variety of different design configurations. **External combustion units are point sources of criteria pollutants, HAPs and GHGs**. A basic control volume is graphically represented in Figure 2-1.

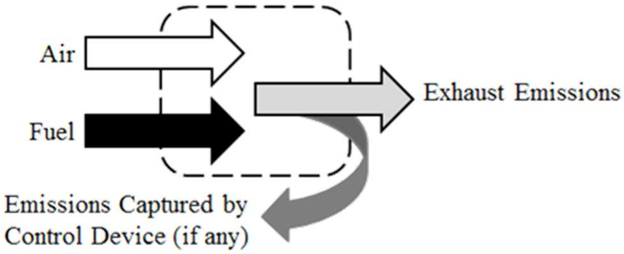

Figure 2-1. Simplified Control Volume for Emissions from External Combustion

A boiler's configuration refers to its method of heat transfer. There are four major types of heat transfer methods associated with boilers: watertube, cast iron, firetube, and tubeless. The watertube configuration is the most common among boilers and works by passing water through tubes that are externally heated. Cast iron boilers work in a similar manner, with the only difference being that the tubes are constructed of cast iron rather than steel. Firetube boilers work by passing hot exhaust gases through a tube, which transfers heat to water circulating around them. The tubeless design consists of a combustion chamber that is surrounded with a water jacket. The water is heated by the combustion of the air/fuel mixture in the combustion chamber and then again by the exhaust gases, which are vented into a shell that surrounds the water jacket.

The maximum heat input capacity of an external combustion source is a measure of that source's maximum heat value it is capable of combusting. Boilers are classified into four categories based on their size and application: Utility, Industrial, Commercial, and Residential. Utility boilers are typically the largest boilers and utilize steam for electricity generation. Utility boilers usually operate at or near maximum capacity and at a steady state. It was determined that there are no utility boilers in use at any USAF installations and they have therefore been removed from this Guide. Industrial boilers are generally not as large as utility boilers and they may be further classified as either “heavy” or “light”, depending on the heat input of the boiler. Industrial boilers can produce electricity or they may generate process steam. The process steam may be used for heat generation or the captured condensate may be used as a solvent or feedstock. Both commercial and residential boilers are considerably smaller than utility and industrial boilers and are used exclusively for comfort heat generation. The main difference between commercial and residential boiler types is that the commercial boilers are considerably larger than residential boilers since they are used to heat larger (commercial) spaces. The boiler types and their respective heat inputs are given in Table 2-1.

Table 2-1. Boiler Types and Sizes

Boiler Type	Size/Heat Input (MMBtu/hr)
Industrial – Heavy	≥100 to 250
Industrial – Light	≥10 to <100
Commercial/Institutional	≥0.3 to <10
Residential	<0.3

SOURCE: Chapter 2 - "Preferred and Alternative Methods for Estimating Air Emissions from Boilers," Point Sources, Vol. 2, U.S. Environmental Protection Agency, Emission Inventory Improvement Program, July 2001. “Industrial” subdivided into “heavy” and “light”.

2.2 New Source Performance Standards (NSPS) and NESHAP Applicability

It should be noted that while this chapter defines utility boilers, the following tables do not provide EF for utility boilers since the USAF does not have any utility boilers at any installations. Although several NSPS have been enacted for utility boilers, those will not be addressed in detail in this section. However, 40 CFR 60 Subparts Db (*Standards of Performance for Industrial-Commercial-Institutional Steam Generating Units*) and Dc (*Standards of Performance for Small Industrial-Commercial-Institutional Steam Generating Units*) stipulate the requirements for smaller external combustion units that are currently in use at USAF installations. These sections detail the PM, NO_X, and SO_X emission limits for those units with a heat input capacity greater than 100 MMBtu/hr. These values may be used to verify the accuracy of EFs which may need to be calculated based on the fuel sulfur content or ash content. Additional information regarding these emission limits and the facilities that are subject to these standards may be found in 40 CFR 60 Subparts Db and Dc.

In addition to the NSPS requirements stated above, there are several NESHAPs that have been enacted that limit the emissions of HAPs from external combustion units. 40 CFR 63 Subpart DDDDD, *National Emission Standards for Hazardous Air Pollutants for Major Sources:*

Industrial, Commercial, and Institutional Boilers and Process Heaters, describes the HAP emission limits for industrial and commercial boilers and process heaters at major sources. Similarly, 40 CFR 63 Subpart JJJJJJ, *National Emission Standards for Hazardous Air Pollutants for Industrial, Commercial, and Institutional Area Sources*, describes the HAP emission limits for external combustion units located at area sources for HAPs. A separate set of standards for coal and oil fired electric utility steam generating units are given in 40 CFR 63 Subpart UUUUU, *National Emission Standards for Hazardous Air Pollutants: Coal and Oil-Fired Electric Utility Steam Generating Units*. Each of these standards provides compliance and reporting information for HAP emissions and may be used to verify HAP emissions from ECOM units conforming to these requirements.

2.3 Mandatory GHG Reporting Rule

The EPA has established mandatory GHG reporting requirements for owners and operators of facilities that directly emit GHGs into the atmosphere. According to 40 CFR 98.2, any facility operating stationary fuel combustion sources is subject to the reporting rules outlined in 40 CFR 98 Subpart C. This applies to facilities whose aggregate maximum rated heat input capacity is 30 MMBtu/hr, and emits 25,000 metric tons of carbon dioxide equivalent (CO_2e) or more per year in combined emissions from all stationary fuel combustion sources. This rule requires that CO_2, CH_4, and N_2O mass emissions must be reported from each stationary combustion unit. Refer to 40 CFR 98 Subpart C for additional information regarding the GHG reporting requirements.

2.4 Emission Factors

EFs are a representative value that attempts to relate the quantity of a pollutant released with the activity associated with the release of that pollutant. For EFs from fuel combustion in boilers, one type of NO_X formation is designated as "thermal NO_X". Most thermal NO_X is formed in high temperatures near the burners and formation increases with increasing temperature, exposure time at peak temperature, and O_2 concentration. Boilers that employ flue gas recirculation (FGR), low NO_X burners (LNB), or staged combustors will reduce NO_X emissions. FGR works by recirculating flue gas through the burners. The recycled flue gases are cooler and composed of inert compounds. Due to their cooler temperatures, the flue gases work to lower the temperature of the flame, suppressing the formation of the thermal NO_X. Additionally, the flue gas also lowers the O_2 concentration of the combustion air, limiting the reaction of the thermal NO_X process. NO_X emissions may be reduced based on the presence of control devices or the firing configuration and practices used in the boiler. Typically, tangentially fired boilers produce less NO_X emissions than horizontally opposed units. Since the formation of thermal NO_X is O_2 and temperature dependent, using Low Excess Air (LEA), over-fire air, or reduced air preheat will also significantly reduce NO_X emissions (though NO_X reductions in LEA fired boilers are less significant). Post combustion NO_X reduction methods include Selective Non-Catalytic Reduction (SNCR) and Selective Catalytic Reduction (SCR). SNCR systems work by injecting either NH_3 or urea at a specific temperature range into the combustion flue gases. The NH_3 or urea reacts with the NO_X to form molecular nitrogen (N_2), O_2, and water. SCR is similar to SNCR in that NH_3 or urea is typically added to mix with flue gases. After mixing, the gases pass through a catalyst chamber where they come into contact with active catalytic components such as vanadium, molybdenum, or tungsten.

VOC, CO, and PM emissions are dependent on the combustion efficiency of the boiler. Improperly tuned boilers and boilers operating outside of the design parameters will decrease the combustion efficiency and result in increased VOC, CO, and PM emissions. Sometimes the addition of LNB and FGR may also reduce the combustion efficiency and result in higher CO emissions. VOC emissions may be reduced by increasing combustion temperatures or through turbulent mixing of the fuel and combustion air. PM emissions from natural gas are typically low, but will increase due to poor air/fuel mixing.

The SO_X produced from the combustion of fuel oil are primarily in the form of SO_2. SO_X emissions are almost entirely dependent on the sulfur content of the fuel combusted and are unaffected by the size of the boiler, the burner design, or the grade of fuel used. Post combustion reduction of SO_X is accomplished through Flue Gas Desulfurization (FGD). This process uses an alkaline reagent that absorbs SO_2 in the flue gas and produces a sodium or calcium sulfate compound, which is then removed. FGD systems may be classified as wet, dry, or semi-dry depending on the state of the reagent as it leaves the absorber and may reduce SO_X emissions by as much as 95 percent.

External combustion results in the formation of GHGs. The most common GHGs are CO_2, CH_4, and N_2O. A well-maintained system will convert almost all fuel carbon to CO_2. For boilers that have not been well maintained, the incomplete combustion of the fuel carbon increases the amount of VOC, CH_4, and N_2O formed. However, it is important to note that even boilers that operate with poor combustion efficiency produce considerably less N_2O and CH_4 compared to CO_2.

The following EFs are presented in a pound per mass format. Many of these may have been derived from the heating value of the fuel used. The heating values of the fuels used are provided in Table 2-2. **Note that in the following sections, the tables do not provide EFs for those boilers classified as "residential". If calculating emissions from residential boilers is required, use those EFs for boilers smaller than 10 MMBtu/hr**.

Table 2-2. Typical Fuel Heating Values

Fuel Type	High Heating Value
Compressed Natural Gas (CNG)	1.03E-03 MMBtu/ft^3
Fuel Oil - No. 6	1.50E-01 MMBtu/gal
Fuel Oil - No. 5	1.40E-01 MMBtu/gal
Fuel Oil - No. 4	1.46E-01 MMBtu/gal
Fuel Oil - No. 1	1.39E-01 MMBtu/gal
Fuel Oil - No. 2/Distillate/Diesel	1.38E-01 MMBtu/gal
Coal - Bituminous	24.93 MMBtu/ton
Coal - Subbituminous	17.25 MMBtu/ton
Coal - Anthracite	25.09 MMBtu/ton
Coal - Lignite	14.21 MMBtu/ton
Liquefied Petroleum Gas (LPG)	9.20E-02 MMBtu/gal
Waste Oil	1.38E-01 MMBtu/gal
Landfill Gas	4.85E-04 MMBtu/ft^3
Digester Gas(a)	6.55E-04 MMBtu/ft^3

SOURCE: "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 98-Mandatory Greenhouse Gas Reporting, Subpart C-General Stationary Fuel Combustion Sources," U.S. Environmental Protection Agency.

a) High heat value for this fuel type assumed to be the same as “Other Biomass Gases” provided in source document.

2.4.1 Natural Gas

Natural gas is used mainly for industrial process, steam and heat production, residential and commercial space heating, and electric power generation. Natural gas is composed of a high percentage of CH_4 with varying amounts of ethane, propane, butane, and inert gases such as nitrogen, CO_2 and helium. In commercial, industrial, and utility natural gas applications, the three major types of boilers are watertube, firetube, and cast iron. For utility and large industrial boilers, the watertube design is the most common and those boilers with heat input levels greater than 100 MMBtu/hr are generally field erected. Field erected units may be either wall-fired or tangential-fired and usually have multiple burners with several NO_X control options. Wall-fired units have multiple individual burners located on a single wall while tangential-fired units have several rows of air and fuel nozzles located in each of the four corners of the boiler. Package units are constructed off site and are generally smaller than field erected units due to shipping constraints. These units typically have heat input levels less than 100 MMBtu/hr, are always wall-fired with one or more individual burners, and are limited in the NO_X control options. Criteria pollutant EFs for natural gas-fired ECOM units are provided in Table 2-3.

Table 2-3. Criteria Pollutant Emission Factors for Natural Gas-Fired ECOM Units

Firing Configuration [SCC]	Control Type[(a)]	Emission Factors (lb/10^6ft^3)						
		NO_X	CO	SO_X	Pb	VOC	PM_{10}[(b)]	$PM_{2.5}$[(b)]
>100MMBtu Wall-Fired [1-01-006-01, 1-02-006-01, and 1-03-006-01]								
Pre-NSPS[(c)]	Uncontrolled	280	84	0.6	5.00E-04	5.5	7.6	7.6
Post-NSPS[(c)]	Uncontrolled	190	84	0.6	5.00E-04	5.5	7.6	7.6
Wall-Fired	LNB	140	84	0.6	5.00E-04	5.5	7.6	7.6
Wall-Fired	FGR	100	84	0.6	5.00E-04	5.5	7.6	7.6
<100MMBtu Wall-Fired [1-01-006-02, 1-02-006-02, 1-02-006-03[(d)], 1-03-006-02, and 1-03-006-03]								
Wall-Fired	Uncontrolled	100	84	0.6	5.00E-04	5.5	7.6	7.6
Wall-Fired	LNB	50	84	0.6	5.00E-04	5.5	7.6	7.6
Wall-Fired	LNB/FGR	32	84	0.6	5.00E-04	5.5	7.6	7.6
All Sizes Tangential-Fired [1-01-006-04 and 1-02-006-04[(d)]]								
Tangential-Fired	Uncontrolled	170	24	0.6	5.00E-04	5.5	7.6	7.6
Tangential-Fired	FGR	76	98	0.6	5.00E-04	5.5	7.6	7.6

SOURCE (Unless otherwise stated): Section 1.4 - “Natural Gas Combustion," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, July 1998. SCC = Source Classification Code.

a) Control types include: Low NO_X Burners (LNB) and Flue Gas Recirculation (FGR).

b) Emission factors from AP-42 provide emission factors for total Particulate Matter (PM). Total PM is assumed to be equal to PM_{10} which is assumed to equal $PM_{2.5}$.

c) New Source Performance Standards (NSPS) defined in 40 CFR 60 Subparts D and Db. Post-NSPS units are boilers >250 Million British thermal units per hour (MMBtu/hr) that commenced construction modification or reconstruction after August 17, 1971 and units 100-250 MMBtu/hr that commenced construction modification or reconstruction after June 19, 1984.

d) SOURCE: "Uncontrolled Emission Factor Listing for Criteria Air Pollutants," Point Sources, Vol. 2, U.S. Environmental Protection Agency, Emission Inventory Improvement Program, July 2001. For Source Classification Code (SCC) 1-02-006-03, no emission factor provided for lead (Pb) or controlled NO_X.

GHG EF for natural gas-fired ECOM units are provided in Table 2-4. The table provides EF for three speciated gases – CO_2, N_2O, and CH_4. All EF were calculated using the default heating value and emission factors provided in 40 CFR 98 Subpart C Tables C-1 and C-2. The composite EF is applicable to all natural gas-fired ECOM units no matter the size or firing configuration since these default GHG EF values were used.

Table 2-4. GHG Emission Factors for Natural Gas-Fired ECOM Units

Firing Configuration [SCC]	Emission Factors ($lb/10^6 ft^3$)			
	CO_2	N_2O	CH_4	$CO_2e^{(a)}$
All Sizes, SCCs, and Firing Configurations	**120,019**	**2.26**	**0.226**	**120,142**

SOURCE: "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 98-Mandatory Greenhouse Gas Reporting, Subpart C-General Stationary Fuel Combustion Sources," U.S. Environmental Protection Agency. SCC = Source Classification Code.

a) CO_2e calculated by summing the product of the default emission factors for CO_2, N_2O, and CH_4 and their respective Global Warming Potentials (GWP). The GWP for CO_2, N_2O, and CH_4 are 1, 298, and 25 respectively.

HAP EF for natural-gas fired ECOM are provided in Table 2-5. Note that the tables do not provide EFs for furnaces. This is because the weighted average of boilers compared to furnaces justifies the removal of these EFs from this guide. Refer to Section 1.4 of AP-42 for information regarding the EFs for furnaces if needed.

Table 2-5. HAP Emission Factors for Natural Gas-Fired ECOM Units

HAP	Emission Factors (lb/10^6ft^3)			
	>100 MMBtu/hr [SCC]	10-100 MMBtu/hr [SCC]	<10 MMBtu/hr [SCC]	All Sizes - Tangential [SCC]
	[1-01-006-01, 1-02-006-01, and 1-03-006-01]	[1-01-006-02, 1-02-006-02, 1-02-006-03(a), 1-03-006-02, and 1-03-006-03]		[1-01-006-04 and 1-02-006-04(a)]
Acenaphthene	1.80E-06	1.80E-06	1.80E-06	1.80E-06
Acenaphthylene	1.80E-06	1.80E-06	1.80E-06	1.80E-06
Acetaldehyde	9.00E-04	3.10E-03	4.30E-03	---
Acrolein	8.00E-04	2.70E-03	2.70E-03	---
Anthracene	2.40E-06	2.40E-06	2.40E-06	2.40E-06
Arsenic	2.00E-04	2.00E-04	2.00E-04	2.00E-04
Benzo(a)anthracene	1.80E-06	1.80E-06	1.80E-06	1.80E-06
Benzene	1.70E-03	5.80E-03	8.00E-03	4.40E-01
Benzo(b)fluoranthene	1.80E-06	1.80E-06	1.80E-06	1.80E-06
Benzo(k)fluoranthene	1.80E-06	1.80E-06	1.80E-06	1.80E-06
Benzo(g,h,i)perylene	1.60E-06	1.60E-06	1.60E-06	1.60E-06
Benzo(a)pyrene	1.60E-06	1.60E-06	1.60E-06	1.60E-06
Beryllium	1.20E-05	1.20E-05	1.20E-05	1.20E-05
Cadmium	1.10E-03	1.10E-03	1.10E-03	1.10E-03
Chromium	1.40E-03	1.40E-03	1.40E-03	1.40E-03
Chrysene	1.80E-06	1.80E-06	1.80E-06	1.80E-06
Cobalt	8.40E-05	8.40E-05	8.40E-05	8.40E-05
Dibenzo(a,h)anthracene	1.60E-06	1.60E-06	1.60E-06	1.60E-06
Dichlorobenzene	1.20E-03	1.20E-03	1.20E-03	1.20E-03
7,12-Dimethylbenz(a)anthracene	1.60E-05	1.60E-05	1.60E-05	1.60E-05
Ethylbenzene	2.00E-03	6.90E-03	9.50E-03	---
Fluoranthene	3.00E-06	3.00E-06	3.00E-06	3.00E-06
Fluorene	2.80E-06	2.80E-06	2.80E-06	2.80E-06
Formaldehyde	7.50E-02	7.50E-02	1.70E-02	7.50E-02
Hexane	1.30E-03	4.60E-03	6.30E-03	1.10E-01
Indeno(1,2,3-cd)pyrene	1.80E-06	1.80E-06	1.80E-06	1.80E-06
Lead	5.00E-04	5.00E-04	5.00E-04	5.00E-04
Manganese	3.80E-04	3.80E-04	3.80E-04	3.80E-04
Mercury	2.60E-04	2.60E-04	2.60E-04	2.60E-04
3-Methylchloranthrene	1.80E-06	1.80E-06	1.80E-06	1.80E-06
2-Methylnaphthalene	2.40E-05	2.40E-05	2.40E-05	2.40E-05
Naphthalene	3.00E-04	3.00E-04	3.00E-04	6.10E-04
Nickel	2.10E-03	2.10E-03	2.10E-03	2.10E-03
Phenanthrene	1.70E-05	1.70E-05	1.70E-05	1.70E-05
Pyrene	5.00E-06	5.00E-06	5.00E-06	5.00E-06
Selenium	2.40E-05	2.40E-05	2.40E-05	2.40E-05
Toluene	7.80E-03	2.65E-02	3.66E-02	2.20E-01

SOURCE (unless otherwise stated): "Emissions Inventory Program, Emission Factors for Boilers," Mojave Desert Air Quality Management District (MDAQMD), 2013. SCC = Source Classification Code.

a) Hazardous Air Pollutant (HAP) emission factors were not provided in the source document for this Source Classification Code (SCC); however, it is assumed that the emission factors provided apply to this SCC.

“---” - No Data Available.

2.4.2 Fuel Oils

Fuel oils may be separated into two categories: distillate oils and residual oils. These oils may be further categorized by grade numbers. No.1 and No. 2 fuel oils are distillate oils, No. 5 and No. 6 are residual oils, and No.4 may be classified either as a distillate or mixture of distillate and residual oils. Distillate oils are more volatile and less viscous than residual oils, have negligible nitrogen and ash contents, and typically 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 are produced from the residue remaining after the lighter fractions (gasoline, kerosene, and distillate oils) have been removed from crude oil. Residual oils contain significant amounts of ash, nitrogen, and sulfur, and are primarily used in utility, industrial, and large commercial applications. EFs for fuel oil-fired ECOM units for criteria pollutants, GHGs, and speciated HAPs are provided in Table 2-6, Table 2-7, and Table 2-8, respectively. Note that the tables do not provide EFs for furnaces. This is because the weighted average of boilers compared to furnaces justifies the removal of these EFs from this guide. Refer to Section 1.3 of AP-42 for information regarding the EFs for furnaces if needed.

Emissions from ECOM equipment that burn fuel oils are dependent on the grade and composition of the fuel, the type and size of the boiler, the control devices used on the equipment, the boiler's firing configuration, and the level of equipment maintenance. Boilers that combust fuel oils are available in all four heat transfer methods: watertube, firetube, cast iron, and tubeless. Watertube designs are primarily found in industrial applications while firetube are often smaller and sold as packaged units. Cast iron and tubeless boilers are used primarily in the residential and commercial sectors.

The conversion of fuel nitrogen to NO_X is particularly important in residual oil boilers as it may account for half of the total NO_X emitted from residual oil firing. For distillate oil burners, thermal NO_X is the more common mechanism for NO_X formation due to the negligible nitrogen content of these lighter oils. It is important to note that distillate oil boilers are much smaller than residual oil boilers, and therefore, do not produce as much thermal NO_X as their larger counterparts, even though thermal NO_X is the primary mechanism of NO_X formation. PM emissions are dependent on the combustion efficiency of the boiler; however, it is also dependent on the grade of the fuel used. Typically, the heavier the fuel oil combusted, the more PM is produced. PM reduction may be achieved by improving oil atomization and combustion aerodynamics. Combustion aerodynamics may be improved using a flame retention device or through recirculation. This also aids in the reduction of NO_X emissions while improving thermal efficiency. Most large utility and industrial boilers may benefit from the use of post combustion PM controls, such as electrostatic precipitators (ESP) or fabric filters (FF). ESPs work by charging the suspended particles and collecting them through electrostatic attraction. New ESPs may reduce PM emissions by as much as 90 percent.

Table 2-6. Criteria Pollutant Emission Factors for Fuel Oil-Fired ECOM Units

Fuel Oil	SCC	Uncontrolled and [Controlled] Emission Factors (lb/10^3 gal)						
		NO_X(a)	CO	SO_X(b)	Pb	VOC(c)	PM_{10}(a,b)	$PM_{2.5}$(a,b)
Industrial Boilers								
No. 6 Fuel Oil	1-02-004-01	47 [40] - LNB	5	162.7**{S}**	4.49E-03(i)	2.80E-01	8.03**{S}**+2.65 [1.77**{S}**+0.58] - MCL	5.23**{S}**+1.73 [3.70E-01**{S}**+1.22E-01] -MCL
	1-02-004-02, 1-02-004-03	55	5	159**{S}**	4.49E-03(i)	2.80E-01	8.03**{S}**+2.65 [1.77**{S}**+0.58] - MCL	5.23**{S}**+1.73 [3.70E-01**{S}**+1.22E-01] -MCL
No. 5 Fuel Oil	1-02-004-04	47	5	162.7**{S}**	4.49E-03(l)	2.80E-01	8.60 [1.90] - MCL	5.60 [4.00E-01] - MCL
Residual	1-02-004-05(e)	55	5	158.6**{S}**	4.49E-03(l)	2.80E-01	7.90**{S}**+2.77	6.90**{S}**+2.42(f)
No. 4 Fuel Oil(j)	1-02-005-04	47	5	155.7**{S}**	8.30E-03(k)	2.00E-01	6.02	3.92
Distillate	1-02-005-01	24	5	7.1(g)	1.24E-03(h)	2.00E-01	1.00	2.50E-01
	1-02-005-02, 1-02-005-03	20	5	7.1(g)	8.30E-03(g)	2.00E-01	1.00	2.50E-01
	1-02-005-05(e)	20	5	143.6**{S}**	1.10E-02(d)	2.00E-01	1.00	9.91E-01(f)
Commercial/Institutional Boilers								
No. 6 Fuel Oil	1-03-004-01	47	5	162.7**{S}**	4.49E-03(l)	1.13	5.79**{S}**+1.91	2.15**{S}**+0.71
	1-03-004-02, 1-03-004-03	55	5	159**{S}**	4.49E-03(l)	1.13	5.79**{S}**+1.91	2.15**{S}**+0.71
No. 5 Fuel Oil	1-03-004-04	55	5	159**{S}**	4.49E-03(l)	1.13	6.20	2.30
No. 4 Fuel Oil(j)	1-03-005-04	20	5	152**{S}**	8.30E-03(k)	3.40E-01	1.08	0.83
Distillate	1-03-005-01	24	5	147.7**{S}**	1.24E-03(h)	3.40E-01	1.08	0.83
	1-03-005-02, 1-03-005-03	20	5	144**{S}**	1.10E-02(d)	3.40E-01	1.08	0.83

SOURCE (Unless otherwise stated): Section 1.3- “Fuel Oil Combustion," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, May 2010. SCC = Source Classification Code.

a) Control devices include: Low NO_X Burner (LNB), Flue Gas Recirculation (FGR), Electrostatic Precipitators (ESP), scrubbers (SCB), and Multi-Cyclones (MCL).

b) In some cases, the emission factor is a function of the sulfur content of the oil. "{S}" is the weight % of sulfur in the oil. For example, if the fuel oil is 1% sulfur, then S=1.

c) Source document provides an emission factor for Non-Methane Total Organic Compounds (NMTOC). Volatile Organic Compound (VOC) assumed to be equal to NMTOC.

d) This value calculated using California Air Resources Board (CARB) speciation data. Particulate matter (PM) total value taken from AP-42 and multiplied by 0.0055 for boilers burning distillate oil. No. 4 fuel oil considered distillate for industrial and commercial boilers.

e) SOURCE: " Uncontrolled Emission Factor Listing for Criteria Air Pollutants," Emission Inventory Improvement Program, 2001.

f) Source provided PM_{10} data only. $PM_{2.5}$ estimated using fractions given by the California Emission Inventory Development and Reporting System (CEIDARS). $PM_{2.5}$ fraction of PM_{10} for residual and distillate oil are given as 0.874 and 0.991 respectively.

g) SOURCE: “Emissions Inventory Program, Emission Factors for Boilers,” Mojave Desert Air Quality Management District (MDAQMD), 2013. SO_X emission factor calculated by source assumes a sulfur weight percent of 0.05%.

h) An average heat value of 138 Million British thermal units per 1,000 gallons (MMBtu/1,000gal) was used for unit conversion from AP-42 value.

i) SOURCE: "CATEF - California Air Toxics Emission Factors," California Environmental Protection Agency, 1996.

j) No. 4 fuel oil for industrial/commercial boilers assumed to be distillate.

k) Source does not provide an emission factor for this pollutant and SCC. Surrogate value (SCC 1-02-005-02 and 1-02-005-03) used.

l) Source does not provide an emission factor for this pollutant and SCC. Surrogate value (SCC 1-02-004-02 and 1-02-004-03) used.

Table 2-7. GHG Emission Factors for Fuel Oil-Fired ECOM Units

Fuel Oil	SCC	Emission Factors ($lb/10^3$ gal)			
		CO_2	N_2O	CH_4	CO_2e[a]
No. 6 and Residual Fuel Oil[b]	1-02-004-01, 1-02-004-02, 1-02-004-03, 1-02-004-05, 1-03-004-01, 1-03-004-02, 1-03-004-03	24,835	0.198	0.992	24,894
No. 5 Fuel Oil	1-02-004-04, 1-03-004-04	22,510	0.185	0.926	22,565
No. 4 Fuel Oil	1-02-005-04, 1-03-005-04	24,153	0.193	0.966	24,211
Distillate[c]	1-02-005-01, 1-02-005-02, 1-02-005-03, 1-02-005-05, 1-03-005-01, 1-03-005-02, 1-03-005-03	22,501	0.183	0.913	22,556

SOURCE: "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 98-Mandatory Greenhouse Gas Reporting, Subpart C-General Stationary Fuel Combustion Sources," U.S. Environmental Protection Agency. SCC = Source Classification Code.

a. CO_2e calculated by summing the product of the default emission factors for CO_2, N_2O, and CH_4 and their respective Global Warming Potentials (GWP). The GWP for CO_2, N_2O, and CH_4 are 1, 298, and 25 respectively.

b. Residual oil emission factors calculated using the default heat value and emission factors provided for no. 6 fuel oil.

c. Distillate emission factors calculated using the default heat value and emission factors for no. 2 fuel oil.

Table 2-8. HAP Emission Factors for Fuel Oil-Fired ECOM Units

Hazardous Air Pollutant	Emission Factors (lb/10^3 gal)				
	Residual Fuel Oils and No. 4 Fuel Oil Blends				Distillate Fuel Oil
	Industrial Boilers No. 6 and No. 5 Fuel Oil	Industrial Boilers No. 4 Fuel Oil(a)	Commercial Boilers No. 6 and No. 5 Fuel Oil(b)	Commercial Boilers No. 4 Fuel Oil(a)	All Types(c)
Acenaphthene	2.30E-05	3.31E-05	2.06E-04	5.63E-05	2.11E-04
Acenaphthylene	3.13E-05	1.02E-05	2.81E-04	1.73E-05	6.50E-05
Acetaldehyde	2.31E-03	5.50E-02	2.07E-02	9.36E-02	3.51E-01
Acrolein	3.52E-03	5.50E-02	3.16E-02	9.36E-02	3.51E-01
Anthracene	2.32E-05	3.75E-06	2.08E-04	6.38E-06	2.39E-05
Antimony	1.09E-03	---(d)	1.09E-03(e)	---(d)	---
Arsenic	5.89E-04	1.60E-03(d)	5.89E-04(e)	1.60E-03(d)	1.60E-03
Benzo(a)anthracene	2.24E-05	2.12E-06	2.01E-04	3.60E-06	1.35E-05
Benzene	3.32E-02	6.91E-04	2.98E-01	1.17E-03	4.40E-03
Benzo(b,k)fluoranthene	1.60E-06	2.32E-07	1.43E-05	3.95E-07	1.48E-06
Benzo(g,h,i)perylene	2.29E-05	1.33E-06	2.05E-04	2.27E-06	8.50E-06
Benzo(a)pyrene	2.50E-05	1.19E-06	2.24E-04	2.02E-06	7.55E-06
Benzo(e)pyrene	9.40E-07	2.20E-06	8.43E-06	3.74E-06	1.40E-05
Beryllium	4.20E-04	---(d)	4.20E-04(e)	---(d)	---
1,3-Butadiene	6.17E-03	2.32E-03	5.53E-02	3.95E-03	1.48E-02
Cadmium	3.43E-03	1.50E-03(d)	3.43E-03(e)	1.50E-03(d)	1.50E-03
Chlorobenzene	---	3.14E-05	---	5.34E-05	2.00E-04
Chloroform	4.96E-03	---	4.45E-02	---	---
Chromium	1.64E-03	6.00E-04(d)	1.64E-03(e)	6.00E-04(d)	6.00E-04
Chromium VI	3.50E-04	1.00E-04(d)	3.50E-04(e)	1.00E-04(d)	1.00E-04
Chrysene	2.56E-05	2.01E-06	2.30E-04	3.42E-06	1.28E-05
Cobalt	2.24E-03	---(d)	2.24E-03(e)	---(d)	---
Dibenzo(a,h)anthracene	2.28E-05	1.02E-06	2.04E-04	1.73E-06	6.49E-06
Ethylbenzene	1.42E-03	3.14E-05	1.27E-02	5.34E-05	2.00E-04
Fluoranthene	2.78E-05	5.21E-06	2.49E-04	8.86E-06	3.32E-05
Fluorene	3.18E-05	1.84E-05	2.85E-04	3.12E-05	1.17E-04
Formaldehyde	5.25E-02	5.50E-02	4.71E-01	9.36E-02	3.51E-01
Hexane	---	5.50E-04	---	9.34E-04	3.50E-03
Hydrogen Chloride	---	2.93E-02	---	4.97E-02	1.86E-01
Indeno(1,2,3-cd)pyrene	2.25E-05	1.04E-06	2.02E-04	1.77E-06	6.64E-06
Lead	4.49E-03	8.30E-03	4.49E-03(e)	8.30E-03	(f)
Manganese	4.38E-02	3.10E-03(d)	4.38E-02(e)	3.10E-03(d)	3.10E-03
Mercury	1.93E-04	2.00E-03(d)	1.93E-04(e)	2.00E-03(d)	2.00E-03
2-Methylnaphthalene	7.99E-05	2.20E-05	7.16E-04	3.74E-05	1.40E-04
Naphthalene	4.95E-03	8.32E-04	4.44E-02	1.41E-03	5.30E-03
Nickel	1.30E-01	3.90E-03(d)	1.30E-01(e)	3.90E-03(d)	3.90E-03
Perylene	---	4.25E-06	---	7.23E-06	2.71E-05
Phenanthrene	4.38E-05	5.84E-05	3.93E-04	9.93E-05	3.72E-04
Phosphorous	2.86E-02	---(d)	2.86E-02(e)	---(d)	---
Pyrene	2.35E-05	6.41E-06	2.11E-04	1.09E-05	4.08E-05
Selenium	3.23E-03	2.20E-03(d)	3.23E-03(e)	2.20E-03(d)	2.20E-03
2,3,7,8-Tetrachlorodibenzo-p-dioxin	6.33E-10	---	5.68E-09	---	---
Toluene	7.30E-03	6.91E-04	6.54E-02	1.17E-03	4.40E-03
1,1,1-Trichloroethane	---	3.71E-05	---	6.30E-05	2.36E-04
Xylenes	9.28E-03	2.51E-04	8.32E-02	4.27E-04	1.60E-03

Notes for Table 2-8 on the following page.

Notes for Table 2-8:

SOURCE (unless otherwise stated): "CATEF - California Air Toxics Emission Factors," California Environmental Protection Agency, 1996. Source lists emission factors for Source Classification Codes (SCC) 1-02-004-01/02/03 only, but these emission factors are assumed to apply to SCCs 1-02-004-04/05 as well.

a) SOURCE (unless otherwise stated): Values are estimates which were calculated by first determining the ratio of Hazardous Air Pollutant (HAP) to Total Organic Compounds (TOC) as provided for Distillate-firing boilers. This ratio was then multiplied by the Non-Methane Total Organic Compounds (NMTOC) emission factor for each HAP to estimate emission factors. These emission factors apply to the following SCC's: for Industrial boilers using No. 4 fuel oil - 1-02-005-04 and for commercial boilers using No. 4 oil - 1-03-005-04. Emission factors for metallic HAPs taken directly from Distillate boilers.

b) SOURCE (unless otherwise stated): Values are estimates which were calculated by first determining the ratio of HAP to Total HAPs (non-metals) as provided for Industrial boilers. This ratio was then multiplied by the NMTOC emission factor for each HAP to estimate emission factors. These emission factors apply to the following SCCs: for commercial boilers using No. 6 and No. 5 oil - 1-03-004-01/02/03/04. Emission factors for metallic HAPs taken directly from Industrial boilers.

c) SOURCE (unless otherwise stated): "Emissions Inventory Program, Emission Factors for Boilers," Mojave Desert Air Quality Management District (MDAQMD), 2013. Though the source only lists SCCs 1-02-005-01/02/03 and 1-03-005-01/02/03, these emission factors are assumed to also apply to SCC 1-02-005-05.

d) Distillate fuel oil emission factor used as a surrogate for this HAP.

e) Industrial no. 6 and no. 5 fuel oil used as a surrogate for this HAP.

f) Refer to Table 2-6 for emission factor specific to this SCC.

“---” - No data available.

2.4.3 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 its volatile matter, fixed carbon, inherent moisture, and O_2 content. Typically, the 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.

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 that is fluidized by an upward flow of air.

Stoker-fired systems account for most coal-fired watertube boilers for industrial, commercial, and institutional applications. Stoker-fired units may be divided into three groups: underfeed stokers, overfeed stokers, and spreader stokers. Underfeed stokers may be horizontal fed, side ash discharge or gravity fed, rear ash discharge and produce ash that may be difficult to completely rake out. In overfeed stokers, coal is fed from a hopper onto a grate that moves the coal into the furnace. Spreader stokers evenly disperse coal over the surface of a moving grate.

FBCs are becoming increasingly popular as this technology has proven effective in combusting fuels that are difficult to ignite, such as high-ash coals or fuels with large variances in heat content. FBCs may operate at either atmospheric conditions or at elevated pressures, where pressurized steam may be used to power a steam turbine. FBCs may be further classified as either bubbling fluidized bed (BFB) or circulating fluidized bed (CFB). In BFBs, the fluidization velocity is relatively low and minimizes the carryover of solids to the combustion chamber. CFBs, however, have high fluidization velocities to maintain a continuous, high-volume recycle rate that results in higher combustion efficiencies than BFB units.

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. NO_X emissions from coal combustion are primarily nitric oxide (NO). As with other external combustion units that burn other fuels, NO_X emissions result from thermal NO_X or fuel NO_X. Fuel NO_X may account for as much as 80 percent of total NO_X from coal combustion.

2.4.3.1 Bituminous and Subbituminous Coal

Bituminous coal is by far the largest group of coal and is characterized as having lower fixed carbon and higher volatile matter than anthracite. Subbituminous coal has a higher moisture content, lower sulfur content with more volatile matter than bituminous coal. Subbituminous coal may be used as an alternative fuel in some boilers originally designed to burn bituminous coals. Criteria pollutant and GHG EFs for external combustion units burning bituminous coal are provided in Table 2-9 and Table 2-10 respectively.

There are a variety of control devices available for external combustion units that burn coal. These control devices are designed to minimize the amount of emissions primarily for SO_X, NO_X, and PM. These control types include: wet scrubbers, spray drying, furnace injection, duct injection, LNB, SNCR, SCR, multiple cyclones, ESP, or a combination of each. When calculating emissions from coal fired units with control devices installed, it may be necessary to contact the manufacturer of the control device to determine the control efficiency. Emissions of the controlled pollutant may then be estimated by calculating emissions of the uncontrolled operation and multiplying by the reduction of that pollutant (which is discussed later in a section of this guide). In the absence of control efficiency data, several EFs have been calculated for a variety of control devices, particularly for PM.

The amount of HAP emissions varies based on the type of coal used, the firing configuration and the presence (or absence) of control devices. There is limited data on the emissions of individual HAPs, however, Table 2-11 provides EFs for speciated HAPs from external combustion units burning bituminous and subbituminous coal. Note that AP-42 provides EFs for speciated HAPs for controlled emissions only. Additionally, since this data is based on test results from few emitting sources, and the fact that coal composition is region-specific, it is always preferable to use on site test data whenever possible in place of the EFs provided here.

Table 2-9. Criteria Pollutant Emission Factors for Bituminous/Subbituminous Coal-Fired ECOM Units

Coal Type	**Firing Configuration [SCC]**	**Emission Factors (lb/ton)**						
		NO$_X$ [Controlled](a)	**CO**	**SO$_X$(b)**	**Pb [Controlled]**	**VOC(c)**	**PM$_{10}$ [Controlled](a,b)**	**PM$_{2.5}$ [Controlled](a,b)**
Bituminous	PC, Wet Bottom, Wall Fired [1-01-002-01, 1-02-002-01, 1-03-002-05]	31	0.5	38**{S}**	1.26E-02 [(e)]	0.04	2.6**{A}** 1.3**{A}** [MCL] 0.042**{A}** [ESP]	1.48**{A}** 0.86**{A}** [MCL] 0.022**{A}** [ESP]
Bituminous	PC, Dry Bottom, Wall Fired, Pre-NSPS/Post NSPS [1-01-002-02, 1-02-002-02, 1-03-002-06]	22 / 12 [11 with LNB]	0.5	38**{S}**	1.26E-02 [4.20E-04]	0.06	2.3**{A}** 0.58**{A}** [MCL] 0.42**{A}** [SCB] 0.054**{A}** [ESP] 0.02**{A}** [BGH]	0.6**{A}** 0.06**{A}** [MCL] 0.3**{A}** [SCB] 0.024**{A}** [ESP] 0.01**{A}** [BGH]
Bituminous	Cyclone Furnace [1-01-002-03, 1-02-002-03, 1-03-002-03]	33	0.5	38**{S}**	1.26E-02 [4.20E-04]	0.11	0.26**{A}** 0.112**{A}** [MCL] 0.011**{A}** [ESP]	0.11**{A}** 0.11**{A}** [MCL] 0.006**{A}** [ESP]
Bituminous	Spreader Stoker [1-01-002-04, 1-02-002-04, 1-03-002-09]	11	5	38**{S}**	1.26E-02 [(e)]	0.05	13.2 12.4 [MCL w/ FAR] 7.8 [MCL] 0.44 [ESP] 0.072 [BGH]	4.6 1.4 [MCL w/ FAR] 3.2 [MCL] 0.30 [ESP] 0.032 [BGH]
Bituminous	Overfeed Stoker [1-01-002-05, 1-02-002-05, 1-03-002-07]	7.5	6	38**{S}**	1.26E-02 [(e)]	0.05	6.0 5.0 [MCL]	2.2 3.8 [MCL]
Bituminous	PC, Wet Bottom, Tangentially Fired [1-01-002-11]	14	0.5	38**{S}**	(e)	0.04(f)	2.6**{A}**(f)	1.48**{A}**(f)
Bituminous	PC, Dry Bottom, Tangentially Fired [1-01-002-12, 1-02-002-12, 1-03-002-16]	15 / 10 [9.7 with LNB]	0.5	38**{S}**	(e) [4.20E-04]	0.06	2.3**{A}** 0.58**{A}** [MCL] 0.42**{A}** [SCB] 0.054**{A}** [ESP] 0.02**{A}** [BGH]	0.6**{A}** 0.06**{A}** [MCL] 0.3**{A}** [SCB] 0.024**{A}** [ESP] 0.01**{A}** [BGH]
Bituminous	PC, Dry Bottom, Cell Burner Fired [1-01-002-15]	31	0.5	38**{S}**	(e)	0.06(g)	2.3**{A}**(g)	0.6**{A}**(g)
Bituminous	FBC, Bubbling Bed [1-01-002-17, 1-02-002-17, 1-03-002-17]	15.2	18	(d)	(e)	0.05	12.4(h)	4.65(i)
Bituminous	FBC, Circulating Bed [1-01-002-18, 1-02-002-18, 1-03-002-18]	5	18	(d)	(e) [4.20E-04]	0.05	12.4(h)	4.65(i)
Bituminous	Underfeed Stoker [1-02-002-06]	9.5	11	31**{S}**	(e)	1.3	6.2	3.8
Bituminous	Hand-fed Units [1-03-002-14]	9.1	275	31**{S}**	(e)	10	6.2(j)	3.8(j)
Subbituminous	PC, Wet Bottom, Wall Fired [1-01-002-21, 1-02-002-21, 1-03-002-21]	24	0.5	35{S}	8.75E-03 [(e)]	0.04	2.6**{A}**(f)	1.48{A}(f)
Subbituminous	PC, Dry Bottom, Wall Fired, Pre-NSPS/Post NSPS [1-01-002-22, 1-02-002-22, 1-03-002-22]	12 / 7.4	0.5	35{S}	8.75E-03 [4.20E-04]	0.06	2.3**{A}**(g)	0.6**{A}**(g)
Subbituminous	Cyclone Furnace [1-01-002-23, 1-02-002-23, 1-03-002-23]	17	0.5	35{S}	8.75E-03 [4.20E-04]	0.11	0.26**{A}**(k)	0.11**{A}**(k)
Subbituminous	Spreader Stoker [1-01-002-24, 1-02-002-24, 1-03-002-24]	8.8	5	35{S}	8.75E-03 [(e)]	0.05	13.2(l)	4.6(l)
Subbituminous	Overfeed Stoker [1-01-002-25, 1-02-002-25, 1-03-002-25]	7.5	6	35{S}	8.75E-03 [(e)]	0.05	6.0(m)	2.2(m)
Subbituminous	PC, Dry Bottom, Tangentially Fired, Pre-NSPS/Post NSPS [1-01-002-26, 1-02-002-26, 1-03-002-26]	8.4 / 7.2	0.5	35{S}	(e) [4.20E-04]	0.06	2.3**{A}**(n)	0.6**{A}**(n)
Subbituminous	PC, Dry Bottom, Cell Burner Fired [1-01-002-35]	14	0.5	35{S}	(e)	0.06(g)	2.3**{A}**(g)	0.6**{A}**(g)
Subbituminous	Underfeed Stoker [1-03-002-08]	9.5	11	31{S}	(e)	1.3	6.2(j)	3.8(j)

Notes for Table 2-9 are provided on the following page

Notes for Table 2-9:

SOURCE: Section 1.1 - “Bituminous and Subbituminous Coal Combustion," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, September 1998. SCC = Source Classification Code, PC = Pulverized Coal, NSPS = New Source Performance Standards, FBC = Fluidized Bed Combustor.

a) Control devices include: Low NO_X burner (LNB), Flue Gas Recirculation (FGR), Electrostatic Precipitators (ESP), Scrubbers (SCB), baghouse (BGH), multi-cyclones (MCL), multi-cyclones with fly-ash reinjection (MCL with FAR).
b) Several emission factors based on the sulfur or ash content of the coal being used. "{S}" is the weight % sulfur content of the fuel as fired. For example, if the fuel is 1.2% sulfur, then S= 1.2. Similarly, if coal ash weight is 2.4%, "{A}" =2.4. Appendix A of AP-42 states that the ash % by weight is 4-20% for bituminous coal. Sulfur oxides (SO_X) emission factors based on the sulfur content of the coal being used. For example, if the fuel is 1.2% sulfur, then S=1.2.
c) Source document provides an emission factor for Total Non-Methane Organic Compounds (TNMOC). TNMOC is assumed to be equal to volatile organic compounds (VOC).
d) Sulfur emission factors for fluidized bed combustor (FBC) are a function of fuel sulfur content and calcium-to-sulfur ratio. Emission factor calculated as follows: $SO_X\ EF = 39.6 \times S \times (Ca/S)^{-1.9}$ where S is the weight % sulfur in the coal and Ca/S is the molar calcium to sulfur ratio in the bed. This equation is valid when the Ca/S ratio is between 1.5 and 7. When no calcium based sorbents are used and the bed material is inert with respect to sulfur capture, use 31**{S}** as the emission factor.
e) AP-42 does not provide an emission factor for lead (Pb) for these SCCs, however, an emission factor for either controlled or uncontrolled emissions may be calculated as follows: $Pb\ EF = 3.4E - 06 \times HV \times (C/A \times PM)^{0.8}$ where C is the concentration of Pb in parts per million by weight (ppmwt). A is the weight fraction of the ash in the coal. For example, 10% ash is 0.1 ash fraction. Particulate matter (PM) is the emission factor for total PM pounds per Million British thermal unit (lb/MMBtu) which may be estimated as follows: $PM = (PM_{10}/[0.4 \times HV])$ where PM_{10} is the emission factor for PM_{10} (lb/ton) 0.4 is the fraction of PM_{10} to PM_{total} as given in Krause, Mike and Smith, Steve, "Methodology to Calculate Particulate Matter (PM) 2.5 and PM 2.5 Significance Thresholds," South Coast Air Quality Management District, October 2006, and HV is the heating value of the coal. Section C of 40 CFR 98 states that the heating values of Bituminous and Subbituminous coal are 24.93MMBtu/ton and 17.25MMBtu/ton respectively.
f) Value provided is a surrogate. This value from SCC 1-01-002-01.
g) Value provided is a surrogate. This value from SCC 1-01-002-02.
h) Per AP-42, spreader stoker with multiple cyclones and reinjection used as a surrogate.
i) Value calculated using the percent $PM_{2.5}$ to PM_{10} per Krause, Mike and Smith, Steve, "Methodology to Calculate Particulate Matter (PM) 2.5 and PM 2.5 Significance Thresholds," South Coast Air Quality Management District, October 2006.
j) SCC 1-02-002-06 used as a surrogate for this value.
k) SCC 1-01-002-03 used as a surrogate for this value.
l) SCC 1-01-002-04 used as a surrogate for this value.
m) SCC 1-01-002-05 used as a surrogate for this value.
n) SCC 1-01-002-12 used as a surrogate for this value.

Table 2-10. GHG Emission Factors for Bituminous/Subbituminous Coal-Fired ECOM Units

Firing Configuration [SCC]	Emission Factors (lb/ton)			
	CO_2	N_2O	CH_4	CO_2e[(a)]
All SCCs and Firing Configurations	5,127	0.088	0.605	5,168

SOURCE: "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 98-Mandatory Greenhouse Gas Reporting, Subpart C-General Stationary Fuel Combustion Sources," U.S. Environmental Protection Agency. SCC = Source Classification Code.

a) CO_2e calculated by summing the product of the default emission factors for CO_2, N_2O, and CH_4 and their respective Global Warming Potentials (GWP). The GWP for CO_2, N_2O, and CH_4 are 1, 298, and 25 respectively.

Table 2-11. HAP Emission Factors for Bituminous/Subbituminous Coal-Fired ECOM Units-CONTROLLED

Hazardous Air Pollutants	Emission Factors (lb/ton)				
	Dry Bottom, Cyclone Furnace, and FBC-Circulating Bed Boilers(a)	Wet Bottom Boilers(b,c)	Spreader and Overfeed Stoker and FBC-Bubbling Bed Boilers(b,d)	Underfeed Boilers(b,e)	Hand-fed Boilers(b,f)
Acenaphthene	5.10E-07	2.31E-06	2.89E-06	7.52E-05	5.78E-04
Acenaphthylene	2.50E-07	1.13E-06	1.42E-06	3.69E-05	2.84E-04
Acetaldehyde	5.70E-04	2.59E-03	3.23E-03	8.40E-02	6.46E-01
Acetophenone	1.50E-05	6.80E-05	8.51E-05	2.21E-03	1.70E-02
Acrolein	2.90E-04	1.32E-03	1.64E-03	4.28E-02	3.29E-01
Anthracene	2.10E-07	9.53E-07	1.19E-06	3.10E-05	2.38E-04
Antimony(g)	1.80E-05	$9.20E{-}07*HV*(C/A*PM)^{0.63}$	$9.20E{-}07*HV*(C/A*PM)^{0.63}$	$9.20E{-}07*HV*(C/A*PM)^{0.63}$	$9.20E{-}07*HV*(C/A*PM)^{0.63}$
Arsenic(g)	4.10E-04	$3.10E{-}06*HV*(C/A*PM)^{0.85}$	$3.10E{-}06*HV*(C/A*PM)^{0.85}$	$3.10E{-}06*HV*(C/A*PM)^{0.85}$	$3.10E{-}06*HV*(C/A*PM)^{0.85}$
Benzo(a)anthracene	8.00E-08	3.63E-07	4.54E-07	1.18E-05	9.07E-05
Benzene	1.30E-03	5.90E-03	7.37E-03	1.92E-01	1.47E+00
Benzo(b,j,k)fluoranthene	1.10E-07	4.99E-07	6.24E-07	1.62E-05	1.25E-04
Benzo(g,h,i)perylene	2.70E-08	1.22E-07	1.53E-07	3.98E-06	3.06E-05
Benzo(a)pyrene	3.80E-08	1.72E-07	2.15E-07	5.60E-06	4.31E-05
Benzyl Chloride	7.00E-04	3.18E-03	3.97E-03	1.03E-01	7.94E-01
Beryllium(g)	2.10E-05	$1.20E{-}06*HV*(C/A*PM)^{1.1}$	$1.20E{-}06*HV*(C/A*PM)^{1.1}$	$1.20E{-}06*HV*(C/A*PM)^{1.1}$	$1.20E{-}06*HV*(C/A*PM)^{1.1}$
Biphenyl	1.70E-06	7.71E-06	9.64E-06	2.51E-04	1.93E-03
Bis(2-ethylhexyl)phthalate	7.30E-05	3.31E-04	4.14E-04	1.08E-02	8.28E-02
Bromoform	3.90E-05	1.77E-04	2.21E-04	5.75E-03	4.42E-02
Cadmium(g)	5.10E-05	$3.30E{-}06*HV*(C/A*PM)^{0.5}$	$3.30E{-}06*HV*(C/A*PM)^{0.5}$	$3.30E{-}06*HV*(C/A*PM)^{0.5}$	$3.30E{-}06*HV*(C/A*PM)^{0.5}$
Carbon Disulfide	1.30E-04	5.90E-04	7.37E-04	1.92E-02	1.47E-01
2-Chloroacetophenone	7.00E-06	3.18E-05	3.97E-05	1.03E-03	7.94E-03
Chlorobenzene	2.20E-05	9.98E-05	1.25E-04	3.24E-03	2.50E-02
Chloroform	5.90E-05	2.68E-04	3.35E-04	8.70E-03	6.69E-02
Chromium(g)	2.60E-04	$3.70E{-}06*HV*(C/A*PM)^{0.58}$	$3.70E{-}06*HV*(C/A*PM)^{0.58}$	$3.70E{-}06*HV*(C/A*PM)^{0.58}$	$3.70E{-}06*HV*(C/A*PM)^{0.58}$
Chromium VI(g)	7.90E-05	---	---	---	---
Chrysene	1.00E-07	4.54E-07	5.67E-07	1.47E-05	1.13E-04
Cobalt(g)	1.00E-04	$1.70E{-}06*HV*(C/A*PM)^{0.69}$	$1.70E{-}06*HV*(C/A*PM)^{0.69}$	$1.70E{-}06*HV*(C/A*PM)^{0.69}$	$1.70E{-}06*HV*(C/A*PM)^{0.69}$
Cumene	5.30E-06	2.40E-05	3.01E-05	7.81E-04	6.01E-03
Cyanide	2.50E-03	1.13E-02	1.42E-02	3.69E-01	2.84E+00
Dimethyl Sulfate	4.80E-05	2.18E-04	2.72E-04	7.08E-03	5.44E-02
2,4-Dinitrotoluene	2.80E-07	1.27E-06	1.59E-06	4.13E-05	3.18E-04
Ethyl Benzene	9.40E-05	4.26E-04	5.33E-04	1.39E-02	1.07E-01
Ethyl Chloride	4.20E-05	1.91E-04	2.38E-04	6.19E-03	4.76E-02
Ethylene Dibromide	1.20E-06	5.44E-06	6.80E-06	1.77E-04	1.36E-03
Ethylene Dichloride	4.00E-05	1.81E-04	2.27E-04	5.90E-03	4.54E-02
Fluoranthene	7.10E-07	3.22E-06	4.03E-06	1.05E-04	8.05E-04
Fluorene	9.10E-07	4.13E-06	5.16E-06	1.34E-04	1.03E-03
Formaldehyde	2.40E-04	1.09E-03	1.36E-03	3.54E-02	2.72E-01
Hexane	6.70E-05	3.04E-04	3.80E-04	9.88E-03	7.60E-02
Hydrogen Chloride(h)	1.20E+00	1.20E+00	1.20E+00	1.20E+00	1.20E+00
Hydrogen Fluoride(h)	1.50E-01	1.50E-01	1.50E-01	1.50E-01	1.50E-01
Indeno(1,2,3-cd)pyrene	6.10E-08	2.77E-07	3.46E-07	8.99E-06	6.92E-05
Isophorone	5.80E-04	2.63E-03	3.29E-03	8.55E-02	6.58E-01
Lead(g)	(i)	$3.40E{-}06*HV*(C/A*PM)^{0.80}$	$3.40E{-}06*HV*(C/A*PM)^{0.80}$	$3.40E{-}06*HV*(C/A*PM)^{0.80}$	$3.40E{-}06*HV*(C/A*PM)^{0.80}$
Manganese(g)	4.90E-04	$3.80E{-}06*HV*(C/A*PM)^{0.60}$	$3.80E{-}06*HV*(C/A*PM)^{0.60}$	$3.80E{-}06*HV*(C/A*PM)^{0.60}$	$3.80E{-}06*HV*(C/A*PM)^{0.60}$
Mercury(g)	8.30E-05	---	---	---	---
Methyl Bromide	1.60E-04	7.26E-04	9.07E-04	2.36E-02	1.81E-01
Methyl Chloride	5.30E-04	2.40E-03	3.01E-03	7.81E-02	6.01E-01
5-Methyl Chrysene	2.20E-08	9.98E-08	1.25E-07	3.24E-06	2.50E-05
Methyl Hydrazine	1.70E-04	7.71E-04	9.64E-04	2.51E-02	1.93E-01
Methyl Methacrylate	2.00E-05	9.07E-05	1.13E-04	2.95E-03	2.27E-02
Methyl Tert-butyl Ether	3.50E-05	1.59E-04	1.98E-04	5.16E-03	3.97E-02

Table 2-11. HAP Emission Factors for Bituminous/Subbituminous Coal-Fired ECOM Units - CONTROLLED (cont.)

Hazardous Air Pollutants	Emission Factors (lb/ton)				
	Dry Bottom, Cyclone Furnace, and FBC-Circulating Bed Boilers(a)	Wet Bottom Boilers(b,c)	Spreader and Overfeed Stoker and FBC-Bubbling Bed Boilers(b,d)	Underfeed Boilers(b,e)	Hand-fed Boilers(b,f)
Methylene Chloride	2.90E-04	1.32E-03	1.64E-03	4.28E-02	3.29E-01
Naphthalene	1.30E-05	5.90E-05	7.37E-05	1.92E-03	1.47E-02
Nickel(g)	2.80E-04	4.40E-06*HV*(C/A*PM)$^{0.48}$	4.40E-06*HV*(C/A*PM)$^{0.48}$	4.40E-06*HV*(C/A*PM)$^{0.48}$	4.40E-06*HV*(C/A*PM)$^{0.48}$
Phenanthrene	2.70E-06	1.22E-05	1.53E-05	3.98E-04	3.06E-03
Phenol	1.60E-05	7.26E-05	9.07E-05	2.36E-03	1.81E-02
Propionaldehyde	3.80E-04	1.72E-03	2.15E-03	5.60E-02	4.31E-01
Pyrene	3.30E-07	1.50E-06	1.87E-06	4.87E-05	3.74E-04
Selenium(g)	1.30E-03	---	---	---	---
Styrene	2.50E-05	1.13E-04	1.42E-04	3.69E-03	2.84E-02
Tetrachloroethylene	4.30E-05	1.95E-04	2.44E-04	6.34E-03	4.88E-02
Toluene	2.40E-04	1.09E-03	1.36E-03	3.54E-02	2.72E-01
1,1,1-Trichloroethane	2.00E-05	9.07E-05	1.13E-04	2.95E-03	2.27E-02
Vinyl Acetate	7.60E-06	3.45E-05	4.31E-05	1.12E-03	8.62E-03
Xylenes	3.70E-05	1.68E-04	2.10E-04	5.46E-03	4.20E-02

SOURCE: Section 1.1- “Bituminous and Subbituminous Coal Combustion”, Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, September 1998. All emission factors assume a control device is used on the boiler. Controls used may be wet limestone scrubbers, electrostatic precipitators, or fabric filters, or any combination of each. Limited data exists for uncontrolled emissions though AP-42 does provide emission factors for some pollutants from uncontrolled emissions. Refer to AP-42 for these values if needed. FBC = Fluidized Bed Combustor.

a) Apply to Source Classification Codes (SCCs): 1-01-002-02, 1-02-002-02, 1-03-002-06, 1-01-002-15, 1-01-002-12, 1-02-002-12, 1-03-002-16, 1-01-002-18, 1-02-002-18, 1-03-002-18, 1-01-002-03, 1-02-002-03, and 1-03-002-03. Refer to note h.

b) These emission factors were calculated using the ratio of the Hazardous Air Pollutant (HAP) to HAP totals (minus the metals) as given in AP-42. This ratio was then multiplied by the Total Non-Methane Organic Compounds (TNMOC) provided in AP-42. Since this ratio was multiplied by the TNMOC, it is assumed to be conservative though the condition of the boiler will have a significant effect on emissions.

c) Applies to SCCs: 1-01-002-01, 1-02-002-01, 1-03-002-05, and 1-01-002-11. Refer to note h.

d) Applies to SCCs: 1-01-002-04, 1-02-002-04, 1-03-002-09, 1-01-002-05, 1-02-002-005, 1-03-002-07, 1-01-002-17, 1-02-002-17, and 1-03-002-17.

e) Emission factors apply to SCC: 1-02-002-06.

f) Emission factors apply to SCC 1-03-002-14.

g) Emission factors for metals may be calculated as shown. (C) is the concentration of the metal in the coal (C) in parts per million weight (ppmwt). (A) is the weight fraction of the ash in the coal. For example, for 10% ash, A=0.1. (PM) is the total particulate matter in units of pounds per Million British thermal units (lb/MMBtu). (HV) is the heating value for each coal. According to 40 CFR 98 Table C-1, the heating values are 24.93 and 17.25 MMBtu/ton for bituminous and subbituminous coal respectively.

h) Source document does not provide an emission factor for this pollutant for the following SCCs: 1-01-002-11/15.

i) Refer to Table 2-9 for SCC-specific emission factors.

“---” - No data available.

2.4.3.2 Anthracite

Anthracite is the highest-ranking coal with more fixed carbon and less volatile matter than the other three coal types. It has been determined that anthracite is not in use on any USAF installations, therefore, the EFs for anthracite have not been included in this guide.

2.4.3.3 Lignite

Lignite is characterized by a high moisture content and low heating value. These properties make shipping and use of lignite unfeasible, and consequently, lignite is burned near where it is mined. The United States has two regions with extensive lignite deposits centered in North Dakota and Texas. Lignite is mainly used for steam/electric production in power plants. Lignite is not in use on any USAF installations, therefore, the EFs for lignite have not been included in this guide.

2.4.4 Liquefied Petroleum Gas (LPG)

LPG usually consists of butane, propane, or a mixture of the two. LPG is available in three different grades: commercial grade propane, commercial grade butane, and fuel-grade propane known as HD-5. The combustion processes that use LPG are similar to those for natural gas, so LPG is commonly used in some applications that burn natural gas. Additionally, LPG is fired as a primary and backup fuel in small commercial and industrial boilers. It is used in space heating equipment, and used to generate heat and process steam for industrial facilities.

Emissions from LPG combustion are dependent upon the burner design, boiler operating parameters, and flue gas venting. NO_X emissions are a combination of thermal NO_X and fuel NO_X. Controls of NO_X emissions include FGR and LNBs, but LPG has a higher NO_X forming potential than natural gas. The LPG criteria pollutant EFs are provided in Table 2-12 while the EF data for GHGs and speciated HAPs are provided in Table 2-13 and Table 2-14 respectively.

Table 2-12. Criteria Pollutant Emission Factors for LPG-Fired ECOM Units

Primary Gas [SCC]	Emission Factors (lb/10^3 gal)						
	NO_X	CO	SO_X[(a)]	Pb[(b)]	VOC[(c)]	PM_{10}[(d)]	$PM_{2.5}$[(d)]
Industrial Boilers							
Butane [1-02-010-01]	15	8.4	0.016	5.10E-05	1.1	0.8	0.8
Propane [1-02-010-02]	13	7.5	0.018	4.58E-05	1.0	0.7	0.7
Commercial Boilers							
Propane [1-03-010-02]	13	7.5	0.018	4.58E-05	1.0	0.7	0.7

SOURCE (Unless otherwise stated): Section 1.5 - “Liquefied Petroleum Gas Combustion," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, July 2008. SCC = Source Classification Code.

a) Sulfur oxides (SO_X) emission factors based on sulfur content expressed in grains per 100 cubic feet (gr/100ft^3) gas vapor. For example, if the sulfur content is 0.18 gr/100ft^3, then S=0.18. For industrial and commercial boilers, the values provided are from "Emissions Inventory Program, Emission Factors for Boilers," Mojave Desert Air Quality Management District (MDAQMD), 2013.

b) SOURCE: "Emissions Inventory Program, Emission Factors for Boilers," Mojave Desert Air Quality Management District (MDAQMD), 2013.

c) AP-42 provides an emission factor for Total Organic Compounds (TOC). This value is used here as a conservative estimate of volatile organic compounds (VOC).

d) AP-42 provides emission factor for total Particulate Matter (PM). This value assumed to be equal to PM_{10} and $PM_{2.5}$.

Table 2-13. GHG Emission Factors for LPG-Fired ECOM Units

Primary Gas [SCC]	Emission Factors (lb/10^3 gal)			
	CO_2	N_2O	CH_4	$CO_2e^{(a)}$
Butane [1-02-010-01]	14,708	0.136	0.681	14,765
Propane [1-02-010-02, 1-03-010-02]	12,613	0.136	0.681	12,671

SOURCE: "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 98-Mandatory Greenhouse Gas Reporting, Subpart C-General Stationary Fuel Combustion Sources," U.S. Environmental Protection Agency. SCC = Source Classification Code.

a) CO_2e calculated by summing the product of the default emission factors for CO_2, N_2O, and CH_4 and their respective Global Warming Potentials (GWP). The GWP for CO_2, N_2O, and CH_4 are 1, 298, and 25 respectively.

Table 2-14. HAP Emission Factors for Liquefied Petroleum Gas (LPG)-Fired ECOM Units

Hazardous Air Pollutant	Emission Factors (lb/10^3 gal)		
	Butane	Propane	
	Industrial [SCC] [1-02-010-01]	Industrial [SCC] [1-02-010-02]	Commercial [SCC] [1-03-010-02]
Acenaphthene	1.84E-07	1.65E-07	1.65E-07
Acenaphthylene	1.84E-07	1.65E-07	1.65E-07
Acetaldehyde	9.18E-05	8.24E-05	2.84E-04
Acrolein	8.16E-05	7.32E-05	2.47E-04
Anthracene	2.45E-07	2.20E-07	2.20E-07
Arsenic	2.04E-05	1.83E-05	1.83E-05
Benzene	1.73E-04	1.56E-04	5.31E-04
Benzo(a)anthracene	1.84E-07	1.65E-07	1.65E-07
Benzo(a)pyrene	1.63E-07	1.46E-07	1.46E-07
Benzo(b)fluoranthene	1.84E-07	1.65E-07	1.65E-07
Benzo(g,h,i)perylene	1.63E-07	1.46E-07	1.46E-07
Benzo(k)fluoranthene	1.84E-07	1.65E-07	1.65E-07
Beryllium	1.22E-06	1.10E-06	1.10E-06
Cadmium	1.12E-04	1.01E-04	1.01E-04
Chromium	1.43E-04	1.28E-04	1.28E-04
Chrysene	1.84E-07	1.65E-07	1.65E-07
Cobalt	8.57E-06	7.69E-06	7.69E-06
Dibenzo(a,h)anthracene	1.63E-07	1.46E-07	1.46E-07
Dichlorobenzene	1.22E-04	1.10E-04	1.10E-04
7,12-Dimethylbenz(a)anthracene	1.63E-06	1.46E-06	1.46E-06
Ethylbenzene	2.04E-04	1.83E-04	6.31E-04
Fluoranthene	3.06E-07	2.75E-07	2.75E-07
Fluorene	2.86E-07	2.56E-07	2.56E-07
Formaldehyde	7.65E-03	6.86E-03	6.86E-03
Hexane	1.33E-04	1.19E-04	4.21E-04
Indeno(1,2,3-cd)pyrene	1.84E-07	1.65E-07	1.65E-07
Lead	5.10E-05	4.58E-05	4.58E-05
Manganese	3.88E-05	3.48E-05	3.48E-05
Mercury	2.65E-05	2.38E-05	2.38E-05
3-Methylchloranthrene	1.84E-07	1.65E-07	1.65E-07
2-Methylnaphthalene	2.45E-06	2.20E-06	2.20E-06
Naphthalene	3.06E-05	2.75E-05	2.75E-05
Nickel	2.14E-04	1.92E-04	1.92E-04
Phenanthrene	1.73E-06	1.56E-06	1.56E-06
Pyrene	5.10E-07	4.58E-07	4.58E-07
Selenium	2.45E-06	2.20E-06	2.20E-06
Toluene	7.96E-04	7.14E-04	2.43E-03
Xylenes	5.92E-04	5.31E-04	1.80E-03

SOURCE: "Emissions Inventory Program, Emission Factors for Boilers," Mojave Desert Air Quality Management District, 2013. SCC = Source Classification Code.

2.4.5 Waste Oil

Waste oil includes used crankcase oils from automobiles and trucks, used industrial lubricating oils, and other used industrial oils (i.e., heat transfer fluids), as well as a minimal amount of oil considered contaminated. After being discarded, the physical properties of these oils changes as the components break down and the oil is contaminated with the materials that are brought into contact with the discarded oils. These waste oils may be burned in a variety of combustion systems and may be burned as mixtures or as single fuels where supplies allow.

Boilers designed to burn No. 6 residual fuel oil can be used to burn waste oil. Modifications may be made to the boiler to optimize combustion, or the waste oil may be blended with fuel oil to improve its combustion or emissions properties. The criteria pollutant, GHG and HAP EFs for waste oil-fired ECOM units are given in Table 2-15, Table 2-16, and Table 2-17 respectively.

Table 2-15. Criteria Pollutant Emission Factors for Waste Oil-Fired ECOM Units

Source Category [SCC]	Emission Factors (lb/10^3 gal)						
	NO_X	CO	SO_X[(a)]	Pb[(b)]	VOC[(c)]	PM_{10}[(d)]	$PM_{2.5}$[(d)]
Boilers [1-01-013-02[(e)], 1-02-013-02[(e)], 1-03-013-02]	19	5.0	147{**S**}	55{**L**}	1.0	51{**A**}	51{**A**}

SOURCE (Unless otherwise stated): Section 1.11 - "Waste Oil Combustion," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, October 1996. SCC = Source Classification Code.

a) Sulfur oxides (SO_X) emission factors based on weight % sulfur in the fuel. For example, if sulfur content is 3.4%, then{S}=3.4.

b) Emission factor based on the weight percent of the lead in the fuel. For example, if the lead content of the waste oil is 5%, then L = 5. If the weight percent lead is unknown and data is unavailable, an emission factor of 2.2 lb/10^3 gal may be used. This value comes from Chapter 14 - "Uncontrolled Emission Factor Listing for Criteria Air Pollutants," Point Sources, Vol. 2, U.S. Environmental Protection Agency, Emission Inventory Improvement Program, July 2001.

c) AP-42 provides an emission factor for Total Organic Compounds (TOC). This value used here as a conservative estimate of volatile organic compounds (VOC). Note that a value is not given in the source document for Source Classification Code (SCC) 1-02-013-02, but it is assumed to be 1.0 lb/10^3gal.

d) Particulate matter (PM) based on the weight % ash of the fuel. For example, if ash content is 5%, then {A}=5. PM_{10} is assumed to be equal to $PM_{2.5}$.

e) SOURCE: Chapter 14-"Uncontrolled Emission Factor Listing for Criteria Air Pollutants," Point Sources, Vol. 2, U.S. Environmental Protection Agency, Emission Inventory Improvement Program, July 2001.

Table 2-16. GHG Emission Factors for Waste Oil-Fired ECOM Units

Source Category	Emission Factors (lb/10^3 gal)			
	CO_2	N_2O	CH_4	CO_2e[(a)]
All Waste Oil Boilers	22,514	0.183	0.913	22,591

SOURCE: "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 98-Mandatory Greenhouse Gas Reporting, Subpart C-General Stationary Fuel Combustion Sources," U.S. Environmental Protection Agency. SCC = Source Classification Code.

a) CO_2e calculated by summing the product of the default emission factors for CO_2, N_2O, and CH_4 and their respective Global Warming Potentials (GWP). The GWP for CO_2, N_2O, and CH_4 are 1, 298, and 25 respectively.

Table 2-17. HAP Emission Factors for Waste Oil-Fired ECOM Units

Hazardous Air Pollutant	Emission Factors (lb/10^3 gal)
	Small Boilers[(a)]
Arsenic	1.10E-01
Cadmium	9.30E-03
Chromium	2.00E-02
Cobalt	2.10E-04
Lead	55{L}[(b)]
Manganese	6.80E-02
Nickel	1.10E-02

SOURCE: Section 1.11 - “Waste Oil Combustion," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, October 1996.

a) Though the source document only stated Source Classification Code (SCC) 1-03-013-02, these emission factors are assumed to apply to the following SCCs as well: 1-01-013-02 and 1-02-013-02.

b) Lead emission factors based on weight % lead in the fuel. For example, if the lead content of the waste oil is 5%, then {L}=5. If the weight % of Pb is unknown and data is unavailable, an emission factor of 2.2 lb/10^3gal may be used. This value comes from the Chapter 14 - "Uncontrolled Emission Factor Listing for Criteria Air Pollutants," Point Sources, Vol. 2, U.S. Environmental Protection Agency, Emission Inventory Improvement Program, July 2001.

2.4.6 Landfill and Digester Gas

Digester gas is formed as organic matter breaks down in the absence of O_2. It is composed primarily of CH_4 and CO_2 with the remainder composed of various other contaminants. With an increased awareness of global warming, there has been a subsequent push to thermally destroy digester gas. This may occur through either combustion or non-combustion technologies. Combustion technologies may involve the use of these gases as a fuel in boilers, turbines, and internal combustion engines. Most often the gas is combusted by a flare converting most of the CH_4 to CO_2, which has a far lower global warming potential. Flares may be either open or enclosed. Open flares are relatively inexpensive and require less maintenance, but are more difficult to control and not as efficient in Non-Methane Organic Compound (NMOC) destruction as enclosed flares. For this reason, enclosed flares are more common. Criteria pollutant EFs for enclosed flares are given in Table 2-18. Similarly, the EFs for GHGs and HAPs for enclosed flares that combust digester gas are provided in Table 2-19 and Table 2-20 respectively. **Note that landfill gas is similar to digester gas and often combusted through flaring. However, the flaring of landfill gas is almost exclusively used in site remediation, so refer to the latest version of the *Air Emissions Guide for Air Force Transitory Sources* for information regarding landfill gas and its associated EFs.**

Table 2-18. Criteria Pollutant Emission Factors for Digester Gas Flares (Enclosed)

Fuel	Emission Factors (lb/10^6ft^3)					
	NO_X	CO	SO_X	VOC[(a)]	PM_{10}	$PM_{2.5}$[(b)]
Digester Gas	48.0	1.8	2.0	12.1	12.0	12.0

SOURCE: "Combustion - Gas Fuels," Air Pollution Control District (APCD), County of San Diego, August 1999.

a) Source document provided emission factor for ROG, which is assumed to be equal to volatile organic compounds (VOC).

b) $PM_{2.5}$ is assumed to be equal to PM_{10} using $PM_{2.5}$ fractions given by Krause, Mike and Smith, Steve, "Methodology to Calculate Particulate Matter (PM) 2.5 and PM 2.5 Significance Thresholds," South Coast Air Quality Management District, October 2006.

Table 2-19. GHG Emission Factors for Digester Gas Flares (Enclosed)

Fuel	Emission Factors (lb/10^6ft^3)			
	CO_2	N_2O	CH_4	CO_2e[(a)]
Digester Gas	75,190	0.910	4.621	75,577

SOURCE: "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 98-Mandatory Greenhouse Gas Reporting, Subpart C-General Stationary Fuel Combustion Sources," U.S. Environmental Protection Agency. SCC = Source Classification Code.

a) CO_2e calculated by summing the product of the default emission factors for CO_2, N_2O, and CH_4 and their respective Global Warming Potentials (GWP). The GWP for CO_2, N_2O, and CH_4 are 1, 298, and 25 respectively.

Table 2-20. HAP Emission Factors for Digester Gas Flares (Enclosed)

Hazardous Air Pollutant	Emission Factors (lb/10^6ft^3)
	Digester Gas
Benzene	2.77E-02
Chlorobenzene	2.00E-04
Dichlorobenzene	1.80E-03
Ethyl Benzene	1.00E-03
Ethylene Dichloride	1.40E-03
Formaldehyde	2.04E-01
Hexane	1.01E-02
Hydrogen Chloride	6.46E-01
Methylene Chloride	1.00E-04
Perchloroethylene	5.00E-04
Toluene	1.01E-02
1,1,1-Trichloroethane	1.00E-04
Trichloroethylene	3.00E-04
Xylenes	4.50E-03

SOURCE: "Combustion – Gas Fuels," Air Pollution Control District (APCD), County of San Diego, August 1999.

2.4.7 VOC Speciation

At USAF installations, external combustion sources are some of the biggest contributors to emissions of criteria pollutants. When conducting an AEI or making major source determinations, the emissions from external combustion sources, such as boilers, may be made more difficult. This may be because of the variables involved in boiler emissions. These variables include different fuel types and sub types with several firing configurations and emission control technologies. EFs are provided by several agencies and in a variety of documents including the *Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources* (AP-42). Several air quality management districts have also independently developed their own set of EFs. Since there is so much variety in the condition of the boiler and its configuration, any EFs are estimates of emissions only and should be used only in the absence of actual measured data.

The following tables provide the weight percent of speciated VOCs and HAPs that have been measured from several boilers using a variety of fuels and firing configurations. Since there are few sources of EFs available, those used in this guide were assumed to be representative of all boilers. The weight percent of individual pollutants were calculated, and are presented in Table 2-21, using the total VOCs as shown:

$$\boldsymbol{P_{Pol} = \frac{A_{Pol}}{AVOC_{Total}}}$$

Equation 2-1

Where,

$\mathbf{P_{Pol}}$ = Weight percent of a given pollutant (%)
$\mathbf{A_{Pol}}$ = Individual pollutant emission factor (lb/unit mass)
$\mathbf{AVOC_{Total}}$ = Total VOC emission factor (lb/unit mass)

Speciated VOCs are calculated by taking the product of the total VOCs and the weighted percentage of the individual VOC as follows:

$$\boldsymbol{E_{Pol} = E_{VOC} \times \frac{P_{Pol}}{100}}$$

Equation 2-2

Where,

$\mathbf{E_{Pol}}$ = Emissions of speciated VOC (lb/yr)
100 = Factor for converting percent to a fraction (%)
$\mathbf{E_{VOC}}$ = Emissions of total VOC (lb/yr)

Table 2-21. Speciated VOC Weight Percent for Boilers

Compound Name	HAP[(a)]	Natural Gas	Fuel Oil		Coal	LPG
			Residual[(b)]	Distillate	Bituminous[(c)]	
Acenaphthene	X	0.00%	0.02%	0.02%	0.01%	0.00%
Acenaphthylene	X	0.00%	0.02%	0.01%	0.00%	0.00%
Acetaldehyde	X	0.04%	1.56%	27.31%	8.97%	0.03%
Acetophenone	X	---	---	---	0.24%	---
Acrolein	X	0.03%	2.38%	27.31%	4.56%	0.03%
Anthracene	X	0.00%	0.02%	0.00%	0.00%	0.00%
Benzaldehyde		0.23%	---	---	---	0.24%
Benzene	X	1.61%	22.44%	0.34%	20.46%	0.06%
Benzo(a)anthracene	X	0.00%	0.01%	0.00%	0.00%	0.00%
Benzo(b,j,k)fluoranthene	X	0.00%	0.00%	0.00%	0.00%	0.00%
Benzo(g,h,i)perylene	X	0.00%	0.02%	0.00%	0.00%	0.00%
Benzo(a)pyrene	X	0.00%	0.02%	0.00%	0.00%	0.00%
Benzo(e)pyrene	X	---	0.00%	0.00%	---	---
Benzyl Chloride	X	---	---	---	11.02%	---
Biphenyl	X	---	---	---	0.03%	---
Bis(2-ethylhexyl)phthalate	X	---	---	---	1.15%	---
Bromoform	X	---	---	---	0.61%	---
1,3-Butadiene	X	---	4.17%	1.15%	---	---
Butane		29.79%	---	---	---	31.29%
Carbon Disulfide	X	---	---	---	2.05%	---
2-Chloroacetophenone	X	---	---	---	0.11%	---
Chlorobenzene	X	---	---	0.02%	0.35%	---
Chloroform	X	---	3.35%	---	0.93%	---
2-Chloronaphthalene		---	0.00%	0.00%	---	---
Chrysene	X	0.00%	0.02%	0.00%	0.00%	0.00%
Cumene	X	---	---	---	0.08%	---
Dibenzo(a,h)anthracene	X	0.00%	0.02%	0.00%	---	0.00%
Dichlorobenzene	X	0.02%	---	---	---	0.02%
7,12-Dimethylbenz(a)anthracene	X	0.00%	---	---	---	0.00%
Dimethyl Sulfate	X	---	---	---	0.76%	---
2,4-Dinitrotoluene	X	---	---	---	0.00%	---
Ethyl Benzene	X	0.09%	0.96%	0.02%	1.48%	0.07%
Ethyl Chloride	X	---	---	---	0.66%	---

Table 2-21. Speciated VOC Weight Percent for Boilers (cont.)

Compound Name	HAP[a]	Natural Gas	Fuel Oil		Coal	LPG
			Residual[b]	Distillate	Bituminous[c]	
Ethylene Dibromide	X	---	---	---	0.02%	---
Ethylene Dichloride	X	---	---	---	0.63%	---
Fluoranthene	X	0.00%	0.02%	0.00%	0.01%	0.00%
Fluorene	X	0.00%	0.02%	0.01%	0.01%	0.00%
Formaldehyde	X	0.86%	35.49%	27.32%	3.78%	1.12%
Hexane	X	0.43%	---	0.27%	1.05%	0.04%
Hydrogen Chloride	X	---	---	14.52%	---	---
Indeno(1,2,3-cd)pyrene	X	0.00%	0.01%	0.00%	0.00%	0.00%
Isophorone	X	---	---	---	9.13%	---
Methyl Bromide	X	---	---	---	2.52%	---
Methyl Chloride	X	---	---	---	8.34%	---
5-Methyl Chrysene	X	---	---	---	0.00%	---
Methyl ethyl ketone		---	---	---	6.14%	---
Methyl Hydrazine	X	---	---	---	2.68%	---
Methyl Methacrylate	X	---	---	---	0.32%	---
Methyl Tert-butyl Ether	X	---	---	---	0.55%	---
3-Methylchloranthrene	X	0.00%	---	---	---	0.00%
2-Methylnaphthalene	X	0.00%	0.05%	0.01%	---	0.00%
Naphthalene	X	0.01%	3.35%	0.41%	0.20%	0.00%
Pentane		36.88%	---	---	---	38.75%
Perylene	X	---	0.00%	0.00%	---	---
Phenanthrene	X	0.00%	0.03%	0.03%	0.04%	0.00%
Phenol	X	---	---	---	0.25%	---
Propane		22.70%	---	---	---	23.84%
Propionaldehyde	X	---	---	---	5.98%	---
Propylene		6.03%	14.80%	0.78%	---	4.06%
Pyrene	X	0.00%	0.02%	0.00%	0.01%	0.00%
Styrene	X	---	---	---	0.39%	---
Toluene	X	1.03%	4.93%	0.34%	3.78%	0.26%
Total Dioxins/Furans	X	---	---	0.00%	0.00%	---
Vinyl Acetate	X	---	---	---	0.12%	---
Xylenes	X	0.25%	6.27%	0.13%	0.58%	0.19%

SOURCE (unless otherwise stated): "Emissions Inventory Program, Emission Factors for Boilers," Mojave Desert Air Quality Management District (MDAQMD), 2013.

a) HAP = Hazardous Air Pollutant. An “X” indicates that pollutant is a HAP.

b) SOURCE: "CATEF - California Air Toxics Emission Factors," California Environmental Protection Agency, 1996.

c) SOURCE: Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency.

A value of 0.00% means that this compound was detected but the calculated weight percent is less than 0.005%.

“---” - No data available

2.5 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. Common control techniques have been described above and include FGR, LNB, SCR, SNCR, FGD, ESPs, and scrubber systems. These controls are primarily designed to reduce NO_X, SO_X, and PM emissions, though they may have an effect on emissions of other criteria pollutants. The average control efficiencies of most control devices have not been determined; rather, a set of EFs for the equipment with the control device has been calculated. If the control efficiency for the device is known, then the emissions from the external combustion device for uncontrolled emissions should be multiplied by the control efficiency of the device. If the efficiency is not known, then the appropriate EF should be selected when calculating emissions.

2.6 Emissions Calculation

If a combustion source is controlled, but a controlled EF is not available, the emissions can still be estimated by using the uncontrolled EF and the efficiency of the control device, if known. If the operation has a pollution control device for which an EF was derived and listed in the appropriate table, or the process is uncontrolled, then use a control efficiency of 0. Emissions from external combustion units can be calculated as follows:

$$\boldsymbol{E_{Pol} = Q \times EF_{Pol} \times \left[1 - \left(\frac{CE}{100}\right)\right]}$$

Equation 2-3

Where,

E_{Pol} = Annual emissions of pollutant (lb/yr)
Q = Annual quantity of fuel consumed (ton/yr for coal, 10^3gal/yr for fuel oils, waste oils, and LPG, and 10^6ft^3/yr for natural/landfill/digester gas)
CE = Efficiency of the control device (%) – 0 for uncontrolled operations
100 = Factor for converting a percent to a fraction
EF_{Pol} = Emission factor (lb/ton for coal, lb/10^3 gal for fuel oils, waste oils, and LPG, and lb/10^6ft^3 for natural gas). **Use the uncontrolled emission factor if calculating emissions from a source with a control device if the control device efficiency is known, otherwise use the emission factor developed for the appropriate control device.**

A detailed control volume for emissions from external combustion engines is provided in Figure 2-2.

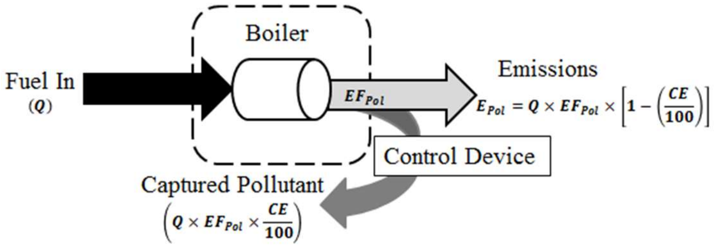

Figure 2-2. External Combustion Control Volume

2.7 Information Resources

Civil Engineering (CE) is usually responsible for operating and maintaining external combustion units on base. CE should be contacted to obtain the information required to calculate emissions (e.g., type and size of combustor, type and quantity of fuel burned, and type of control equipment). Fuel consumption data may be available through the Base Supply Fuels Maintenance office. Additionally, it may be necessary to contact the fuel supplier to determine metal content, sulfur weight percent, or other pertinent fuel data for the calculation of emissions. For specific data regarding emissions limits or reporting requirements, review the following: 40 CFR 60 Subparts Db and Dc or 40 CFR 63 Subparts DDDDD, UUUUU, or JJJJJJ.

2.8 Example Problem

A 12 MMBtu/hr industrial boiler (SCC 1-02-005-02) is fueled with 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 percent. Approximately 18,200 gallons (gal) of fuel oil was combusted in the boiler during the year. Calculate NO_X, VOC, and SO_2 emissions from the boiler.

Step 1 – **Select and record the appropriate emission factor.** Since the control efficiency is known for this device, select the uncontrolled EF for NO_X, SO_X, and VOC for an industrial boiler using distillate oil as provided in Table 2-6. For SCC 1-02-005-02, the NO_X, SO_X, and VOC EFs are listed as **20, 7.1**, and **0.2 lb/10^3 gal,** respectively.

Step 2 – **Convert the fuel units**. It is important to remember that the EFs for distillate fuel are in units of lb/10^3 gal, so the fuel consumption of 18,200 gal must be converted into the appropriate units as follows:

$$\boldsymbol{Q} = 18{,}200\,\frac{\cancel{gal}}{yr} \times \frac{1}{1000}\,\frac{10^3 gal}{\cancel{gal}} = \mathbf{18.2}\,\frac{\mathbf{10^3 gal}}{\boldsymbol{yr}}$$

Step 3 **- Calculate the NO$_X$ emissions.** Since NO$_X$ is the only pollutant of concern whose emissions are controlled, it is calculated using Equation 2-3, the EF as found in Step 1, and the stated control efficiency of 60 percent.

$$E_{Pol} = Q \times EF_{Pol} \times \left[1 - \left(\frac{CE}{100}\right)\right]$$

$$\mathrm{E}_{\mathrm{NO}_X} = 18.2 \frac{10^3 gal}{yr} \times 20 \frac{\mathrm{lb}}{10^3\mathrm{gal}} \times \left[1 - \left(\frac{60\cancel{\%}}{100\cancel{\%}}\right)\right]$$

$$\mathrm{E}_{\mathrm{NO}_X} = 18.2 \frac{10^3 gal}{yr} \times 20 \frac{\mathrm{lb}}{10^3\mathrm{gal}} \times [1 - (0.6)]$$

$$\mathrm{E}_{\mathrm{NO}_X} = 18.2 \frac{\cancel{10^3 gal}}{yr} \times 20 \frac{\mathrm{lb}}{\cancel{10^3\mathrm{gal}}} \times [0.4]$$

$$\boxed{\boldsymbol{E_{NO_X} = 145.60 \frac{lb}{yr}}}$$

Step 4 **- Calculate emissions of the uncontrolled pollutants**. Since FGR has no stated effect on the VOC or SO$_X$ emissions, these pollutants may be calculated using the EFs from Step 1, the fuel consumed from Step 2, and a control efficiency of "0" for both pollutants.

$$\mathrm{E}_{\mathrm{Pol}} = \mathrm{Q} \times EF_{Pol} \times \left[1 - \left(\frac{\mathrm{CE}}{100}\right)\right]$$

For SO$_X$ emissions:

$$E_{SO_X} = 18.2 \frac{10^3 gal}{yr} \times 7.1 \frac{lb}{10^3 gal} \times \left[1 - \frac{0\%}{100\%}\right]$$

$$E_{SO_X} = 18.2 \frac{\cancel{10^3 gal}}{yr} \times 7.1 \frac{lb}{\cancel{10^3 gal}} \times [1]$$

$$\boxed{\mathbf{E_{SOx} = 129.22 \frac{lb}{yr}}}$$

For VOC emissions:

$$E_{VOC} = 18.2 \frac{10^3 gal}{yr} \times 0.2 \frac{lb}{10^3 gal} \times \left[1 - \left(\frac{0\cancel{\%}}{100\cancel{\%}}\right)\right]$$

$$E_{VOC} = 18.2 \frac{\cancel{10^3 gal}}{yr} \times 0.2 \frac{lb}{\cancel{10^3 gal}} \times [1]$$

$$\boxed{\boldsymbol{E_{VOC} = 3.64 \frac{lb}{yr}}}$$

2.9 References

40 CFR 60 Subpart D, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New Stationary Sources, Subpart D-Standards of Performance for Fossil-Fuel-Fired Steam Generators," U.S. Environmental Protection Agency

40 CFR 60 Subpart Da, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New Stationary Sources, Subpart Da-Standards of Performance for Electric Utility Steam Generating Units," U.S. Environmental Protection Agency

40 CFR 60 Subpart Db, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New Stationary Sources, Subpart Db-Standards of Performance for Industrial-Commercial-Institutional Steam Generating Units," U.S. Environmental Protection Agency

40 CFR 60 Subpart Dc, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New Stationary Sources, Subpart Dc-Standards of Performance for Small Industrial-Commercial-Institutional Steam Generating Units," U.S. Environmental Protection Agency

40 CFR 63 Subpart DDDDD, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 63-National Emission Standards for Hazardous Air Pollutants for Source Categories, Subpart DDDDD-National Emission Standards for Hazardous Air Pollutants for Major Sources: Industrial, Commercial, and Institutional Boilers and Process Heaters," U.S. Environmental Protection Agency

40 CFR 63 Subpart UUUUU, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 63-National Emission Standards for Hazardous Air Pollutants for Source Categories, Subpart UUUUU-National Emission Standards for Hazardous Air Pollutants: Coal and Oil-Fired Electric Utility Steam Generating Units," U.S. Environmental Protection Agency

40 CFR 63 Subpart JJJJJJ, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 63-National Emission Standards for Hazardous Air Pollutants for Source Categories, Subpart JJJJJJ-National Emission Standards for Hazardous Air Pollutants for Industrial, Commercial, and Institutional Boilers Area Sources," U.S. Environmental Protection Agency

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USEPA 1996a, Section 1.2-“Anthracite Coal Combustion," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, October 1996

USEPA 1996b, Section 1.11-“Waste Oil Combustion," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, October 1996

USEPA 1998a, Section 1.1-“Bituminous and Subbituminous Coal Combustion," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, September 1998

USEPA 1998b, Section 1.4-“Natural Gas Combustion,” Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, July 1998

USEPA 1998c, Section 1.7-“Lignite Combustion,” Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, September 1998

USEPA 2008, Section 1.5-“Liquefied Petroleum Gas Combustion," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, July 2008

USEPA 2010, Section 1.3-“Fuel Oil Combustion," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, May 2010

3 STATIONARY INTERNAL COMBUSTION ENGINES (ICOM)

- *Point Source*

3.1 Introduction

Stationary Internal Combustion (ICOM) engines typically found at a USAF base may include generators, pumps, and compressors. Stationary ICOM engines should not be confused with non-road engines because stationary ICOM engines do not "propel a motor vehicle, aircraft, or a vehicle used solely for competition" (40 CFR 60.4219). **This section is exclusively concerned with emissions from stationary ICOM engines emitted during normal use and maintenance operations. Emissions from non-road ICOM engines are given in the latest version of the *Air Emissions Guide for Air Force Mobile Sources*.**

Stationary ICOM engines may be broken up into two categories: reciprocating and gas turbine. For reciprocating engines, a piston moves inside a cylinder to compress an air/fuel mixture. The air/fuel mixture combusts and expands, pushing the piston through the cylinder. The piston returns, pushing out the exhaust gases, and the cycle is repeated. For gas turbine engines, ambient air is pressurized with a compressor. Fuel is introduced to this compressed air and is ignited. The high temperature, high pressure air flows through a turbine where it expands, producing shaft energy that is used to drive both the compressor and the electric generator.

Reciprocating engines may differ in design by the diameter of the cylinders in the engine, known as the bore, and the length of the linear movement of the piston in each cylinder, known as the stroke. The size of the ICOM engine is related to its displacement per cylinder, which is a measure of the area of the cylinder multiplied by the length of the stroke. A reciprocating engine may be classified as either 4-stroke or 2-stroke. For a 4-stroke engine, the combustion cycle involves two revolutions of the crankshaft, to which the pistons are connected, and the cycle consists of four stages. The induction stroke occurs when the piston moves down within the cylinder, creating a vacuum and drawing in air or an air/fuel mixture. During the compression stroke, the piston moves up to pressurize the air or air/fuel mixture which then ignites. The heated air expands generating a force on the piston such that it is forced downward again in what is called the power stroke. Finally, the piston moves upward again to force the exhaust gas out of the cylinder during the exhaust stroke and returns to the starting position of the induction stroke so the cycle may be repeated. 2-stroke engines operate with just one revolution of the crankshaft because induction of the air or air/fuel mixture occurs concurrently with the release of the exhaust gas.

Detonation of the air/fuel mixture during the compression stroke may occur either through compression or spark ignition. In a Compression Ignition (CI) engine, air is first compressed by the piston in the cylinder, which causes the temperature of the air to rise. Fuel is added to the heated air and combusts since the temperature of the air is above the auto-ignition temperature of the fuel. CI engines may either run solely on diesel fuel or may use natural gas for operation in what is commonly called a dual fuel engine. Dual fuel engines utilize a combination of diesel fuel to ignite through compression and natural gas to sustain engine operation. Spark ignition (SI) engines, which use gasoline or natural gas, differ from CI engines in that the fuel/air mixture does not ignite spontaneously, but rather by a spark.

Emissions from ICOM engines will vary due to operating conditions such as temperature, humidity, torque, ignition timing, or even air/fuel mixture. An engine designed to operate near the stoichiometric air to fuel ratio is known as a rich-burn engine. An engine that operates with excess O_2 is known as a lean-burn engine. Typically, lean-burn engines will produce fewer NO_X emissions than rich-burn engines. Variation in the air/fuel mixture for either engine type will occur due to engine wear or atmospheric conditions, and even slight changes will dramatically affect pollutant emissions.

Gas turbine engines may be more advantageous than reciprocating engines because of their lower operational cost, lower levels of CO and VOC emissions, and potential use in cogeneration systems. However, gas turbine engines are not common on a USAF base due to the high initial cost. Most likely, the only turbine engines at a USAF installation will be found on the jet aircraft whose emissions are given in the latest version of the *Air Emissions Guide for Air Force Mobile Sources*. **Stationary ICOM engines and gas turbines are considered point sources** and a simple representation of these emissions is provided in Figure 3-1.

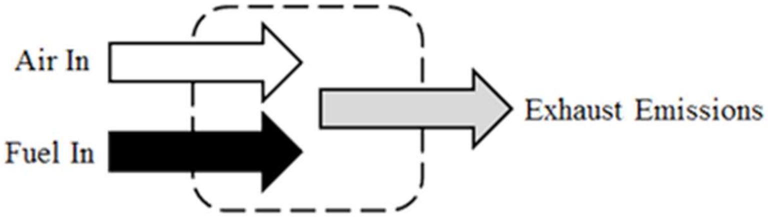

Figure 3-1. Simplified Control Volume for Emissions from Stationary ICOM Engines

3.2 NSPS and NESHAP Applicability

Internal combustion engines comprise a large list of pollutant-emitting equipment. The number of devices that fall into this category (both stationary and non-stationary) has led to the rise of several standards to help minimize the volume of emissions produced. One NSPS, which is given in 40 CFR 60 Subpart IIII, *Standards of Performance for Stationary Compression Ignition Internal Combustion Engines*, provides performance standards applicable to manufacturers, owners, and operators of engines with a displacement of less than 30 liters per cylinder. Subpart

IIII establishes criteria pollutant emissions limits for stationary CI engines based on the size and model year of the engine. This subpart requires most new stationary diesel engines to meet the Tier 1–4 emission standards for nonroad engines. Similarly, 40 CFR 60 Subpart JJJJ, *Standards of Performance for Stationary Spark Ignition Internal Combustion Engines*, provides emissions limits for SI reciprocating internal combustion engines based on hp and manufacture date. Stationary combustion turbines with a heat input at peak load equal to or greater than 10.7 gigajoules per hour have standards outlined in 40 CFR 60 Subpart GG, *Standards of Performance for Stationary Gas Turbines.* Additional standards are found in 40 CFR 60 Subpart KKKK, *Standards of Performance for Stationary Combustion Turbines*. Subpart GG applies to those turbines whose construction, modification, or reconstruction commenced after October 3, 1977. Subpart KKKK is applicable to turbines whose construction commenced after February 18, 2005.

In addition to the NSPS, NESHAPs have also been developed for stationary combustion turbines and stationary reciprocating internal combustion engines. Both standards apply to engines at facilities that are major sources of HAP emissions. Title 40 CFR 63 Subpart YYYY, *National Emission Standards for Hazardous Air Pollutants for Stationary Combustion Turbines*, specifies the HAP emissions limits and operational limits for stationary combustion turbines. Likewise, 40 CFR 63 Subpart ZZZZ, *National Emissions Standards for Hazardous Air Pollutants for Stationary Reciprocating Internal Combustion Engines*, outlines the emissions limits and operational limits for both SI and CI reciprocating internal combustion engines. Consult the sections listed above in the CFR for more information or to verify that the engines located on site comply with these standards.

3.3 Mandatory Greenhouse Gas Reporting Rule

The EPA has established mandatory GHG reporting requirements for owners and operators of facilities that directly emit GHGs into the atmosphere. According to 40 CFR 98.2, any facility operating stationary fuel combustion sources is subject to GHG reporting requirements under certain conditions. If the aggregate maximum rated heat input capacity is 30 MMBtu/hr and the facility emits 25,000 metric tons of equivalent CO_2 (CO_2e) or more per year in combined emissions from all stationary fuel combustion sources, the facility is subject to the reporting rules outlined in 40 CFR 98 Subpart C, *General Stationary Fuel Combustion Sources*. This rule requires that CO_2, CH_4, and N_2O mass emissions must be reported from each stationary combustion unit. Refer to 40 CFR 98 Subpart C for additional information regarding the GHG reporting requirements.

3.4 Emission Factors

Chapter 3 of AP-42 provides EFs for stationary ICOM engines based on the fuel type used and size of the equipment. However, increasingly stringent emissions requirements have driven the manufacture of engines that produce far less emissions than those engines that served as a basis for the development of the EFs found in AP-42. While these EFs may apply to older engines, their use in emissions calculations for newer engines may result in the overestimation of pollutant emissions. To reflect the increased engine efficiency and reduced emissions of the newer equipment replacing older inventory, the minimum required emission standards should be used. These minimum federal emission standards adopted by the EPA are known as NSPS. The NSPS thresholds were proposed to set standards not only for newly manufactured engines, but also older engines that have been rebuilt or modified.

EFs in this chapter are presented in units of both lb/hp-hr or lb/MMBtu so that emissions may be estimated using the fuel consumption method or load factor method described in Section 3.5. Conversion between these units is accomplished by applying a Brake Specific Fuel Consumption (BSFC) factor. The BSFC is an average of the fuel efficiency for the engine and the BSFC used for unit conversion is provided in the table notes.

3.4.1 Reciprocating Engines – Compression Ignition (CI)

For nonroad engines, increasingly stringent emission standards were implemented with each having a phase-in period known as Tier 1 - 4. Beginning in 2007, stationary CI ICOM emission standards were implemented and based on the nonroad engine tiers. The NSPS standards for CI engines are described in 40 CFR 60 Subpart IIII. The EPA has elected to have different emission standards for non-emergency, emergency (non-fire pump), and fire pump CI engines. Note that according to 40 CFR 60.4201(f)(1), CI engines used solely in areas of Alaska not accessible by the Federal Aid Highway System or at marine offshore installations are not required to comply with these standards.

To determine if an owner/operator of a stationary CI internal combustion engine (ICE) is subject to NSPS, refer to 40 CFR 60.4200. According to 40 CFR 60.4200:

(1) Owners and operators of stationary CI ICE that commence construction after July 11, 2005 where the stationary CI ICE are:
  (i) Manufactured after April 1, 2006, and are not fire pump engines, or
  (ii) Manufactured as a certified National Fire Protection Association (NFPA) fire pump engine after July 1, 2006.
(2) Owners and operators of any stationary CI ICE that are modified or reconstructed after July 11, 2005 and any person that modifies or reconstructs any stationary CI ICE after July 11, 2005.

(3) Owners and operators of any stationary CI ICE that are modified or reconstructed after July 11, 2005 and any person that modifies or reconstructs any stationary CI ICE after July 11, 2005.

For non-emergency stationary CI and dual-fuel ICE, select the appropriate EF from Table 3-3. If the engine is subject to NSPS, refer to the model year and pollutant for the appropriate EF. Engines not subject to NSPS are designated in the table. The table provides EFs in units of pound per horsepower-hour (lb/hp-hr) or pound per million British thermal units (lb/MMBtu) depending on the method used for calculation which is described later in this chapter. EFs for emergency non-fire pump and emergency fire pump are similarly listed in Table 3-4 and Table 3-5 respectively. Note that the tables do not provide EFs for engines with a displacement of 30 or more liters per cylinder. Since NSPS often provide emission limits for NO_X and either non-methane hydrocarbons (NMHC) or total hydrocarbons (THC), the NO_X and VOC EFs were calculated using the ratio of NOX to hydrocarbons calculated using AP-42.

3.4.1.1 NO_X Emission Factor Calculation

Depending on the size and year of manufacture, the NSPS standards stipulate a limit of emissions for some criteria pollutants. Frequently, there is a stated emission limit for the total combined emissions of NMHC and NO_X compounds. The presentation of a combined NO_X+NMHC emissions threshold is problematic since a value for the individual pollutants, NO_X and NMHC, must be determined. To estimate NO_X, the ratio of NO_X to NO_X plus NMHC, using the EFs given in AP-42, is multiplied to the standard given in NSPS. This is illustrated in the equation below.

$$NO_{X_{NSPS}} = \left[\frac{(NO_X + NMHC)_{NSPS}}{\left(NO_{X_{AP42}} + NMHC_{AP42}\right)}\right] \times NO_{X_{AP42}}$$

Where,

$NO_{X_{NSPS}}$ = NO_X emission factor using NSPS emission limits and NO_X/NMHC ratio as determined from previous test results.

$(NO_X+NMHC)_{NSPS}$ = Maximum allowable combined NO_X and NMHC emissions from an ICOM engine for a specified year as defined by the EPA.

$NO_{X_{AP42}}$ = NO_X emission factor provided in the appropriate table of Chapter 3 in AP-42.

$NMHC_{AP42}$ = NMHC emission factor **calculated** using the emission factor data from the appropriate table of Chapter 3 in AP-42. **Calculation of this emission factor is described in the next section of this guide.**

3.4.1.2 VOC Emission Factor Determination Using NSPS

AP-42 does not provide an EF for NMHC. This value must be calculated using the Total Organic Compounds (TOC) EF provided. In the introduction, AP-42 defines TOC to include "all VOCs and all exempted organic compounds including methane, ethane, chlorofluorocarbons, toxics and HAPs, aldehydes, and semi-volatile compounds." Similarly, VOCs are defined as "compounds of carbon, excluding carbon monoxide, carbon dioxide, carbonic acid, metallic carbides or carbonates, and ammonium carbonate." Additionally, the California Air Resources Board (CARB) defines an alternative category known as Total Organic Gas (TOG) as "compounds of carbon, excluding carbon monoxide, carbon dioxide, carbonic acid, metallic carbides or carbonates, and ammonium carbonate. TOG includes all organic gas compounds emitted to the atmosphere, including the low reactivity, or 'exempt VOC', compounds (e.g. methane, ethane, various chlorinated fluorocarbons, acetone, perchloroethylene, volatile methyl siloxanes, etc.)." Based on these definitions, TOC may be assumed to be equivalent to TOG. Using this substitution, NMHC may then be estimated using the ratio of TOG to total hydrocarbon (THC), and THC to NMHC or VOC. With the NMHC calculated, the NO_X EF is estimated using the equation provided in section 3.4.1.1. The conversion factors are provided in Table 3-1.

Table 3-1. Hydrocarbon Conversion Factors

Engine Type	TOG/THC	NMHC/THC	VOC/THC
Diesel	1.070	0.984	1.053
2-Stroke Gasoline	1.044	0.991	1.034
4-Stroke Gasoline	1.043	0.900	0.933

SOURCE: "Conversion Factors for Hydrocarbon Emission Components," U.S. Environmental Protection Agency (EPA), Office of Transportation and Air Quality, July 2010.

3.4.1.3 SO_X Emission Factor Determination Using Fuel Sulfur Content

Though the EPA has established emissions thresholds for several criteria pollutants, there are currently no thresholds for SO_X. For CI engines, the SO_X EF was taken directly from AP-42. For large CI engines (engines > 600 hp), the SO_X EF in AP-42 is a function of the sulfur content of the fuel used. In the following tables, the SO_X EF was calculated using the fuel data in Table 3-2.

Table 3-2. Data for Common Fuels Used in Stationary ICOM Engines

Fuel Type	Heating Value (Btu/Unit Fuel)	Sulfur Content (wt. %)(a)
Diesel	138,000 Btu/gal	0.0015(b)
MOGAS	125,000 Btu/gal	0.02
CNG	1,026 Btu/ft^3	0.0007
LPG	92,000 Btu/gal	Negligible
Landfill Gas	485 Btu/ft^3	0.00469(c)
Digester Gas	655 Btu/ft^3	---

SOURCE (unless otherwise stated): Table C-1 of "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 98-Mandatory Greenhouse Gas Reporting, Subpart C- General Stationary Fuel Combustion Sources," U.S. Environmental Protection Agency.

a) SOURCE: (unless otherwise stated): "Household Vehicles Energy Use: Latest Data & Trends," Energy Information Administration (EIA), Office of Energy Markets and End Use, U.S. Department of Energy, November 2005.

b) SOURCE: "Regulatory Announcement: Clean Air Nonroad Diesel Rule," U.S. Environmental Protection Agency (EPA), Office of Transportation and Air Quality, May 2004.

c) SOURCE: This value assumes a typical sulfur compound concentration of 46.9 parts per million by volume (ppmv) as given in "Section 2.4 - “Municipal Solid Waste Landfills," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, November 1998.

“---” – No Data available.

Table 3-3. Criteria Pollutant Emission Factors for Stationary Non-Emergency Compression Ignition ICOM Engines

Internal Combustion Engine Emission Factors															
Displacement (liters/cylinder)	**Maximum Engine Power (hp)**	**NSPS Applicability**	**Model Year**	**NO$_X$(a)**		**CO**		**SO$_X$(b)**		**VOC(c)**		**PM$_{10}$(d)**		**PM$_{2.5}$(d)**	
				lb/hp-hr	**lb/MMBtu**	**lb/hp-hr**	**lb/MMBtu**	**lb/hp-hr**	**lb/MMBtu**	**lb/hp-hr**	**lb/MMBtu**	**lb/hp-hr**	**lb/MMBtu**	**lb/hp-hr**	**lb/MMBtu**
All Dual Fuel Engines															
All				1.80E-02(e)	2.70E+00(e)	7.50E-03(e)	1.16E+00(e)	7.31E-06(e,f)	7.02E-04(e,f)	1.32E-03(e,g)	2.00E-01(e,g)	7.00E-04(h)	1.00E-01(h)	7.00E-04(h)	1.00E-01(h)
Diesel Fuel Engines															
D < 10	≤600 hp	non-NSPS	All years	3.57E-02(e)	4.41E+00(e)	7.68E-03(e)	9.50E-01(e)	1.26E-05	1.55E-03	2.79E-03(e)	3.44E-01(e)	2.51E-03(e)	3.10E-01(e)	2.51E-03(e)	3.10E-01(e)
	<11 hp	NSPS	Pre-2007	1.60E-02	1.98E+00	1.32E-02	1.64E+00	1.26E-05	1.55E-03	1.25E-03	1.55E-01	1.65E-03	2.04E-01	1.65E-03	2.04E-01
			2007	1.15E-02	1.42E+00	1.32E-02	1.64E+00	1.26E-05	1.55E-03	8.99E-04	1.11E-01	1.32E-03	1.64E-01	1.32E-03	1.64E-01
			2008	1.15E-02	1.42E+00	1.32E-02	1.64E+00	1.26E-05	1.55E-03	8.99E-04	1.11E-01	6.61E-04	8.18E-02	6.61E-04	8.18E-02
	11 ≤ hp < 25	NSPS	Pre-2007	1.46E-02	1.80E+00	1.08E-02	1.34E+00	1.26E-05	1.55E-03	1.14E-03	1.41E-01	1.32E-03	1.64E-01	1.32E-03	1.64E-01
			2007	1.15E-02	1.42E+00	1.08E-02	1.34E+00	1.26E-05	1.55E-03	8.99E-04	1.11E-01	1.32E-03	1.64E-01	1.32E-03	1.64E-01
			2008	1.15E-02	1.42E+00	1.08E-02	1.34E+00	1.26E-05	1.55E-03	8.99E-04	1.11E-01	6.61E-04	8.18E-02	6.61E-04	8.18E-02
	25 ≤ hp < 50	NSPS	Pre-2007	1.46E-02	1.80E+00	9.04E-03	1.12E+00	1.26E-05	1.55E-03	1.14E-03	1.41E-01	1.32E-03	1.64E-01	1.32E-03	1.64E-01
			2007	1.15E-02	1.42E+00	9.04E-03	1.12E+00	1.26E-05	1.55E-03	8.99E-04	1.11E-01	9.92E-04	1.23E-01	9.92E-04	1.23E-01
			2008	1.15E-02	1.42E+00	9.04E-03	1.12E+00	1.26E-05	1.55E-03	8.99E-04	1.11E-01	4.85E-04	6.00E-02	4.85E-04	6.00E-02
			2013	7.19E-03	8.89E-01	9.04E-03	1.12E+00	1.26E-05	1.55E-03	5.62E-04	6.94E-02	4.41E-05	5.45E-03	4.41E-05	5.45E-03
	50 ≤ hp < 75	NSPS	Pre-2007	1.52E-02	1.88E+00	7.68E-03(e)	9.50E-01(e)	1.26E-05	1.55E-03	2.79E-03(e)	3.44E-01(e)	2.51E-03(e)	3.10E-01(e)	2.51E-03(e)	3.10E-01(e)
			2007	1.15E-02	1.42E+00	8.16E-03	1.01E+00	1.26E-05	1.55E-03	8.99E-04	1.11E-01	6.61E-04	8.18E-02	6.61E-04	8.18E-02
			2008	7.19E-03	8.89E-01	8.16E-03	1.01E+00	1.26E-05	1.55E-03	5.62E-04	6.94E-02	6.61E-04(i)	8.18E-02(i)	6.61E-04(i)	8.18E-02(i)
			2013	7.19E-03	8.89E-01	8.16E-03	1.01E+00	1.26E-05	1.55E-03	5.62E-04	6.94E-02	4.41E-05	5.45E-03	4.41E-03	5.45E-01
	75 ≤ hp < 100	NSPS	Pre-2007	1.52E-02	1.88E+00	7.68E-03(e)	9.50E-01(e)	1.26E-05	1.55E-03	2.79E-03(e)	3.44E-01(e)	2.51E-03(e)	3.10E-01(e)	2.51E-03(e)	3.10E-01(e)
			2007	1.15E-02	1.42E+00	8.16E-03	1.01E+00	1.26E-05	1.55E-03	8.99E-04	1.11E-01	6.61E-04	8.18E-02	6.61E-04	8.18E-02
			2008	7.19E-03	8.89E-01	8.16E-03	1.01E+00	1.26E-05	1.55E-03	5.62E-04	6.94E-02	6.61E-04	8.18E-02	6.61E-04	8.18E-02
			2012	7.19E-03(j)	8.89E-01(j)	8.16E-03	1.01E+00	1.26E-05	1.55E-03	5.62E-04(j)	6.95E-02(j)	2.20E-05	2.73E-03	2.20E-05	2.73E-03
			2014	6.61E-04	8.18E-02	8.16E-03	1.01E+00	1.26E-05	1.55E-03	3.30E-04	4.08E-02	2.20E-05	2.73E-03	2.20E-05	2.73E-03
	100 ≤ hp < 175	NSPS	Pre-2007	1.52E-02	1.88E+00	7.68E-03(e)	9.50E-01(e)	1.26E-05	1.55E-03	2.79E-03(e)	3.44E-01(e)	2.51E-03(e)	3.10E-01(e)	2.51E-03(e)	3.10E-01(e)
			2007	6.16E-03	7.62E-01	8.16E-03	1.01E+00	1.26E-05	1.55E-03	4.81E-04	5.95E-02	4.85E-04	6.00E-02	4.85E-04	6.00E-02
			2008	6.16E-03	7.62E-01	8.16E-03	1.01E+00	1.26E-05	1.55E-03	4.81E-04	5.95E-02	4.85E-04	6.00E-02	4.85E-04	6.00E-02
			2012	6.16E-03(j)	7.62E-01(j)	8.16E-03	1.01E+00	1.26E-05	1.55E-03	4.81E-04(j)	5.95E-02(j)	2.20E-05	2.73E-03	2.20E-05	2.73E-03
			2014	6.61E-04	8.18E-02	8.16E-03	1.01E+00	1.26E-05	1.55E-03	3.30E-04	4.08E-02	2.20E-05	2.73E-03	2.20E-05	2.73E-03
	175 ≤ hp ≤ 600	NSPS	Pre-2007	1.52E-02	1.88E+00	1.87E-02	2.32E+00	1.26E-05	1.55E-03	2.36E-03	2.92E-01	8.82E-04	1.09E-01	8.82E-04	1.09E-01
			2007	6.16E-03	7.62E-01	5.73E-03	7.09E-01	1.26E-05	1.55E-03	4.81E-04	5.95E-02	3.31E-04	4.09E-02	3.31E-04	4.09E-02
			2011	6.16E-03(j)	7.62E-01(j)	5.73E-03	7.09E-01	1.26E-05	1.55E-03	4.81E-04(j)	5.95E-02(j)	2.20E-05	2.73E-03	2.20E-05	2.73E-03
			2014	6.61E-04	8.18E-02	5.73E-03	7.09E-01	1.26E-05	1.55E-03	3.30E-04	4.08E-02	2.20E-05	2.73E-03	2.20E-05	2.73E-03

Table 3-3. Criteria Pollutant Emission Factors for Stationary Non-Emergency Compression Ignition ICOM Engines (cont.)

Internal Combustion Engine Emission Factors															
Displacement (liters/cylinder)	Maximum Engine Power (hp)	NSPS Applicability	Model Year	NO_X(a)		CO		SO_X(b)		VOC(c)		PM_{10}(d)		$PM_{2.5}$(d)	
				lb/hp-hr	lb/MMBtu	lb/hp-hr	lb/MMBtu	lb/hp-hr	lb/MMBtu	lb/hp-hr	lb/MMBtu	lb/hp-hr	lb/MMBtu	lb/hp-hr	lb/MMBtu
D < 10	>600 hp	non-NSPS	All years	2.59E-02(e)	3.20E+00(e)	6.88E-03(e)	8.50E-01(e)	1.26E-05	1.55E-03	7.16E-04(e)	8.86E-02(e)	8.09E-04(e)	1.00E-01(e)	8.09E-04(e)	1.00E-01(e)
	600 < hp < 750	NSPS	Pre-2007	1.52E-02	1.88E+00	1.87E-02	2.32E+00	1.26E-05	1.55E-03	2.36E-03	2.92E-01	8.82E-04	1.09E-01	8.82E-04	1.09E-01
			2007	6.45E-03	7.97E-01	5.73E-03	7.09E-01	1.26E-05	1.55E-03	1.78E-04	2.21E-02	3.31E-04	4.09E-02	3.31E-04	4.09E-02
			2011	6.45E-03(j)	7.97E-01(j)	5.73E-03	7.09E-01	1.26E-05	1.55E-03	1.78E-04(j)	2.21E-02(j)	2.20E-05	2.73E-03	2.20E-05	2.73E-03
			2014	6.61E-04	8.18E-02	5.73E-03	7.09E-01	1.26E-05	1.55E-03	3.30E-04	4.08E-02	2.20E-05	2.73E-03	2.20E-05	2.73E-03
	750 ≤ hp ≤ 1200	NSPS	Pre-2007	1.52E-02	1.88E+00	1.87E-02	2.32E+00	1.26E-05	1.55E-03	2.36E-03	2.92E-01	8.82E-04	1.09E-01	8.82E-04	1.09E-01
			2007	1.03E-02	1.28E+00	5.73E-03	7.09E-01	1.26E-05	1.55E-03	2.86E-04	3.53E-02	3.31E-04	4.09E-02	3.31E-04	4.09E-02
			2011	5.73E-03	7.09E-01	5.73E-03	7.09E-01	1.26E-05	1.55E-03	7.08E-04	8.75E-02	1.65E-04	2.04E-02	1.65E-04	2.04E-02
			2015 Gen	1.10E-03	1.36E-01	5.73E-03	7.09E-01	1.26E-05	1.55E-03	3.30E-04	4.08E-02	4.41E-05	5.45E-03	4.41E-05	5.45E-03
			2015 Other	5.73E-03	7.09E-01	5.73E-03	7.09E-01	1.26E-05	1.55E-03	3.30E-04	4.08E-02	6.61E-05	8.18E-03	6.61E-05	8.18E-03
	1200 < hp ≤ 3000	NSPS	Pre-2007	1.52E-02	1.88E+00	1.87E-02	2.32E+00	1.26E-05	1.55E-03	2.36E-03	2.92E-01	8.82E-04	1.09E-01	8.82E-04	1.09E-01
			2007	1.03E-02	1.28E+00	5.73E-03	7.09E-01	1.26E-05	1.55E-03	2.86E-04	3.53E-02	3.31E-04	4.09E-02	3.31E-04	4.09E-02
			2011 Gen	1.10E-03	1.36E-01	5.73E-03	7.09E-01	1.26E-05	1.55E-03	7.08E-04	8.75E-02	1.65E-04	2.04E-02	1.65E-04	2.04E-02
			2011 Other	5.73E-03	7.09E-01	5.73E-03	7.09E-01	1.26E-05	1.55E-03	7.08E-04	8.75E-02	1.65E-04	2.04E-02	1.65E-04	2.04E-02
			2015 Gen	1.10E-03	1.36E-01	5.73E-03	7.09E-01	1.26E-05	1.55E-03	3.30E-04	4.08E-02	4.41E-05	5.45E-03	4.41E-05	5.45E-03
			2015 Other	5.73E-03	7.09E-01	5.73E-03	7.09E-01	1.26E-05	1.55E-03	3.30E-04	4.08E-02	6.61E-05	8.18E-03	6.61E-05	8.18E-03
	hp > 3000	NSPS	Pre-2007	1.52E-02	1.88E+00	1.87E-02	2.32E+00	1.26E-05	1.55E-03	2.36E-03	2.92E-01	8.82E-04	1.09E-01	8.82E-04	1.09E-01
			2007	1.52E-02	1.88E+00	1.87E-02	2.32E+00	1.26E-05	1.55E-03	2.36E-03	2.92E-01	8.82E-04	1.09E-01	8.82E-04	1.09E-01
			2011 Gen	1.10E-03	1.36E-01	5.73E-03	7.09E-01	1.26E-05	1.55E-03	7.08E-04	8.75E-02	1.65E-04	2.04E-02	1.65E-04	2.04E-02
			2011 Other	5.73E-03	7.09E-01	5.73E-03	7.09E-01	1.26E-05	1.55E-03	7.08E-04	8.75E-02	1.65E-04	2.04E-02	1.65E-04	2.04E-02
			2015 Gen	1.10E-03	1.36E-01	5.73E-03	7.09E-01	1.26E-05	1.55E-03	3.30E-04	4.08E-02	4.41E-05	5.45E-03	4.41E-05	5.45E-03
			2015 Other	5.73E-03	7.09E-01	5.73E-03	7.09E-01	1.26E-05	1.55E-03	3.30E-04	4.08E-02	6.61E-05	8.18E-03	6.61E-05	8.18E-03
10 ≤ D < 15	≤ 600 hp	non-NSPS	All years	3.57E-02(e)	4.41E+00(e)	7.68E-03(e)	9.50E-01(e)	1.26E-05	1.55E-03	2.79E-03(e)	3.44E-01(e)	2.51E-03(e)	3.10E-01(e)	2.51E-03(e)	3.10E-01(e)
		NSPS	Pre-2007	2.80E-02(k)	3.46E+00(k)	7.68E-03(e)	9.50E-01(e)	1.26E-05	1.55E-03	2.79E-03(e)	3.44E-01(e)	2.51E-03(e)	3.10E-01(e)	2.51E-03(e)	3.10E-01(e)
			2007	1.19E-02	1.47E+00	8.16E-03	1.01E+00	1.26E-05	1.55E-03	9.30E-04	1.15E-01	4.41E-04	5.45E-02	4.41E-04	5.45E-02
			2013	9.44E-03	1.17E+00	8.16E-03	1.01E+00	1.26E-05	1.55E-03	7.37E-04	9.12E-02	2.20E-04	2.73E-02	2.20E-04	2.73E-02
	> 600 hp	non-NSPS	All years	2.59E-02(e)	3.20E+00(e)	6.88E-03(e)	8.50E-01(e)	1.26E-05	1.55E-03	7.16E-04(e)	8.86E-02(e)	8.09E-04(e)	1.00E-01(e)	8.09E-04(e)	1.00E-01(e)
		NSPS	Pre-2007	2.80E-02(k)	3.46E+00(k)	6.88E-03(e)	8.50E-01(e)	1.26E-05	1.55E-03	7.16E-04(e)	8.86E-02(e)	8.09E-04(e)	1.00E-01(e)	8.09E-04(e)	1.00E-01(e)
			2007	1.25E-02	1.54E+00	8.16E-03	1.01E+00	1.26E-05	1.55E-03	3.45E-04	4.26E-02	4.41E-04	5.45E-02	4.41E-04	5.45E-02
	600 < hp < 4958 hp		2013	1.25E-02	1.54E+00	8.16E-03	1.01E+00	1.26E-05	1.55E-03	3.45E-04	4.26E-02	2.20E-04	2.73E-02	2.20E-04	2.73E-02
	hp ≥ 4958 hp			1.25E-02	1.54E+00	8.16E-03	1.01E+00	1.26E-05	1.55E-03	3.45E-04	4.26E-02	4.41E-04	5.45E-02	4.41E-04	5.45E-02

Table 3-3. Criteria Pollutant Emission Factors for Stationary Non-Emergency Compression Ignition ICOM Engines (cont.)

Internal Combustion Engine Emission Factors															
Displacement (liters/cylinder)	**Maximum Engine Power (hp)**	**NSPS Applicability**	**Model Year**	**NO$_X$(a)**		**CO**		**SO$_X$(b)**		**VOC(c)**		**PM$_{10}$(d)**		**PM$_{2.5}$(d)**	
				lb/hp-hr	**lb/MMBtu**	**lb/hp-hr**	**lb/MMBtu**	**lb/hp-hr**	**lb/MMBtu**	**lb/hp-hr**	**lb/MMBtu**	**lb/hp-hr**	**lb/MMBtu**	**lb/hp-hr**	**lb/MMBtu**
15 ≤ D < 20	≤ 600 hp	non-NSPS	All years	3.57E-02(e)	4.41E+00(e)	7.68E-03(e)	9.50E-01(e)	1.26E-05	1.55E-03	2.79E-03(e)	3.44E-01(e)	2.51E-03(e)	3.10E-01(e)	2.51E-03(e)	3.10E-01(e)
		NSPS	Pre-2007	2.80E-02(k)	3.46E+00(k)	7.68E-03(e)	9.50E-01(e)	1.26E-05	1.55E-03	2.79E-03(e)	3.44E-01(e)	2.51E-03(e)	3.10E-01(e)	2.51E-03(e)	3.10E-01(e)
			2007	1.33E-02	1.65E+00	8.16E-03	1.01E+00	1.26E-05	1.55E-03	1.04E-03	1.29E-01	8.16E-04	1.01E-01	8.16E-04	1.01E-01
			2014	1.07E-02	1.32E+00	8.16E-03	1.01E+00	1.26E-05	1.55E-03	8.34E-04	1.03E-01	5.51E-04	6.81E-02	5.51E-04	6.81E-02
	> 600 hp	non-NSPS	All years	2.59E-02(e)	3.20E+00(e)	6.88E-03(e)	8.50E-01(e)	1.26E-05	1.55E-03	7.16E-04(e)	8.86E-02(e)	8.09E-04(e)	1.00E-01(e)	8.09E-04(e)	1.00E-01(e)
		NSPS	Pre-2007	2.80E-02(k)	3.46E+00(k)	6.88E-03(e)	8.50E-01(e)	1.26E-05	1.55E-03	7.16E-04(e)	8.86E-02(e)	8.09E-04(e)	1.00E-01(e)	8.09E-04(e)	1.00E-01(e)
	600 < hp < 4425		2007	1.40E-02	1.73E+00	8.16E-03	1.01E+00	1.26E-05	1.55E-03	3.86E-04	4.78E-02	8.16E-04	1.01E-01	8.16E-04	1.01E-01
	hp ≥ 4425 hp			1.57E-02	1.94E+00	8.16E-03	1.01E+00	1.26E-05	1.55E-03	4.34E-04	5.37E-02	8.16E-04	1.01E-01	8.16E-04	1.01E-01
	600 < hp < 2681		2014	1.12E-02	1.38E+00	8.16E-03	1.01E+00	1.26E-05	1.55E-03	3.09E-04	3.82E-02	5.51E-04	6.81E-02	5.51E-04	6.81E-02
20 ≤ D < 25	≤ 600 hp	non-NSPS	All years	3.57E-02(e)	4.41E+00(e)	7.68E-03(e)	9.50E-01(e)	1.26E-05	1.55E-03	2.79E-03(e)	3.44E-01(e)	2.51E-03(e)	3.10E-01(e)	2.51E-03(e)	3.10E-01(e)
		NSPS	Pre-2007	2.80E-02(k)	3.46E+00(k)	7.68E-03(e)	9.50E-01(e)	1.26E-05	1.55E-03	2.79E-03(e)	3.44E-01(e)	2.51E-03(e)	3.10E-01(e)	2.51E-03(e)	3.10E-01(e)
			2007	1.50E-02	1.85E+00	8.16E-03	1.01E+00	1.26E-05	1.55E-03	1.17E-03	1.45E-01	8.16E-04	1.01E-01	8.16E-04	1.01E-01
			2014	1.50E-02	1.85E+00	8.16E-03	1.01E+00	1.26E-05	1.55E-03	1.17E-03	1.45E-01	4.41E-04	5.45E-02	4.41E-04	5.45E-02
	> 600 hp	non-NSPS	All years	2.59E-02(e)	3.20E+00(e)	6.88E-03(e)	8.50E-01(e)	1.26E-05	1.55E-03	7.16E-04(e)	8.86E-02(e)	8.09E-04(e)	1.00E-01(e)	8.09E-04(e)	1.00E-01(e)
		NSPS	Pre-2007	2.80E-02(k)	3.46E+00(k)	6.88E-03(e)	8.50E-01(e)	1.26E-05	1.55E-03	7.16E-04(e)	8.86E-02(e)	8.09E-04(e)	1.00E-01(e)	8.09E-04(e)	1.00E-01(e)
			2007	1.57E-02	1.94E+00	8.16E-03	1.01E+00	1.26E-05	1.55E-03	4.34E-04	5.37E-02	8.16E-04	1.01E-01	8.16E-04	1.01E-01
	600 < hp < 2681		2014	1.57E-02	1.94E+00	8.16E-03	1.01E+00	1.26E-05	1.55E-03	4.34E-04	5.37E-02	4.41E-04	5.45E-02	4.41E-04	5.45E-02
25 ≤ D < 30	≤ 600 hp	non-NSPS	All years	3.57E-02(e)	4.41E+00(e)	7.68E-03(e)	9.50E-01(e)	1.26E-05	1.55E-03	2.79E-03(e)	3.44E-01(e)	2.51E-03(e)	3.10E-01(e)	2.51E-03(e)	3.10E-01(e)
		NSPS	Pre-2007	2.80E-02(k)	3.46E+00(k)	7.68E-03(e)	9.50E-01(e)	1.26E-05	1.55E-03	2.79E-03(e)	3.44E-01(e)	2.51E-03(e)	3.10E-01(e)	2.51E-03(e)	3.10E-01(e)
			2007	1.68E-02	2.08E+00	8.16E-03	1.01E+00	1.26E-05	1.55E-03	1.31E-03	1.62E-01	8.16E-04	1.01E-01	8.16E-04	1.01E-01
			2014	1.68E-02	2.08E+00	8.16E-03	1.01E+00	1.26E-05	1.55E-03	1.31E-03	1.62E-01	4.41E-04	5.45E-02	4.41E-04	5.45E-02
	> 600 hp	non-NSPS	All years	2.59E-02(e)	3.20E+00(e)	6.88E-03(e)	8.50E-01(e)	1.26E-05	1.55E-03	7.16E-04(e)	8.86E-02(e)	8.09E-04(e)	1.00E-01(e)	8.09E-04(e)	1.00E-01(e)
		NSPS	Pre-2007	2.80E-02(k)	3.46E+00(k)	6.88E-03(e)	8.50E-01(e)	1.26E-05	1.55E-03	7.16E-04(e)	8.86E-02(e)	8.09E-04(e)	1.00E-01(e)	8.09E-04(e)	1.00E-01(e)
			2007	1.76E-02	2.18E+00	8.16E-03	1.01E+00	1.26E-05	1.55E-03	4.88E-04	6.03E-02	8.16E-04	1.01E-01	8.16E-04	1.01E-01
	600 < hp < 2681		2014	1.76E-02	2.18E+00	8.16E-03	1.01E+00	1.26E-05	1.55E-03	4.88E-04	6.03E-02	4.41E-04	5.45E-02	4.41E-04	5.45E-02

Notes for Table 3-3 provided on the next page.

Notes for Table 3-3:

SOURCE (unless otherwise stated): "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New Stationary Sources, Subpart IIII-Standards of Performance for Stationary Compression Ignition Internal Combustion Engines," U.S. Environmental Protection Agency. "Gen" Refers to generators. A brake-specific fuel consumption (BSFC) value of 8089 Btu/hp-hr was used to convert from lb/MMBtu to lb/hp-hr. This BSFC is given in Shire, Theresa M., et al, "Compendium of Greenhouse Gas Emissions Estimation Methodologies for the Oil and Natural Gas Industry," August 2009. NSPS = New Source Performance Standards.

a) Where thresholds of NO_X+NMHC or NO_X+THC were provided, the NO_X emission factor was calculated using the NO_X to NMHC or NO_X to THC ratio as determined by the emission factors provided in AP-42. Conversion of organics performed using ratios given in Table 3-1.

b) SO_X EF calculated using the following equation: S X 0.02 X D X (1/HV), where S = weight percent sulfur content of the fuel, 0.02 = conversion factor converting the weight percent to a weight fraction multiplied by the ratio of the molecular weight of SO2 to the molecular weight of sulfur, D = the density of the fuel, and HV = the heating value of the fuel. For this calculation, the values used were S - 0.0015%, D - 7.14 lb/gal, and HV - 0.138 MMBtu/gal. Emission factor calculated in units of lb/MMBtu and converted to lb/hp-hr using an average Brake-Specific Fuel Consumption (BSFC) of 8089 Btu/hp-hr.

c) VOC emission factors were estimated using the THC, NMHC, or TOC values calculated as in Note (a). Emission factor given in AP-42 was converted from units of lb/MMBtu to lb/hp-hr using an average BSFC of 8089 Btu/hp-hr. The TOC emission factor given in AP-42 assumed to be equal TOG and the conversion of organics to VOC was performed using the ratios given in Table 3-1.

d) For particulate matter (PM), it is assumed that $PM=PM_{10}=PM_{2.5}$.

e) SOURCE: *Compilation of Air Pollutant Emission Factors Volume I: Stationary Point and Area Sources.* Fifth Edition. 2000. Chapter 3. Emission factors converted from units of lb/MMBtu to lb/hp-hr using an average Brake-Specific Fuel Consumption (BSFC) of 8089 Btu/hp-hr.

f) SO_X emission factor calculated using the equation provided in the source document. The percent sulfur in the fuel oil and natural gas were assumed to be 0.0015 and 0.0007 respectively.

g) VOC emission factor taken from the source document as the "nonmethane" portion of the TOC.

h) Emission factor from large stationary diesel engines was used as a surrogate.

i) Regulation provides two options for meeting this limit, either all engines within this time frame must meet an emission limit of 0.22 g/hp-hr, OR may meet the previous limit (0.3 g/hp-hr) until 2012 and all 2012 engines would need to meet 2013 limits (0.022 g/hp-hr). Most conservative estimate assumes only previous emission limit is achieved and that value is provided here.

j) Regulation allows for the phasing in of the emission limits. Since an engine may or may not meet the more restrictive emission limit, the emission limit for the previous year is given.

k) NO_X emission limits vary depending on max test speed of the engine. The value provided is the most conservative value.

Table 3-4. Criteria Pollutant Emission Factors for Stationary Emergency Non-Fire Pump Compression Ignition ICOM Engines

Internal Combustion Engine Emission Factors															
Displacement (liters/cylinder)	**Maximum Engine Power (hp)**	**NSPS Applicability**	**Model Year**	**NO_X(a)**		**CO**		**SO_X(b)**		**VOC(c)**		**PM_{10}(d)**		**$PM_{2.5}$(d)**	
				lb/hp-hr	**lb/MMBtu**	**lb/hp-hr**	**lb/MMBtu**	**lb/hp-hr**	**lb/MMBtu**	**lb/hp-hr**	**lb/MMBtu**	**lb/hp-hr**	**lb/MMBtu**	**lb/hp-hr**	**lb/MMBtu**
D < 10	≤600 hp	non-NSPS	All years	3.57E-02(e)	4.41E+00(e)	7.68E-03(e)	9.50E-01(e)	1.26E-05	1.55E-03	2.79E-03(e)	3.44E-01(e)	2.51E-03(e)	3.10E-01(e)	2.51E-03(e)	3.10E-01(e)
	hp < 11	NSPS	Pre-2007	1.60E-02	1.98E+00	1.32E-02	1.64E+00	1.26E-05	1.55E-03	1.25E-03	1.55E-01	1.65E-03	2.04E-01	1.65E-03	2.04E-01
			2007	1.15E-02	1.42E+00	1.32E-02	1.64E+00	1.26E-05	1.55E-03	8.99E-04	1.11E-01	1.32E-03	1.64E-01	1.32E-03	1.64E-01
			2008	1.15E-02	1.42E+00	1.32E-02	1.64E+00	1.26E-05	1.55E-03	8.99E-04	1.11E-01	6.61E-04	8.18E-02	6.61E-04	8.18E-02
	11 ≤ hp < 25	NSPS	Pre-2007	1.46E-02	1.80E+00	1.08E-02	1.34E+00	1.26E-05	1.55E-03	1.14E-03	1.41E-01	1.32E-03	1.64E-01	1.32E-03	1.64E-01
			2007	1.15E-02	1.42E+00	1.08E-02	1.34E+00	1.26E-05	1.55E-03	8.99E-04	1.11E-01	1.32E-03	1.64E-01	1.32E-03	1.64E-01
			2008	1.15E-02	1.42E+00	1.08E-02	1.34E+00	1.26E-05	1.55E-03	8.99E-04	1.11E-01	6.61E-04	8.18E-02	6.61E-04	8.18E-02
	25 ≤ hp < 50	NSPS	Pre-2007	1.46E-02	1.80E+00	1.08E-02	1.34E+00	1.26E-05	1.55E-03	1.14E-03	1.41E-01	1.32E-03	1.64E-01	1.32E-03	1.64E-01
			2007	1.15E-02	1.42E+00	9.04E-03	1.12E+00	1.26E-05	1.55E-03	8.99E-04	1.11E-01	9.92E-04	1.23E-01	9.92E-04	1.23E-01
			2008	1.15E-02	1.42E+00	9.04E-03	1.12E+00	1.26E-05	1.55E-03	8.99E-04	1.11E-01	4.85E-04	6.00E-02	4.85E-04	6.00E-02
	50 ≤ hp < 100	NSPS	Pre-2007	1.52E-02	1.88E+00	7.68E-03(e)	9.50E-01(e)	1.26E-05	1.55E-03	2.79E-03(e)	3.44E-01(e)	2.51E-03(e)	3.10E-01(e)	2.51E-03(e)	3.10E-01(e)
			2007	1.15E-02	1.42E+00	8.16E-03	1.01E+00	1.26E-05	1.55E-03	8.99E-04	1.11E-01	6.61E-04	8.18E-02	6.61E-04	8.18E-02
			2008	7.19E-03	8.89E-01	8.16E-03	1.01E+00	1.26E-05	1.55E-03	5.62E-04	6.94E-02	6.61E-04	8.18E-02	6.61E-04	8.18E-02
	100 ≤ hp < 175	NSPS	Pre-2007	1.52E-02	1.88E+00	7.68E-03(e)	9.50E-01(e)	1.26E-05	1.55E-03	2.79E-03(e)	3.44E-01(e)	2.51E-03(e)	3.10E-01(e)	2.51E-03(e)	3.10E-01(e)
			2007	6.16E-03	7.62E-01	8.16E-03	1.01E+00	1.26E-05	1.55E-03	4.81E-04	5.95E-02	4.85E-04	6.00E-02	4.85E-04	6.00E-02
	175 ≤ hp < 600	NSPS	Pre-2007	1.52E-02	1.88E+00	1.87E-02	2.32E+00	1.26E-05	1.55E-03	2.36E-03	2.92E-01	8.82E-04	1.09E-01	8.82E-04	1.09E-01
			2007	6.16E-03	7.62E-01	5.73E-03	7.09E-01	1.26E-05	1.55E-03	4.81E-04	5.95E-02	3.31E-04	4.09E-02	3.31E-04	4.09E-02
	>600 hp	non-NSPS	All years	2.59E-02(e)	3.20E+00(e)	6.88E-03(e)	8.50E-01(e)	1.26E-05	1.55E-03	7.16E-04(e)	8.86E-02(e)	8.09E-04(e)	1.00E-01(e)	8.09E-04(e)	1.00E-01(e)
	600 ≤ hp < 750	NSPS	Pre-2007	1.52E-02	1.88E+00	1.87E-02	2.32E+00	1.26E-05	1.55E-03	2.36E-03	2.92E-01	8.82E-04	1.09E-01	8.82E-04	1.09E-01
			2007	6.45E-03	7.97E-01	5.73E-03	7.09E-01	1.26E-05	1.55E-03	1.78E-04	2.21E-02	3.31E-04	4.09E-02	3.31E-04	4.09E-02
	750 < hp ≤ 3000	NSPS	Pre-2007	1.52E-02	1.88E+00	1.87E-02	2.32E+00	1.26E-05	1.55E-03	2.36E-03	2.92E-01	8.82E-04	1.09E-01	8.82E-04	1.09E-01
			2007	1.03E-02	1.28E+00	5.73E-03	7.09E-01	1.26E-05	1.55E-03	2.86E-04	3.53E-02	3.31E-04	4.09E-02	3.31E-04	4.09E-02
	hp > 3000	NSPS	Pre-2007	1.52E-02	1.88E+00	1.87E-02	2.32E+00	1.26E-05	1.55E-03	2.36E-03	2.92E-01	8.82E-04	1.09E-01	8.82E-04	1.09E-01
			2007	1.52E-02	1.88E+00	1.87E-02	2.32E+00	1.26E-05	1.55E-03	2.36E-03	2.92E-01	8.82E-04	1.09E-01	8.82E-04	1.09E-01
			2011	1.03E-02	1.28E+00	5.73E-03	7.09E-01	1.26E-05	1.55E-03	2.86E-04	3.53E-02	3.31E-04	4.09E-02	3.31E-04	4.09E-02
10 ≤ D < 15	≤ 600 hp	non-NSPS	All years	3.57E-02(e)	4.41E+00(e)	7.68E-03(e)	9.50E-01(e)	1.26E-05	1.55E-03	2.79E-03(e)	3.44E-01(e)	2.51E-03(e)	3.10E-01(e)	2.51E-03(e)	3.10E-01(e)
		NSPS	Pre-2007	2.80E-02(f)	3.46E+00(f)	7.68E-03(e)	9.50E-01(e)	1.26E-05	1.55E-03	2.79E-03(e)	3.44E-01(e)	2.51E-03(e)	3.10E-01(e)	2.51E-03(e)	3.10E-01(e)
			2007	1.19E-02	1.47E+00	8.16E-03	1.01E+00	1.26E-05	1.55E-03	9.30E-04	1.15E-01	4.41E-04	5.45E-02	4.41E-04	5.45E-02
			2013	9.44E-03	1.17E+00	8.16E-03	1.01E+00	1.26E-05	1.55E-03	7.37E-04	9.12E-02	2.20E-04	2.73E-02	2.20E-04	2.73E-02
	> 600 hp	non-NSPS	All years	2.59E-02(e)	3.20E+00(e)	6.88E-03(e)	8.50E-01	1.26E-05	1.55E-03	7.16E-04(e)	8.86E-02(e)	8.09E-04(e)	1.00E-01(e)	8.09E-04(e)	1.00E-01(e)
		NSPS	Pre-2007	2.80E-02(f)	3.46E+00(f)	6.88E-03(e)	8.50E-01(e)	1.26E-05	1.55E-03	7.16E-04(e)	8.86E-02(e)	8.09E-04(e)	1.00E-01	8.09E-04(e)	1.00E-01(e)
			2007	1.25E-02	1.54E+00	8.16E-03	1.01E+00	1.26E-05	1.55E-03	3.45E-04	4.26E-02	4.41E-04	5.45E-02	4.41E-04	5.45E-02
	600 < hp < 4958 hp		2013	1.25E-02	1.54E+00	8.16E-03	1.01E+00	1.26E-05	1.55E-03	3.45E-04	4.26E-02	2.20E-04	2.73E-02	2.20E-04	2.73E-02
	hp ≥ 4958 hp			1.25E-02	1.54E+00	8.16E-03	1.01E+00	1.26E-05	1.55E-03	3.45E-04	4.26E-02	4.41E-04	5.45E-02	4.41E-04	5.45E-02

Table 3-4. Criteria Pollutant Emission Factors for Stationary Emergency Non-Fire Pump Compression Ignition ICOM Engines (cont.)

Internal Combustion Engine Emission Factors															
Displacement (liters/cylinder)	Maximum Engine Power (hp)	NSPS Applicability	Model Year	NO$_X$(a)		CO		SO$_X$(b)		VOC(c)		PM$_{10}$(d)		PM$_{2.5}$(d)	
				lb/hp-hr	lb/MMBtu	lb/hp-hr	lb/MMBtu	lb/hp-hr	lb/MMBtu	lb/hp-hr	lb/MMBtu	lb/hp-hr	lb/MMBtu	lb/hp-hr	lb/MMBtu
15 ≤ D < 20	≤ 600 hp	non-NSPS	All years	3.57E-02(e)	4.41E+00(e)	7.68E-03(e)	9.50E-01(e)	1.26E-05	1.55E-03	2.79E-03(e)	3.44E-01(e)	2.51E-03(e)	3.10E-01(e)	2.51E-03(e)	3.10E-01(e)
		NSPS	Pre-2007	2.80E-02(f)	3.46E+00(f)	7.68E-03(e)	9.50E-01(e)	1.26E-05	1.55E-03	2.79E-03(e)	3.44E-01(e)	2.51E-03(e)	3.10E-01(e)	2.51E-03(e)	3.10E-01(e)
			2007	1.33E-02	1.65E+00	8.16E-03	1.01E+00	1.26E-05	1.55E-03	1.04E-03	1.29E-01	8.16E-04	1.01E-01	8.16E-04	1.01E-01
			2014	1.07E-02	1.32E+00	8.16E-03	1.01E+00	1.26E-05	1.55E-03	8.34E-04	1.03E-01	5.51E-04	6.81E-02	5.51E-04	6.81E-02
	> 600 hp	non-NSPS	All years	2.59E-02(e)	3.20E+00(e)	6.88E-03(e)	8.50E-01(e)	1.26E-05	1.55E-03	7.16E-04(e)	8.86E-02(e)	8.09E-04(e)	1.00E-01(e)	8.09E-04(e)	1.00E-01(e)
		NSPS	Pre-2007	2.80E-02(f)	3.46E+00(f)	6.88E-03(e)	8.50E-01(e)	1.26E-05	1.55E-03	7.16E-04(e)	8.86E-02(e)	8.09E-04(e)	1.00E-01(e)	8.09E-04(e)	1.00E-01(e)
			2007	1.40E-02	1.73E+00	8.16E-03	1.01E+00	1.26E-05	1.55E-03	3.86E-04	4.78E-02	8.16E-04	1.01E-01	8.16E-04	1.01E-01
	600 < hp < 2682 hp		2014	1.12E-02	1.38E+00	8.16E-03	1.01E+00	1.26E-05	1.55E-03	3.09E-04	3.82E-02	5.51E-04	6.81E-02	5.51E-04	6.81E-02
	hp ≥ 2682 hp			1.40E-02	1.73E+00	8.16E-03	1.01E+00	1.26E-05	1.55E-03	3.86E-04	4.78E-02	8.16E-04	1.01E-01	8.16E-04	1.01E-01
20 ≤ D < 25	≤ 600 hp	non-NSPS	All years	3.57E-02(e)	4.41E+00(e)	7.68E-03(e)	9.50E-01(e)	1.26E-05	1.55E-03	2.79E-03(e)	3.44E-01(e)	2.51E-03(e)	3.10E-01(e)	2.51E-03(e)	3.10E-01(e)
		NSPS	Pre-2007	2.80E-02(f)	3.46E+00(f)	7.68E-03(e)	9.50E-01(e)	1.26E-05	1.55E-03	2.79E-03(e)	3.44E-01(e)	2.51E-03(e)	3.10E-01(e)	2.51E-03(e)	3.10E-01(e)
			2007	1.50E-02	1.85E+00	8.16E-03	1.01E+00	1.26E-05	1.55E-03	1.17E-03	1.45E-01	8.16E-04	1.01E-01	8.16E-04	1.01E-01
			2014	1.50E-02	1.85E+00	8.16E-03	1.01E+00	1.26E-05	1.55E-03	1.17E-03	1.45E-01	4.41E-04	5.45E-02	4.41E-04	5.45E-02
	> 600 hp	non-NSPS	All years	2.59E-02(e)	3.20E+00(e)	6.88E-03(e)	8.50E-01(e)	1.26E-05	1.55E-03	7.16E-04(e)	8.86E-02(e)	8.09E-04(e)	1.00E-01(e)	8.09E-04(e)	1.00E-01(e)
		NSPS	Pre-2007	2.80E-02(f)	3.46E+00(f)	6.88E-03(e)	8.50E-01(e)	1.26E-05	1.55E-03	7.16E-04(e)	8.86E-02(e)	8.09E-04(e)	1.00E-01(e)	8.09E-04(e)	1.00E-01(e)
			2007	1.57E-02	1.94E+00	8.16E-03	1.01E+00	1.26E-05	1.55E-03	4.34E-04	5.37E-02	8.16E-04	1.01E-01	8.16E-04	1.01E-01
	600 < hp < 2681		2014	1.57E-02	1.94E+00	8.16E-03	1.01E+00	1.26E-05	1.55E-03	4.34E-04	5.37E-02	4.41E-04	5.45E-02	4.41E-04	5.45E-02
	hp ≥ 2682 hp			1.57E-02	1.94E+00	8.16E-03	1.01E+00	1.26E-05	1.55E-03	4.34E-04	5.37E-02	8.16E-04	1.01E-01	8.16E-04	1.01E-01
25 ≤ D < 30	≤ 600 hp	non-NSPS	All years	3.57E-02(e)	4.41E+00(e)	7.68E-03(e)	9.50E-01(e)	1.26E-05	1.55E-03	2.79E-03(e)	3.44E-01(e)	2.51E-03(e)	3.10E-01(e)	2.51E-03(e)	3.10E-01(e)
		NSPS	Pre-2007	2.80E-02(f)	3.46E+00(f)	7.68E-03(e)	9.50E-01(e)	1.26E-05	1.55E-03	2.79E-03(e)	3.44E-01(e)	2.51E-03(e)	3.10E-01(e)	2.51E-03(e)	3.10E-01(e)
			2007	1.68E-02	2.08E+00	8.16E-03	1.01E+00	1.26E-05	1.55E-03	1.31E-03	1.62E-01	8.16E-04	1.01E-01	8.16E-04	1.01E-01
			2014	1.68E-02	2.08E+00	8.16E-03	1.01E+00	1.26E-05	1.55E-03	1.31E-03	1.62E-01	4.41E-04	5.45E-02	4.41E-04	5.45E-02
	> 600 hp	non-NSPS	All years	2.59E-02(e)	3.20E+00(e)	6.88E-03(e)	8.50E-01(e)	1.26E-05	1.55E-03	7.16E-04(e)	8.86E-02(e)	8.09E-04(e)	1.00E-01(e)	8.09E-04(e)	1.00E-01(e)
		NSPS	Pre-2007	2.80E-02(f)	3.46E+00(f)	6.88E-03(e)	8.50E-01(e)	1.26E-05	1.55E-03	7.16E-04(e)	8.86E-02(e)	8.09E-04(e)	1.00E-01(e)	8.09E-04(e)	1.00E-01(e)
			2007	1.76E-02	2.18E+00	8.16E-03	1.01E+00	1.26E-05	1.55E-03	4.88E-04	6.03E-02	8.16E-04	1.01E-01	8.16E-04	1.01E-01
	600 < hp < 2682 hp		2014	1.76E-02	2.18E+00	8.16E-03	1.01E+00	1.26E-05	1.55E-03	4.88E-04	6.03E-02	4.41E-04	5.45E-02	4.41E-04	5.45E-02
	hp ≥ 2682 hp			1.76E-02	2.18E+00	8.16E-03	1.01E+00	1.26E-05	1.55E-03	4.88E-04	6.03E-02	8.16E-04	1.01E-01	8.16E-04	1.01E-01

Notes for Table 3-4 given on the following page.

Notes for Table 3-4:

SOURCE (unless otherwise stated): "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New Stationary Sources, Subpart IIII-Standards of Performance for Stationary Compression Ignition Internal Combustion Engines," U.S. Environmental Protection Agency. "Gen" Refers to generators. A brake-specific fuel consumption (BSFC) value of 8089 Btu/hp-hr was used to convert from lb/MMBtu to lb/hp-hr. This BSFC is given in Shire, Theresa M., et al, "Compendium of Greenhouse Gas Emissions Estimation Methodologies for the Oil and Natural Gas Industry," August 2009. NSPS = New Source Performance Standards.

a) Where thresholds of NO_X+NMHC or NO_X+THC were provided, the NO_X emission factor was calculated using the NO_X to NMHC or NO_X to THC ratio as determined by the emission factors provided in AP-42. Conversion of organics performed using ratios given in Table 3-1.

b) SO_X emission factor calculated using the following equation: S X 0.02 X D X (1/HV), where S = weight percent sulfur content of the fuel, 0.02 = conversion factor converting the weight percent to a weight fraction multiplied by the ratio of the molecular weight of SO2 to the molecular weight of sulfur, D = the density of the fuel, and HV = the heating value of the fuel. For this calculation, the values used were S - 0.0015%, D - 7.14 lb/gal, and HV - 0.138 MMBtu/gal. Emission factor calculated in units of lb/MMBtu and converted to lb/hp-hr using an average Brake-Specific Fuel Consumption (BSFC) of 8089 Btu/hp-hr.

c) VOC emission factors were estimated using the THC, NMHC, or TOC values calculated as in Note (a). Emission factor given in AP-42 was converted from units of lb/MMBtu to lb/hp-hr using an average BSFC of 8089 Btu/hp-hr. The TOC emission factor given in AP-42 assumed to be equal TOG and the conversion of organics to VOC was performed using the ratios given in Table 3-1. TOC values provided in Compilation of Air Pollutant Emission Factors Volume I: Stationary Point and Area Sources used the "exhaust" values.

d) For Particulate Matter (PM), it is assumed that $PM=PM_{10}=PM_{2.5}$.

e) SOURCE: *Compilation of Air Pollutant Emission Factors Volume I: Stationary Point and Area Sources.* Fifth Edition. 2000. Chapter 3. Emission factors converted from units of lb/MMBtu to lb/hp-hr using an average Brake-Specific Fuel Consumption (BSFC) of 8089 Btu/hp-hr.

f) NO_X emission limits vary depending on max test speed of the engine. The value provided is the most conservative value.

Table 3-5. Criteria Pollutant Emission Factors for Stationary Emergency Fire Pump Compression Ignition ICOM Engines

Internal Combustion Engine Emission Factors															
Displacement (liters/cylinder)	Maximum Engine Power (hp)	NSPS Applicability	Model Year	NO_X(a)		CO		SO_X(b)		VOC(c)		PM_{10}(d)		$PM_{2.5}$(d)	
				lb/hp-hr	lb/MMBtu	lb/hp-hr	lb/MMBtu	lb/hp-hr	lb/MMBtu	lb/hp-hr	lb/MMBtu	lb/hp-hr	lb/MMBtu	lb/hp-hr	lb/MMBtu
All	≤600 hp	non-NSPS	All Years	3.57E-02(e)	4.41E+00(e)	7.68E-03(e)	9.50E-01(e)	1.26E-05	1.55E-03	2.79E-03(e)	3.44E-01(e)	2.51E-03(e)	3.10E-01(e)	2.51E-03(e)	3.10E-01(e)
	hp < 11	NSPS	Pre-2011	1.60E-02	1.98E+00	1.32E-02	1.64E+00	1.26E-05	1.55E-03	1.25E-03	1.55E-01	1.65E-03	2.04E-01	1.65E-03	2.04E-01
			2011	1.15E-02	1.42E+00	1.32E-02	1.64E+00	1.26E-05	1.55E-03	8.99E-04	1.11E-01	6.61E-04	8.18E-02	6.61E-04	8.18E-02
	11 ≤ hp < 25	NSPS	Pre-2011	1.46E-02	1.80E+00	1.08E-02	1.34E+00	1.26E-05	1.55E-03	1.14E-03	1.41E-01	1.32E-03	1.64E-01	1.32E-03	1.64E-01
			2011	1.15E-02	1.42E+00	1.08E-02	1.34E+00	1.26E-05	1.55E-03	8.99E-04	1.11E-01	6.61E-04	8.18E-02	6.61E-04	8.18E-02
	25 ≤ hp < 50	NSPS	Pre-2011	1.46E-02	1.80E+00	9.04E-03	1.12E+00	1.26E-05	1.55E-03	1.14E-03	1.41E-01	1.32E-03	1.64E-01	1.32E-03	1.64E-01
			2011	1.15E-02	1.42E+00	9.04E-03	1.12E+00	1.26E-05	1.55E-03	8.99E-04	1.11E-01	4.85E-04	6.00E-02	4.85E-04	6.00E-02
	50 ≤ hp < 100	NSPS	Pre-2011	1.60E-02	1.98E+00	8.16E-03	1.01E+00	1.26E-05	1.55E-03	1.25E-03	1.55E-01	1.32E-03	1.64E-01	1.32E-03	1.64E-01
			2011(f)	1.60E-02	1.98E+00	8.16E-03	1.01E+00	1.26E-05	1.55E-03	1.25E-03	1.55E-01	1.32E-03	1.64E-01	1.32E-03	1.64E-01
	100 ≤ hp < 175	NSPS	Pre-2010	1.60E-02	1.98E+00	8.16E-03	1.01E+00	1.26E-05	1.55E-03	1.25E-03	1.55E-01	1.32E-03	1.64E-01	1.32E-03	1.64E-01
			2010()	1.60E-02	1.98E+00	8.16E-03	1.01E+00	1.26E-05	1.55E-03	1.25E-03	1.55E-01	1.32E-03	1.64E-01	1.32E-03	1.64E-01
	175 ≤ hp < 600	NSPS	Pre-2009	1.60E-02	1.98E+00	5.73E-03	7.09E-01	1.26E-05	1.55E-03	1.25E-03	1.55E-01	8.82E-04	1.09E-01	8.82E-04	1.09E-01
			2009(f)	1.60E-02	1.98E+00	5.73E-03	7.09E-01	1.26E-05	1.55E-03	1.25E-03	1.55E-01	8.82E-04	1.09E-01	8.82E-04	1.09E-01
	>600 hp	non-NSPS	All Years	2.59E-02(e)	3.20E+00(e)	6.88E-03(e)	8.50E-01(e)	1.26E-05	1.55E-03	7.16E-04(e)	8.86E-02(e)	8.09E-04(e)	1.00E-01(e)	8.09E-04(e)	1.00E-01(e)
	600 ≤ hp ≤ 750	NSPS	Pre-2009	1.68E-02	2.07E+00	5.73E-03	7.09E-01	1.26E-05	1.55E-03	4.64E-04	5.74E-02	8.82E-04	1.09E-01	8.82E-04	1.09E-01
			2009(f)	1.68E-02	2.07E+00	5.73E-03	7.09E-01	1.26E-05	1.55E-03	4.64E-04	5.74E-02	8.82E-04	1.09E-01	8.82E-04	1.09E-01
	hp > 750	NSPS	Pre-2008	1.68E-02	2.07E+00	5.73E-03	7.09E-01	1.26E-05	1.55E-03	4.64E-04	5.74E-02	8.82E-04	1.09E-01	8.82E-04	1.09E-01
			2008	1.03E-02	1.28E+00	5.73E-03	7.09E-01	1.26E-05	1.55E-03	2.86E-04	3.53E-02	3.31E-04	4.09E-02	3.31E-04	4.09E-02

SOURCE (unless otherwise stated): "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New Stationary Sources, Subpart IIII-Standards of Performance for Stationary Compression Ignition Internal Combustion Engines," U.S. Environmental Protection Agency. "Gen" Refers to generators. A brake-specific fuel consumption (BSFC) value of 8089 Btu/hp-hr was used to convert from lb/MMBtu to lb/hp-hr. This BSFC is given in Shire, Theresa M., et al, "Compendium of Greenhouse Gas Emissions Estimation Methodologies for the Oil and Natural Gas Industry," August 2009. NSPS = New Source Performance Standards.

a) Where thresholds of NO_X+NMHC or NO_X+THC were provided, the NO_X emission factor was calculated using the NO_X to NMHC or NO_X to THC ratio as determined by the emission factors provided in AP-42. Conversion of organics performed using ratios given in Table 3-1.

b) SO_X emission factor calculated using the following equation: S X 0.02 X D X (1/HV), where S = weight percent sulfur content of the fuel, 0.02 = conversion factor converting the weight percent to a weight fraction multiplied by the ratio of the molecular weight of SO_2 to the molecular weight of sulfur, D = the density of the fuel, and HV = the heating value of the fuel. For this calculation, the values used were S - 0.0015%, D - 7.14 lb/gal, and HV - 0.138 MMBtu/gal. Emission factor calculated in units of lb/MMBtu and converted to lb/hp-hr using an average Brake-Specific Fuel Consumption (BSFC) of 8089 Btu/hp-hr.

c) VOC emission factors were estimated using the THC, NMHC, or TOC values calculated as in Note (a). Emission factor given in AP-42 was converted from units of lb/MMBtu to lb/hp-hr using an average Brake-Specific Fuel Consumption (BSFC) of 8089 Btu/hp-hr. The TOC emission factor given in AP-42 assumed to be equal TOG and the conversion of organics to VOC was performed using the ratios given in Table 3-1.

d) For Particulate Matter (PM) it is assumed that PM=PM_{10}=$PM_{2.5}$.

e) SOURCE: Compilation of Air Pollutant Emission Factors Volume I: Stationary Point and Area Sources. Fifth Edition. 2000. Chapter 3. Emission factors converted from units of lb/MMBtu to lb/hp-hr using an average Brake-Specific Fuel Consumption (BSFC) of 8089 Btu/hp-hr.

f) Regulation allows for the phasing in of these emission limits for engines within these model years that operate at a rated speed > 2650 rpm. For simplicity, the emission limits for the previous model year is provided.

3.4.1.4 GHG Emission Factor Calculation

As attention to global climate change intensifies, the estimation of GHG emissions becomes increasingly more significant. A composite GHG EF, in terms of CO_2e, was calculated using the default EF as given in Tables C-1 and C-2 of 40 CFR 98 for three GHGs using the methodology described in Section 1.4.4 of this guide. The emission factors are provided in Table 3-6 in both units of lb/hr and lb/MMBtu using a BSFC of 8089 Btu/hp-hr.

Table 3-6. GHG Emission Factors for Stationary Compression Ignition ICOM Engines

Source Category	Emission Factors							
	CO_2		CH_4		N_2O		CO_2e[(a)]	
	lb/hp-hr[(b)]	lb/MMBtu	lb/hp-hr[(b)]	lb/MMBtu	lb/hp-hr[(b)]	lb/MMBtu	lb/hp-hr	lb/MMBtu
All Stationary CI ICOM	1.32E+00	1.63E+02	5.35E-05	6.61E-03	1.07E-05	1.32E-03	1.32E+00	1.64E+02

SOURCE: "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 98-Mandatory Greenhouse Gas Reporting, Subpart C-General Stationary Fuel Combustion Sources," U.S. Environmental Protection Agency.

a) CO_2e calculated by summing the product of the default emission factors for CO_2, N_2O, and CH_4 and their respective Global Warming Potentials (GWP). The GWP for CO_2, N_2O, and CH_4 are 1, 298, and 25 respectively.

b) A Brake Specific Fuel Consumption (BSFC) value of 8089 Btu/hp-hr was used for unit conversion. This value from Shires, Theresa M., et al, "Compendium of Greenhouse Gas Emissions Estimation Methodologies for the Oil and Natural Gas Industry," August 2009.

3.4.1.5 HAP Speciation Emission Factor Determination

The NESHAP for stationary reciprocating ICOMs are given in 40 CFR 63 Subpart ZZZZ. The HAP EFs for stationary ICOM CI engines are provided in Table 3-7. Again, the EFs are presented in both units of lb/hp-hr and lb/MMBtu. The table designates the EFs applicable to NSPS and non-NSPS engines. Those EF for the non-NSPS are taken directly from sections 3.3 and 3.4 of AP-42, depending on the size of the engine. The NSPS values were calculated using the ratio of the pollutant to total VOC, given in AP-42, and multiplied by the total VOC as given in Table 3-3, Table 3-4, or Table 3-5. Since AP-42 provides EFs for engines less than or equal to 600 hp, and greater than 600 hp, the values were calculated for these size ranges. To minimize the size of the table, the most conservative VOC values within these size ranges from Table 3-3, Table 3-4, and Table 3-5 were used in the calculations.

Table 3-7. HAP Emission Factors for Stationary Compression Ignition ICOM Engines

Compound	Emission Factors											
	non-NSPS				NSPS(a)							
	Emergency and non-Emergency				non-Emergency and non-Fire Pump Emergency				Fire Pumps			
	All Displacements				All Displacements				All Displacements			
	All Model Years				2007 to Present				(b)			
	≤600 hp		>600 hp(c)		≤600 hp		>600 hp		≤600 hp		>600 hp	
	lb/hp-hr	lb/MMBtu	lb/hp-hr	lb/MMBtu	lb/hp-hr	lb/MMBtu	lb/hp-hr	lb/MMBtu	lb/hp-hr	lb/MMBtu	lb/hp-hr	lb/MMBtu
1,3-Butadiene	3.16E-07	3.91E-05	---	---	1.49E-07	1.84E-05	---	---	1.43E-07	1.76E-05	---	---
Acenaphthene	1.15E-08	1.42E-06	3.79E-08	4.68E-06	5.41E-09	6.69E-07	1.25E-08	1.54E-06	5.18E-09	6.40E-07	2.45E-08	3.03E-06
Acenaphthylene	4.09E-08	5.06E-06	7.47E-08	9.23E-06	1.93E-08	2.38E-06	2.46E-08	3.04E-06	1.84E-08	2.28E-06	4.84E-08	5.98E-06
Acetaldehyde	6.20E-06	7.67E-04	2.04E-07	2.52E-05	2.92E-06	3.61E-04	6.72E-08	8.31E-06	2.80E-06	3.46E-04	1.32E-07	1.63E-05
Acrolein	7.48E-07	9.25E-05	6.37E-08	7.88E-06	3.52E-07	4.36E-05	2.10E-08	2.60E-06	3.37E-07	4.17E-05	4.13E-08	5.11E-06
Anthracene	1.51E-08	1.87E-06	9.95E-09	1.23E-06	7.12E-09	8.81E-07	3.28E-09	4.05E-07	6.82E-09	8.43E-07	6.45E-09	7.97E-07
Benz(a)anthracene	1.36E-08	1.68E-06	5.03E-09	6.22E-07	6.40E-09	7.91E-07	1.66E-09	2.05E-07	6.12E-09	7.57E-07	3.26E-09	4.03E-07
Benzene	7.55E-06	9.33E-04	6.28E-06	7.76E-04	3.55E-06	4.39E-04	2.07E-06	2.56E-04	3.40E-06	4.20E-04	4.07E-06	5.03E-04
Benzo(a)pyrene	1.52E-09	1.88E-07	2.08E-09	2.57E-07	7.16E-10	8.85E-08	6.85E-10	8.47E-08	6.85E-10	8.47E-08	1.35E-09	1.66E-07
Benzo(b)fluoranthene	8.02E-10	9.91E-08	8.98E-09	1.11E-06	3.78E-10	4.67E-08	2.96E-09	3.66E-07	3.61E-10	4.47E-08	5.82E-09	7.19E-07
Benzo(g,h,i)perylene	3.96E-09	4.89E-07	4.50E-09	5.56E-07	1.86E-09	2.30E-07	1.48E-09	1.83E-07	1.78E-09	2.20E-07	2.91E-09	3.60E-07
Benzo(k)fluoranthene	1.25E-09	1.55E-07	1.76E-09	2.18E-07	5.90E-10	7.30E-08	5.81E-10	7.18E-08	5.65E-10	6.98E-08	1.14E-09	1.41E-07
Chrysene	2.86E-09	3.53E-07	1.24E-08	1.53E-06	1.34E-09	1.66E-07	4.08E-09	5.04E-07	1.29E-09	1.59E-07	8.02E-09	9.91E-07
Dibenz(a,h)anthracene	4.72E-09	5.83E-07	2.80E-09	3.46E-07	2.22E-09	2.75E-07	9.22E-10	1.14E-07	2.12E-09	2.63E-07	1.81E-09	2.24E-07
Fluoranthene	6.16E-08	7.61E-06	3.26E-08	4.03E-06	2.90E-08	3.58E-06	1.07E-08	1.33E-06	2.77E-08	3.43E-06	2.11E-08	2.61E-06
Fluorene	2.36E-07	2.92E-05	1.04E-07	1.28E-05	1.11E-07	1.38E-05	3.41E-08	4.22E-06	1.06E-07	1.32E-05	6.71E-08	8.29E-06
Formaldehyde	9.55E-06	1.18E-03	6.38E-07	7.89E-05	4.50E-06	5.56E-04	2.10E-07	2.60E-05	4.30E-06	5.32E-04	4.13E-07	5.11E-05
Indeno(1,2,3-c,d)pyrene	3.03E-09	3.75E-07	3.35E-09	4.14E-07	1.43E-09	1.77E-07	1.10E-09	1.36E-07	1.37E-09	1.69E-07	2.17E-09	2.68E-07
Naphthalene	6.86E-07	8.48E-05	1.05E-06	1.30E-04	3.23E-07	3.99E-05	3.47E-07	4.28E-05	3.09E-07	3.82E-05	6.81E-07	8.42E-05
Phenanthrene	2.38E-07	2.94E-05	3.30E-07	4.08E-05	1.12E-07	1.38E-05	1.09E-07	1.34E-05	1.07E-07	1.32E-05	2.14E-07	2.64E-05
Pyrene	3.87E-08	4.78E-06	3.00E-08	3.71E-06	1.82E-08	2.25E-06	9.89E-09	1.22E-06	1.74E-08	2.15E-06	1.94E-08	2.40E-06
Toluene	3.31E-06	4.09E-04	2.27E-06	2.81E-04	1.56E-06	1.93E-04	7.49E-07	9.26E-05	1.49E-06	1.84E-04	1.47E-06	1.82E-04
Xylenes	2.31E-06	2.85E-04	1.56E-06	1.93E-04	1.09E-06	1.34E-04	5.15E-07	6.36E-05	1.04E-06	1.28E-04	1.01E-06	1.25E-04

SOURCE (unless otherwise stated): Section 3.3 - "Gasoline and Diesel Industrial Engines," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, October 1996.

a) Source: Values calculated using the ratio of the pollutant to total Volatile Organic Compounds (VOC) as given in Chapter 3 of "Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition." This ratio was then multiplied by the total VOC as given in Table 3-3, Table 3-4, and Table 3-5. The most conservative VOC value was used to condense this table. The values used in calculations were: 1.62E-01 for non-emergency engines less than or equal to 600 hp; 2.92E-02 for non-emergency engines greater than 600 hp; 1.55E-01 for fire pumps less than or equal to 600 hp; and 5.74E-02 for fire pumps greater than 600 hp. NSPS = New Source Performance Standards.

b) Depending on the size of the engine, determines the applicability of the NSPS used in calculation of these emission factors. For engines less than 100 hp, the model year is 2011. For engines greater than or equal to 100 hp and less than 175 hp, the model year is 2010. For engines greater than or equal to 175 hp and less than or equal to 750 hp, the model year is 2009. For all engines greater than 750 hp, the model year is 2008.

c) SOURCE (unless otherwise stated): Section 3.4 - "Large Stationary Diesel and all Stationary Dual-fuel Engines," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, October 1996.

"---" – No data available.

3.4.2 Reciprocating Engines – Spark Ignition (SI)

The NSPS standards for SI engines are given in 40 CFR 60 Subpart JJJJ. As with CI engines, there have been different standards set by the EPA for both emergency and non-emergency engines. The criteria pollutant EFs come directly from AP-42 and are given in Table 3-8 while the GHG EFs are given in Table 3-9. Similarly, the HAP EFs, which are given in AP-42, are provided in Table 3-10.

3.4.3 Turbine Engines

Though there are emissions standards for turbine engines, these standards are often higher than those developed in AP-42. For this reason, turbine engines emissions may be calculated using the EFs given in Section 3.1 of AP-42. While there are likely to be very few turbine engines found at a USAF installation, those that are in operation may use diesel, natural gas, landfill gas, or digester gas as the primary fuel. The criteria pollutant and GHG EFs for turbines using these fuels are in Table 3-11 and Table 3-12 respectively. Additionally, Table 3-13 provides HAP speciation data for Turbine engines.

Table 3-8. Criteria Pollutant Emission Factors for Stationary Spark Ignition ICOM Engines

Fuel	Emission Factors											
	NO_X(a)		CO(a)		SO_X		VOC		PM_{10}		$PM_{2.5}$	
	lb/hp-hr(b)	lb/MMBtu	lb/hp-hr(b)	lb/MMBtu	lb/hp-hr(b)	lb/MMBtu	lb/hp-hr(b)	lb/MMBtu	lb/hp-hr(b)	lb/MMBtu	lb/hp-hr(b)	lb/MMBtu
Natural Gas - 2 Stroke Lean Burn	1.52E-02	1.94E+00	2.77E-03	3.53E-01	4.62E-06	5.88E-04	9.43E-04	1.20E-01	3.02E-04	3.84E-02	3.02E-04	3.84E-02
Natural Gas - 4 Stroke Lean Burn	6.66E-03	8.47E-01	4.38E-03	5.57E-01	4.62E-06	5.88E-04	9.27E-04	1.18E-01	6.06E-07	7.71E-05	6.06E-07	7.71E-05
Natural Gas - 4 Stroke Rich Burn	1.78E-02	2.27E+00	2.76E-02	3.51E+00	4.62E-06	5.88E-04	2.33E-04	2.96E-02	7.47E-05	9.50E-03	7.47E-05	9.50E-03
Gasoline	1.10E-02	1.63E+00	6.96E-03	9.90E-01	5.91E-04	8.40E-02	1.34E-02(c)	1.88E+00(c)	7.21E-04	1.00E-01	7.21E-04	1.00E-01

SOURCE: U.S. EPA. *Compilation of Air Pollutant Emission Factors Volume I: Stationary Point and Area Sources.* Fifth Edition. 2000. Chapter 3.

a) NO_X and CO emission factors for natural gas assume engine operates at <90% load.

b) An average Brake Specific Fuel Consumption (BSFC) of 7858 Btu/hp-hr for natural gas was used for unit conversion. This value from Shires, Theresa M., et al, "Compendium of Greenhouse Gas Emissions Estimation Methodologies for the Oil and Natural Gas Industry," August 2009.

c) Value converted from Total Organic Compounds (TOC) to VOC assuming TOC is equal to Total Organic Gas (TOG) and using the ratios provided in Table 3-1 for 4-stroke gasoline engines.

Table 3-9. GHG Emission Factors for Stationary Spark Ignition ICOM Engines

Fuel	Emission Factors							
	CO_2		CH_4		N_2O		CO_2e(a)	
	lb/hp-hr(b)	lb/MMBtu	lb/hp-hr(b)	lb/MMBtu	lb/hp-hr(b)	lb/MMBtu	lb/hp-hr	lb/MMBtu
Natural Gas	9.19E-01	1.17E+02	1.73E-05	2.20E-03	1.73E-06	2.20E-04	9.20E-01	1.17E+02
Gasoline	1.08E+00	1.55E+02	4.63E-05	6.61E-03	9.26E-06	1.32E-03	1.09E+00	1.55E+02

SOURCE: "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 98-Mandatory Greenhouse Gas Reporting, Subpart C-General Stationary Fuel Combustion Sources," U.S. Environmental Protection Agency.

a) CO_2e calculated by summing the product of the default emission factors for CO_2, N_2O, and CH_4 and their respective Global Warming Potentials (GWP). The GWP for CO_2, N_2O, and CH_4 are 1, 298, and 25 respectively.

b) A Brake Specific Fuel Consumption (BSFC) value of 7858 and 7000 Btu/hp-hr were used for unit conversion for natural gas and gasoline respectively. These values from Shires, Theresa M., et al, "Compendium of Greenhouse Gas Emissions Estimation Methodologies for the Oil and Natural Gas Industry," August 2009.

Table 3-10. HAP Emission Factors for Stationary Spark Ignition ICOM Engines

Compound	Emission Factors					
	Natural Gas					
	2-Stroke Lean Burn		4-Stroke Lean Burn		4-Stroke Rich Burn	
	lb/hp-hr(a)	lb/MMBtu	lb/hp-hr(a)	lb/MMBtu	lb/hp-hr(a)	lb/MMBtu
1,1,2,2,-Tetrachloroethane	5.21E-07	6.63E-05	3.14E-07	4.00E-05	1.99E-07	2.53E-05
1,1,2-Trichloroethane	4.14E-07	5.27E-05	2.50E-07	3.18E-05	1.20E-07	1.53E-05
1,1-Dichloroethane	3.07E-07	3.91E-05	1.85E-07	2.36E-05	8.88E-08	1.13E-05
1,2-Dichloropropane	3.50E-07	4.46E-05	2.11E-07	2.69E-05	1.02E-07	1.30E-05
1,3-Butadiene	6.44E-06	8.20E-04	2.10E-06	2.67E-04	5.21E-06	6.63E-04
1,3-Dichloropropene	3.44E-07	4.38E-05	2.07E-07	2.64E-05	9.98E-08	1.27E-05
2,2,4-Trimethylpentane	6.65E-06	8.46E-04	1.96E-06	2.50E-04	---	---
Acenaphthene	1.05E-08	1.33E-06	9.82E-09	1.25E-06	---	---
Acenaphthylene	2.49E-08	3.17E-06	4.35E-08	5.53E-06	---	---
Acetaldehyde	6.10E-05	7.76E-03	6.57E-05	8.36E-03	2.19E-05	2.79E-03
Acrolein	6.11E-05	7.78E-03	4.04E-05	5.14E-03	2.07E-05	2.63E-03
Anthracene	5.64E-09	7.18E-07	---	---	---	---
Benz(a)anthracene	2.64E-09	3.36E-07	---	---	---	---
Benzene	1.52E-05	1.94E-03	3.46E-06	4.40E-04	1.24E-05	1.58E-03
Benzo(a)pyrene	4.46E-11	5.68E-09	---	---	---	---
Benzo(b)fluoranthene	6.69E-11	8.51E-09	1.30E-09	1.66E-07	---	---
Benzo(g,h,i)perylene	1.95E-10	2.48E-08	3.25E-09	4.14E-07	---	---
Benzo(k)fluoranthene	3.35E-11	4.26E-09	---	---	---	---
Biphenyl	3.10E-08	3.95E-06	1.67E-06	2.12E-04	---	---
Carbon Tetrachloride	4.77E-07	6.07E-05	2.88E-07	3.67E-05	1.39E-07	1.77E-05
Chlorobenzene	3.49E-07	4.44E-05	2.39E-07	3.04E-05	1.01E-07	1.29E-05
Chloroethane	---	---	1.47E-08	1.87E-06	---	---
Chloroform	3.70E-07	4.71E-05	2.24E-07	2.85E-05	1.08E-07	1.37E-05
Chrysene	5.28E-09	6.72E-07	5.45E-09	6.93E-07	---	---
Ethylbenzene	8.49E-07	1.08E-04	3.12E-07	3.97E-05	1.95E-07	2.48E-05
Ethylene Dibromide	5.77E-07	7.34E-05	3.48E-07	4.43E-05	1.67E-07	2.13E-05
Ethylene Dichloride	3.32E-07	4.22E-05	1.85E-07	2.36E-05	8.88E-08	1.13E-05
Fluoranthene	2.84E-09	3.61E-07	8.72E-09	1.11E-06	---	---
Fluorene	1.33E-08	1.69E-06	4.46E-08	5.67E-06	---	---
Formaldehyde	4.34E-04	5.52E-02	4.15E-04	5.28E-02	1.61E-04	2.05E-02
Indeno(1,2,3-c,d)pyrene	7.80E-11	9.93E-09	---	---	---	---
Methanol	1.95E-05	2.48E-03	1.96E-05	2.50E-03	2.40E-05	3.06E-03
Methylene Chloride	1.16E-06	1.47E-04	1.57E-07	2.00E-05	3.24E-07	4.12E-05
n-Hexane	3.50E-06	4.45E-04	8.72E-06	1.11E-03	---	---
Naphthalene	7.57E-07	9.63E-05	5.85E-07	7.44E-05	7.63E-07	9.71E-05
Phenanthrene	2.77E-08	3.53E-06	8.17E-08	1.04E-05	---	---
Phenol	3.31E-07	4.21E-05	1.89E-07	2.40E-05	---	---
Pyrene	4.59E-09	5.84E-07	1.07E-08	1.36E-06	---	---
Styrene	4.31E-07	5.48E-05	1.85E-07	2.36E-05	9.35E-08	1.19E-05
Toluene	7.57E-06	9.63E-04	3.21E-06	4.08E-04	4.38E-06	5.58E-04
Vinyl Chloride	1.94E-07	2.47E-05	1.17E-07	1.49E-05	5.64E-08	7.18E-06
Xylenes	2.11E-06	2.68E-04	1.45E-06	1.84E-04	1.53E-06	1.95E-04

SOURCE: U.S. EPA. Compilation of Air Pollutant Emission Factors Volume I: Stationary Point and Area Sources. Fifth edition. 2000. Chapter 3.

a) An average Brake Specific Fuel Consumption (BSFC) of 7858 Btu/hp-hr for natural gas was used for unit conversion. This value from Shires, Theresa M., et al, "Compendium of Greenhouse Gas Emissions Estimation Methodologies for the Oil and Natural Gas Industry," August 2009.

“---” – No data available.

Table 3-11. Criteria Pollutant Emission Factors for Stationary Turbine ICOM Engines

Fuel	**Control Type**	**Emission Factors**											
		NO_X		**CO**		**SO_X(a)**		**VOC**		**PM_{10}(b)**		**$PM_{2.5}$(b)**	
		lb/hp-hr(c)	**lb/MMBtu**	**lb/hp-hr(c)**	**lb/MMBtu**	**lb/hp-hr(c)**	**lb/MMBtu**	**lb/hp-hr(c)**	**lb/MMBtu**	**lb/hp-hr(c)**	**lb/MMBtu**	**lb/hp-hr(c)**	**lb/MMBtu**
Natural Gas	Uncontrolled	3.32E-03	3.20E-01	8.51E-04	8.20E-02	6.83E-06	6.58E-04	2.18E-05	2.10E-03	6.85E-05	6.60E-03	6.85E-05	6.60E-03
	Water-Steam Injection	1.35E-03	1.30E-01	3.11E-04	3.00E-02	6.83E-06(d)	6.58E-04(d)	2.18E-05(d)	2.10E-03(d)	6.85E-05(d)	6.60E-03(d)	6.85E-05(d)	6.60E-03(d)
	Lean-Premix	1.03E-03	9.90E-02	1.56E-04	1.50E-02	6.83E-06(d)	6.58E-04(d)	2.18E-05(d)	2.10E-03(d)	6.85E-05(d)	6.60E-03(d)	6.85E-05(d)	6.60E-03(d)
Diesel Fuel	Uncontrolled	7.11E-03	8.80E-01	2.67E-05	3.30E-03	1.22E-05	1.52E-03	3.31E-06	4.10E-04	9.69E-06	1.20E-03	9.69E-06	1.20E-03
	Water-Steam Injection	1.94E-03	2.40E-01	6.14E-04	7.60E-02	1.22E-05(d)	1.52E-03(d)	3.31E-06(d)	4.10E-04(d)	9.69E-06(d)	1.20E-03(d)	9.69E-06(d)	1.20E-03(d)
Landfill Gas	Uncontrolled	1.13E-03	1.40E-01	3.55E-03	4.40E-01	3.64E-04	4.50E-02	1.05E-04	1.30E-02	1.86E-04	2.30E-02	1.86E-04	2.30E-02
Digester Gas	Uncontrolled	1.29E-03	1.60E-01	1.37E-04	1.70E-02	5.25E-05	6.50E-03	4.69E-05	5.80E-03	9.69E-05	1.20E-02	9.69E-05	1.20E-02

SOURCE: U.S. EPA. *Compilation of Air Pollutant Emission Factors Volume I: Stationary Point and Area Sources*. Fifth edition. 2000. Chapter 3.

a) For natural gas and diesel fuel-fired turbines, the SO_X emission factor was calculated using the equation from AP-42 and the sulfur content of the fuel for Natural gas and diesel as given in Table 3-2.

b) For Natural Gas and Distillate oil-fired turbines, the source provides a total PM emission factor though the source does provide a PM_{10} emission factor for landfill gas and digester gas-fired units. It is assumed that $PM=PM_{10}=PM_{2.5}$.

c) A Brake Specific Fuel Consumption (BSFC) of 10,379 Btu/hp-hr was used for unit conversion for natural gas turbines. A BSFC of 8078 Btu/hp-hr was used for all other turbines. These values come from Shires, Theresa M., et al, "Compendium of Greenhouse Gas Emissions Estimation Methodologies for the Oil and Natural Gas Industry," August 2009.

d) Source does not provide an emission factor for this pollutant using this control device. In lieu of any other data, the use of the non-controlled emission factor for this pollutant is recommended and provided here.

Table 3-12. GHG Emission Factors for Stationary Turbine ICOM Engines

Fuel	Emission Factors							
	CO_2		CH_4		N_2O		CO_2e[(a)]	
	lb/hp-hr[(b)]	lb/MMBtu	lb/hp-hr[(b)]	lb/MMBtu	lb/hp-hr[(b)]	lb/MMBtu	lb/hp-hr	lb/MMBtu
Natural Gas	1.21E+00	1.17E+02	2.29E-05	2.20E-03	2.29E-06	2.20E-04	1.22E+00	1.17E+02
Diesel	1.32E+00	1.63E+02	5.34E-05	6.61E-03	1.07E-05	1.32E-03	1.32E+00	1.64E+02
Landfill Gas	9.27E-01	1.15E+02	5.70E-05	7.05E-03	1.12E-05	1.39E-03	9.32E-01	1.15E+02
Digester Gas	9.27E-01	1.15E+02	5.70E-05	7.05E-03	1.12E-05	1.39E-03	9.32E-01	1.15E+02

SOURCE: "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 98-Mandatory Greenhouse Gas Reporting, Subpart C-General Stationary Fuel Combustion Sources," U.S. Environmental Protection Agency.

a) CO_2e calculated by summing the product of the default emission factors for CO_2, N_2O, and CH_4 and their respective Global Warming Potentials (GWP). The GWP for CO_2, N_2O, and CH_4 are 1, 298, and 25 respectively.

b) A Brake Specific Fuel Consumption (BSFC) value of 10379 Btu/hp-hr was used for unit conversion for natural gas. A BSFC of 8078 Btu/hp-hr was used for all other fuel-fired turbines. These values from Shires, Theresa M., et al, "Compendium of Greenhouse Gas Emissions Estimation Methodologies for the Oil and Natural Gas Industry," August 2009.

Table 3-13. HAP Emission Factors for Stationary Turbine ICOM Engines

Compound	Emission Factors							
	Gas Turbines							
	Natural Gas		Diesel		Landfill Gas		Digester Gas	
	lb/hp-hr(a)	lb/MMBtu	lb/hp-hr(a)	lb/MMBtu	lb/hp-hr(a)	lb/MMBtu	lb/hp-hr(a)	lb/MMBtu
1,3-Butadiene	4.46E-09	4.30E-07	1.29E-07	1.60E-05	---	---	7.92E-08	9.80E-06
1,4-Dichlorobenzene	---	---	---	---	---	---	1.62E-07	2.00E-05
Acetaldehyde	4.15E-07	4.00E-05	---	---	---	---	4.28E-07	5.30E-05
Acetonitrile	---	---	---	---	9.69E-08	1.20E-05	---	---
Acrolein	6.64E-08	6.40E-06	---	---	---	---	---	---
Benzene	1.25E-07	1.20E-05	4.44E-07	5.50E-05	1.70E-07	2.10E-05	---	---
Benzyl Chloride	---	---	---	---	9.69E-08	1.20E-05	---	---
Carbon Tetrachloride	---	---	---	---	1.45E-08	1.80E-06	1.62E-07	2.00E-05
Chlorobenzene	---	---	---	---	2.34E-08	2.90E-06	1.29E-07	1.60E-05
Chloroform	---	---	---	---	1.13E-08	1.40E-06	1.37E-07	1.70E-05
Ethylbenzene	3.32E-07	3.20E-05	---	---	---	---	---	---
Ethylene Dichloride	---	---	---	---	---	---	1.21E-07	1.50E-05
Formaldehyde	7.37E-06	7.10E-04	2.26E-06	2.80E-04	---	---	1.53E-06	1.90E-04
Methylene Chloride	---	---	---	---	1.86E-08	2.30E-06	1.05E-07	1.30E-05
Naphthalene	1.35E-08	1.30E-06	2.83E-07	3.50E-05	---	---	---	---
Propylene Oxide	3.01E-07	2.90E-05	---	---	---	---	---	---
Tetrachloroethylene	---	---	---	---	2.02E-08	2.50E-06	1.70E-07	2.10E-05
Toluene	1.35E-06	1.30E-04	---	---	8.89E-07	1.10E-04	---	---
Trichloroethylene	---	---	---	---	1.53E-08	1.90E-06	1.45E-07	1.80E-05
Vinyl Chloride	---	---	---	---	1.29E-08	1.60E-06	2.91E-07	3.60E-05
Vinylidene Chloride	---	---	---	---	---	---	1.21E-07	1.50E-05
Xylenes	6.64E-07	6.40E-05	---	---	2.50E-07	3.10E-05	---	---

SOURCE: U.S. EPA. *Compilation of Air Pollutant Emission Factors Volume I: Stationary Point and Area Sources*. Fifth edition. 2000. Chapter 3.

a) An average Brake Specific Fuel Consumption (BSFC) of 10379 Btu/hp-hr for natural gas was used for unit conversion. A BSFC of 8078 was used for all other turbines. These values from Shires, Theresa M., et al, "Compendium of Greenhouse Gas Emissions Estimation Methodologies for the Oil and Natural Gas Industry," August 2009.

“---” – No data available.

3.4.4 Using Emission Factors from Other Sources

In place of the EFs provided in this document, emissions may be estimated using EFs calculated directly from engine performance testing. Contact the APIMS helpdesk prior to using any EFs generated from emissions testing and for any guidance as needed.

3.4.4.1 Emissions Testing

Another option for emissions estimation utilizes the results from emissions tests conducted on the engine. The EPA has approved and promulgated test methods for determining pollutant emissions from stationary sources. Any emissions tests must adhere to the requirements of these established methods or be approved by the EPA for establishing valid data and subsequent EFs. Some of the most commonly used test methods include:

- **Method 1** – Establishes the location of data sampling points within the exhaust stack.
- **Method 2** – Used to determine stack gas velocity and volumetric flow rate.
- **Method 3** – Used to determine oxygen and CO_2 content as well as the dry molecular weight of the exhaust gas.
- **Method 4** – Used to determine the moisture content of the exhaust gas.
- **Method 5** – Used to determine PM emissions.
- **Method 6** – Used to determine SO_2 emissions.
- **Method 7** – Used to determine NO_X emissions.
- **Method 10** – Used to determine CO emissions.
- **Method 25** – Used to determine Total Organic Gas (TOG).

This list is not exhaustive, and multiple methods have been established depending on the pollutant of interest. Refer to the EPA's list of promulgated test methods for more information. The test methods outline the minimum equipment and calibration requirements needed to provide valid results.

If the results from emissions testing are used to establish EFs for a family of engines, only data from valid test runs may be used. A minimum of three tests should be conducted before an average emission rate is calculated, though more test results may yield EFs that are more representative of the engine being tested. Additional data points may also reveal any potential data outliers.

3.4.4.2 Exhaust Certification Data Sheets (Discouraged)

An engine manufacturer may be contacted to provide emissions certification sheets; however, the use of these certification sheets for EF development is not recommended. This is because the certification sheets were generated from data collected from tests conducted in a lab environment under ideal conditions. Unfortunately, this means that the engine is highly unlikely to achieve the same levels of performance and resulting emission rates. In contrast, a new engine may fall well short of the emission thresholds established by NSPS, so that when the engine is operated in the field, that engine may emit at a higher rate than the certification sheet, but may still emit below the NSPS thresholds. EFs developed from performance testing is acceptable since the tests are conducted in the field, under realistic environmental conditions.

3.5 Emissions Calculation

There are multiple methods to calculate emissions from stationary internal combustion engines. Calculation methods used are dependent on the data available to estimate emissions, the equations below show the various methods to calculate emissions.

3.5.1 Fuel Consumption Method

The fuel consumption method is the simplest method for calculating the emissions from stationary ICOM engines because all that is needed is the total fuel consumed by that engine and the EF. The emissions are calculated as follows:

$$\boldsymbol{E_{Pol} = Q \times HV \times \frac{1}{10^6} \times EF_{Pol}}$$

Equation 3-1

Where,

E_{Pol} = Annual emissions of pollutant (lb/yr)
Q = Annual quantity of fuel consumed (gal/yr) or (ft^3/yr)
HV = Heating value of the fuel used from Table 3-2(Btu/gal) or (Btu/ft^3)
10^6 = Factor to convert Btu to MMBtu (MMBtu/Btu)
EF_{Pol} = Emission factor from Table 3-3, Table 3-4, Table 3-5, Table 3-6, Table 3-7, Table 3-8, Table 3-9, Table 3-10, Table 3-11, Table 3-12, or Table 3-13

A detailed representation of the emissions from stationary ICOM engines is provided in Figure 3-2.

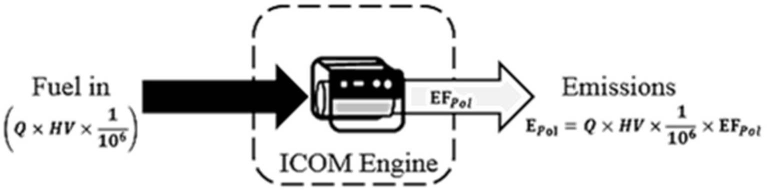

Figure 3-2. Stationary ICOM Control Volume - Fuel Consumption Method

3.5.2 Load Factor Method

To calculate the most accurate emissions for stationary ICOM engines, the first step is to gather the required data to look up and select the appropriate EF. To use the load factor method, the engine's rated power, operating time, and load factor must be known. Table 3-14 provides typical load factors for several categories of ICOM engines. The use of actual site-specific loading factors is preferable to using the typical load factor. Contact the Power Production shop for guidance in using an appropriate load factor for the engines at the installation. With the selected EF and load factor, the ICOM emissions are calculated using the following equation:

$$\boldsymbol{E_{Pol} = OT \times PO \times \frac{LF}{100} \times EF_{Pol}}$$

Equation 3-2

Where,

E_{Pol} = Annual emissions of pollutant (lb/yr)
PO = Rated power output of the engine (hp)
LF = Engine load factor (%)
100 = Factor for converting percent to fraction (%)
OT = Annual engine operating time (hr/yr)
EF_{Pol} = Emission factor from Table 3-3, Table 3-4, Table 3-5, Table 3-6, Table 3-7, Table 3-8, Table 3-9, Table 3-10, Table 3-11, Table 3-12, or Table 3-13

Table 3-14. Typical Load Factors for Common Stationary ICOM Equipment

Equipment Type	Diesel Load Factor (%)	Non-Diesel Load Factor[(a)] (%)
Air Compressor	48	56
Generator Set	74	68
Pumps	74	69
Refrigeration/AC	43[(a)]	46
Welders	45	68

SOURCE (Unless otherwise noted): "Software User's Guide: URBEMIS2007 for Windows," South Coast Air Quality Management District (SCAQMD), November 2007.

a) SOURCE: "Median Life, Annual Activity, and Load Factor Values for Nonroad Engine Emissions Modeling," U.S. Environmental Protection Agency (EPA), Office of Transportation and Air Quality, July 2010.

A representation of the emissions from stationary ICOM engines is provided in Figure 3-3.

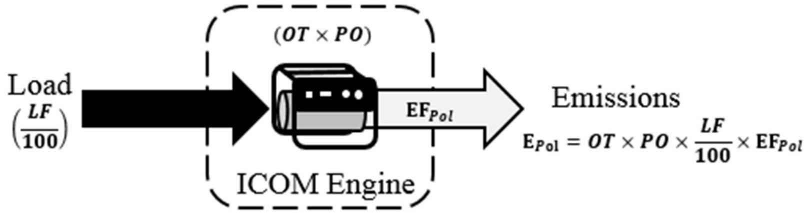

Figure 3-3. Stationary ICOM Control Volume - Load Factor Method

3.5.3 Discouraged Methods

Previous source guides have proposed alternative methods for emergency generators using the peak demand of the generator. This method assumes that the peak electrical demand is approximately the same as the power output of the generator. This is not recommended because this assumes that the generator was properly sized. As a result, this calculation method may significantly underestimate emissions and should no longer be used.

3.6 Information Resources

All EFs presented are conservative by necessity since each applies to a large range of equipment sizes and designs. To obtain data required for emissions calculations, contact the group responsible for operating and maintaining stationary ICOM equipment on base, typically CE power production. Additionally, consult the equipment specification sheets or contact the manufacturer directly. Since the EFs provided are applicable to a wide range of equipment sizes, the accuracy of emissions calculations may be enhanced by reviewing the CFR. This will help to determine the emissions thresholds of each pollutant for all stationary ICOM engines found on base. Alternatively, the manufacturer may be contacted to request any emissions data they may have on file for those engine models. If the engine's BSFC is available, either through the specification sheet or from the manufacturer, then that value should be used for EF unit conversion. Finally, since SO_X emissions are a function of the sulfur content of the fuel used, the installation's fuel supplier should be contacted to obtain the actual average sulfur content of the fuel used at that installation. These sulfur content values should be used in place of those provided in Table 3-2.

3.7 Example Problems

3.7.1 Problem #1 - Fuel Consumption Method

A USAF base is looking to determine the NO_X emissions from a natural gas-fired generator using spark ignition for the previous year. Determine the NO_X emissions from this generator for last year using the fuel consumption method. This installation is <u>not</u> located in Alaska. The generator is a 4-stroke, lean burn engine that used a total of 870 ft^3 of fuel last year.

<u>**Step 1**</u> **– Select and record emission factor and fuel heating value.** The EFs for natural gas-fired engines are provided in Table 3-8. For a 4-stroke, lean burn engine, the NO$_X$ EF is **8.47E-01 lb/MMBtu**. Table 3-2 shows the heating value of natural gas to be **1,026 Btu/ft^3.**

<u>**Step 2**</u> **– Choose a calculation method and record the appropriate equation.** For demonstration purposes, the calculation method was already assigned in the problem statement. However, it should be recognized that this is the most appropriate method to use since the power output and load factor are not provided while the annual fuel consumption is given. The formula for the fuel consumption method is:

$$E_{Pol} = Q \times HV \times \frac{1}{10^6} \times EF_{Pol}$$

<u>**Step 3**</u> **– Calculate emissions.** Using the fuel quantity data and EF and heating value recorded in Step 1, NO$_X$ emissions may be calculated using Equation 3-1.

$$E_{NO_X} = 870\left(\frac{\cancel{ft^3}}{yr}\right) \times 1{,}026\left(\frac{\cancel{Btu}}{\cancel{ft^3}}\right) \times \frac{1}{10^6}\left(\frac{\cancel{MMBtu}}{\cancel{Btu}}\right) \times 0.847\left(\frac{lb}{\cancel{MMBtu}}\right)$$

$$\boxed{\boldsymbol{E_{NO_X} = 0.76\frac{lb}{yr}}}$$

3.7.2 Problem #2 - Load Factor Method

A USAF base must calculate emissions from a stationary non-emergency diesel-fired generator. The installation is <u>not</u> located in Alaska. The generator is 1250 hp, has a displacement of 2.0 liters (L) per cylinder, was manufactured in 2004, and operated for 550 hours last year. Calculate the VOC emitted by this generator from last year using the load factor method.

<u>**Step 1**</u> **– Select and record emission factor and load factor.** The EFs for stationary diesel ICOM engines are provided in Table 3-3. For a 1250 hp diesel engine manufactured in 2004 (non-NSPS) with 2.0 L per cylinder displacement, the VOC EF is **7.16E-04 lb/hp-hr**. Similarly, Table 3-14 shows that the typical load factor for a diesel generator is **74%**.

<u>**Step 2**</u> **– Choose a calculation method and record the appropriate equation.** For demonstration purposes, the method was already assigned in the problem statement. The formula for the load factor method is:

$$E_{Pol} = OT \times PO \times \frac{LF}{100} \times EF_{Pol}$$

<u>Step 3</u> – Calculate emissions. Using the data above, VOC emissions are calculated as follows:

$$E_{VOC} = 550\left(\frac{hr}{yr}\right) \times 1250(hp) \times \frac{74\cancel{\%}}{100\cancel{\%}} \times 0.000716\left(\frac{lb}{hp-hr}\right)$$

$$E_{VOC} = 550\left(\frac{\cancel{hr}}{yr}\right) \times 1250(\cancel{hp}) \times 0.74 \times 0.000716\left(\frac{lb}{\cancel{hp-hr}}\right)$$

$$\boxed{\boldsymbol{E_{VOC} = 364.27\frac{lb}{yr}}}$$

3.8 References

40 CFR 60 Subpart GG, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New Stationary Sources, Subpart GG-Standards of Performance for Stationary Gas Turbines," U.S. Environmental Protection Agency

40 CFR 60 Subpart IIII, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New Stationary Sources, Subpart IIII-Standards of Performance for Stationary Compression Ignition Internal Combustion Engines," U.S. Environmental Protection Agency

40 CFR 60 Subpart JJJJ, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New Stationary Sources, Subpart JJJJ-Standards of Performance for Stationary Spark Ignition Internal Combustion Engines," U.S. Environmental Protection Agency

40 CFR 60 Subpart KKKK, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New Stationary Sources, Subpart KKKK-Standards of Performance for Stationary Combustion Turbines," U.S. Environmental Protection Agency

40 CFR 63 Subpart YYYY, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 63-National Emission Standards for Hazardous Air Pollutants for Source Categories, Subpart YYYY-National Emission Standards for Hazardous Air Pollutants for Stationary Combustion Turbines," U.S. Environmental Protection Agency

40 CFR 63 Subpart ZZZZ, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 63-National Emission Standards for Hazardous Air Pollutants for Source Categories, Subpart ZZZZ-National Emissions Standards for Hazardous Air Pollutants for Stationary Reciprocating Internal Combustion Engines," U.S. Environmental Protection Agency

40 CFR 98 Subpart C, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 98-Mandatory Greenhouse Gas Reporting, Subpart C- General Stationary Fuel Combustion Sources," U.S. Environmental Protection Agency

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SCAQMD 2007, “Software User's Guide: URBEMIS2007 for Windows,” South Coast Air Quality Management District (SCAQMD), November 2007

Shires 2009, Shires, Theresa M., et al, "Compendium of Greenhouse Gas Emissions Estimation Methodologies for the Oil and Natural Gas Industry," August 2009

USEPA 1996a, Section 3.3-“Gasoline and Diesel Industrial Engines," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, October 1996

USEPA 1996b, Section 3.4-“Large Stationary Diesel and All Stationary Dual-Fuel Engines," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, October 1996

USEPA 2000a, Section 3.2-“Natural Gas-Fired Reciprocating Engines," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, July 2000

USEPA 2000b, Section 3.1-“Stationary Gas Turbines," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, April 2000

USEPA 2004, "Regulatory Announcement: Clean Air Nonroad Diesel Rule," U.S. Environmental Protection Agency (EPA), Office of Transportation and Air Quality, May 2004

USEPA 2010a, "Conversion Factors for Hydrocarbon Emission Components," U.S. Environmental Protection Agency (EPA), Office of Transportation and Air Quality, July 2010

USEPA 2010b, "Median Life, Annual Activity, and Load Factor Values for Nonroad Engine Emissions Modeling," U.S. Environmental Protection Agency (EPA), Office of Transportation and Air Quality, July 2010

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4 AIRCRAFT ENGINE TESTING (JET)

- *Point Source*

***Applies to test cells, not engines still attached to aircraft.**

4.1 Introduction

Aircraft engine testing is performed at many USAF installations 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 is conducted in an enclosed test cell, though some installations perform limited engine testing on the aircraft or on test stands mounted in the open. **While testing of engines is generally considered a stationary source, if the engine is still on the aircraft during testing, it must be considered a mobile source as a flight operations source.** Additionally, some state/local regulatory agencies may have different interpretations of what may be considered a stationary or mobile source. Therefore, the appropriate state and/or local regulatory agency(s) should be contacted to confirm proper designation prior to performing an AEI. **The aircraft engine is a point source for criteria pollutants, HAPs, and GHGs.** A simple control volume for emissions from aircraft engine testing is given in Figure 4-1.

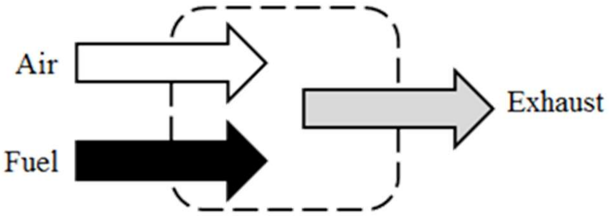

Figure 4-1. Simplified Aircraft Engine Testing Control Volume

4.2 NESHAP Applicability

NESHAPs from engine test cells/stands located at major sources of HAPs are outlined in 40 CFR 63 Subpart PPPPP, *National Emission Standards for Hazardous Air Pollutants for Engine Test Cells/Stands*. This Subpart provides emissions and operating limits for those installations determined to be major sources for HAPs. Additionally, this CFR states that each test cell/stand must use a continuous parameter monitoring system or a continuous emission monitoring system to verify compliance with these emission limits. To verify that the aircraft engine testing is adhering to these standards, or to review the general compliance requirements, consult 40 CFR 63 Subpart PPPPP.

4.3 Emission Factors

EFs for the calculation of emissions from aircraft engine testing have been calculated and may be obtained from the latest version of the *Air Emissions Guide for Air Force Mobile Sources.* It is important to understand the differences in flight operations and engine testing so that the correct EF may be selected from the tables in the *Air Emissions Guide for Air Force Mobile Sources*. An aircraft in use operates across several different power settings such as Idle, Approach, Intermediate, Military, and Afterburner. The tables provide an engine thrust percentage (if available), fuel flow rate, and an EF for each power setting. For calculation of emissions from flight operations, often the mode and time in mode are known, so calculations may be made simply by selecting the EFs for these modes for the appropriate engine. It is important to note that for each engine, there exists a range of values for fuel flow rate and engine thrust percentages which apply to the corresponding mode. The values provided in the tables are representative of specific power settings, though a range of values are acceptable. For calculating emissions from jet engine testing, the flight mode may not apply. Rather, testing occurs across varying fuel flow rates which are used to select the appropriate EFs. For calculating emissions, select the EF from the table with corresponding fuel flow rate closest to the fuel flow rate used during engine testing.

4.4 Emissions Calculation

Emissions from the testing of an aircraft engine may be determined by first calculating the emissions associated with testing at each different fuel flow rate. These emissions are then summed to provide total emissions for each pollutant of interest. Calculating emissions may be accomplished by multiplying the appropriate EF by the actual fuel flow rate, then by the actual time spent testing the engine at the specified fuel flow rate. The equation used to estimate aircraft engine testing emissions is as follows:

$$\boldsymbol{E_{Pol} = FFR \times \frac{1}{1000} \times T_{Test} \times EF_{Pol}}$$

Equation 4-1

Where,

E_{Pol} = Annual emissions of pollutant (lb/yr)

FFR = Fuel flow rate (lb/hr)

EF_{Pol} = Emission factor provided in the latest version of the *Air Emissions Guide for Air Force Mobile Sources* (lb/10^3 lb)

T_{Test} = Total annual time engine testing occurred while operating at the applicable fuel flow rate (hr/yr)

1000 = Factor for converting pounds to 10^3 pounds (lb/10^3lb)

A more detailed control volume describing the calculation of emissions from jet engine testing is given in Figure 4-2.

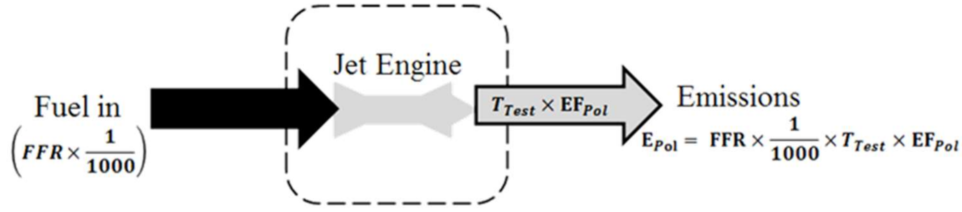

Figure 4-2. Aircraft Engine Testing Control Volume

The tables in the *Air Emissions Guide for Air Force Mobile Sources* provide SO_X EFs for each engine. The assumption is that all the sulfur in the fuel is converted to SO_X (as SO_2) during combustion. The SO_X EFs given in the tables assume a national average sulfur weight percent of 0.053 percent. For enhanced accuracy, if the sulfur weight percent of the fuel is known, a more accurate SO_X EF may be calculated using the following equation:

$$EF_{SO_x} = 20 \times S$$

Equation 4-2

Where,

EF_{SOx} = SO_x emission factor (lb/10^3 lb)
S = Weight percent sulfur content of the fuel (%)
20 = Factor for converting units from weight percent to lb/10^3 lb (lb/% 10^3 lb)

Note the conversion factor of "20" is the product of the factor to convert weight percent to a fraction, the respective weight of SO_2 to sulfur, and a factor converting lb to 10^3 lb as shown:

$$20 = \frac{1}{100\%} \times 2\frac{SO_2}{S} \times 1000\frac{lb}{10^3\ lb}$$

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, use the average sulfur content per region as provided in the latest version of the *Air Emissions Guide for Air Force Mobile Sources*. The *Air Emissions Guide for Air Force Mobile Sources* cites the *Petroleum Quality Information System Fuels Data* document as the data source used for fuel sulfur data.

4.5 Information Resources

The Aircraft Engine Maintenance organization should be contacted to obtain the information needed to calculate emissions from aircraft engine testing operations. This includes the types of engines tested, the total time spent testing an engine at each fuel flow rate, and the corresponding power setting. EFs may then be found in the latest version of the *Air Emissions Guide for Air Force Mobile Sources*.

4.6 Example Problem

A USAF installation uses a test cell to perform evaluations on the TF34-GE-100A engine that is used on their A-10 aircraft. According to records kept by the Aircraft Engine Maintenance organization, 108 engine tests were performed during the year. Each test used JP-8 with an average sulfur content of 0.055 percent. Calculate criteria pollutant emissions for this engine. The operating times and fuel flow rates were approximately the same for each test, and are:

Average Fuel Flow Rate During Testing (lb/hr)	Average Operating Time per test (minutes)
685	15
915	40
1,333	30
2,801	15

Step 1 **- Calculate the total time (hours) during the year in which testing was performed for each fuel flow rate.** Since the problem stated that the fuel flow rate was approximately the same for each test, this value may be multiplied by the number of tests and converted into hours as follows:

$$\boldsymbol{Total\,Time_{685\frac{lb}{hr}}} = 108\,\frac{\cancel{test}}{yr} \times 15\,\frac{\cancel{min}}{\cancel{test}} \times \frac{1}{60}\,\frac{hr}{\cancel{min}} = \mathbf{27}\,\boldsymbol{\frac{hr}{yr}}$$

$$\boldsymbol{Total\,Time_{915\frac{lb}{hr}}} = 108\,\frac{\cancel{test}}{yr} \times 40\,\frac{\cancel{min}}{\cancel{test}} \times \frac{1}{60}\,\frac{hr}{\cancel{min}} = \mathbf{72}\,\boldsymbol{\frac{hr}{yr}}$$

$$\boldsymbol{Total\,Time_{1333\frac{lb}{hr}}} = 108\,\frac{\cancel{test}}{yr} \times 30\,\frac{\cancel{min}}{\cancel{test}} \times \frac{1}{60}\,\frac{hr}{\cancel{min}} = \mathbf{54}\,\boldsymbol{\frac{hr}{yr}}$$

$$\boldsymbol{Total\,Time_{2801\frac{lb}{hr}}} = 108\,\frac{\cancel{test}}{yr} \times 15\,\frac{\cancel{min}}{\cancel{test}} \times \frac{1}{60}\,\frac{hr}{\cancel{min}} = \mathbf{27}\,\boldsymbol{\frac{hr}{yr}}$$

Step 2 – **Calculate the SO_X EF.** The problem stated that the average sulfur weight percent in the fuel was 0.055 percent which is different than the national average of 0.054 percent. Therefore, the SO_X EF must be calculated using Equation 4-2, as shown:

$$EF_{SO_x} = 20 \times S$$

$$\boldsymbol{EF_{SO_x}} = 20 \times 0.055 = \mathbf{1.10}$$

Step 3 - **Determine the appropriate EF to be used for each fuel flow rate.** The EFs (excluding SO_X) from the *Air Emissions Guide for Air Force Mobile Sources* (AFCEC, 2016) are as follows:

Aircraft Engine	Fuel Flow Rate(lb/hr)	Power Setting	Emission Factors (lb/1000 lb fuel)						
			NO_x	CO	VOC	HAP	PM_{10}	$PM_{2.5}$	CO_2e
TF34-GE-100A	498	Idle (Taxi)	0.32	65.62	2.24	2.03	8.13	3.60	3,233.87
	933	Approach	3.09	27.92	1.44	1.34	6.21	2.12	3,233.87
	1,512	Intermediate	5.61	8.88	0.13	0.09	8.93	6.95	3,233.87
	2,628	Military	9.11	3.94	0.07	.04	2.66	1.68	3,233.87

Comparing the fuel flow rates (FFR) from testing to those provided in the *Air Emissions Guide for Air Force Mobile Sources* (AFCEC, 2016), the appropriate EFs to use in emissions calculations are given below:

FFR from testing (lb/hr)	Nearest FFR in Guide (lb/hr)	Emission Factors (lb/1000 lb fuel)							
		NO_x	SO_x	CO	VOC	HAP	PM_{10}	$PM_{2.5}$	CO_2e
685	498	0.32	1.10	65.62	2.24	2.03	8.13	3.60	3,233.87
915	933	3.09	1.10	27.92	1.44	1.34	6.21	2.12	3,233.87
1,333	1,512	5.61	1.10	8.88	0.13	0.09	8.93	6.95	3,233.87
2,801	2,628	9.11	1.10	3.94	0.07	0.04	2.66	1.68	3,233.87

Step 4 - **Calculate EFs.** Using Equation 4-1, the appropriate EFs, and the total time (hr/yr) calculated in Step 1, determine the individual emissions.

$$E_{Pol} = FFR \times \frac{1}{1000} \times T_{Test} \times EF_{Pol}$$

For NO_X:

$$\boldsymbol{E}_{\boldsymbol{NO_X-685\frac{lb}{hr}}} = 685\frac{\cancel{lb}}{\cancel{hr}} \times \frac{1}{1000}\frac{\cancel{10^3 lb}}{\cancel{lb}} \times 27\frac{\cancel{hr}}{yr} \times 0.32\frac{lb}{\cancel{10^3 lb}} = \boldsymbol{5.92\frac{lb}{yr}}$$

$$\boldsymbol{E}_{\boldsymbol{NO_X-915\frac{lb}{hr}}} = 915\frac{\cancel{lb}}{\cancel{hr}} \times \frac{1}{1000}\frac{\cancel{10^3 lb}}{\cancel{lb}} \times 72\frac{\cancel{hr}}{yr} \times 3.09\frac{lb}{\cancel{10^3 lb}} = \boldsymbol{203.6\frac{lb}{yr}}$$

$$\boldsymbol{E}_{\boldsymbol{NO_X-1333\frac{lb}{hr}}} = 1333\frac{\cancel{lb}}{\cancel{hr}} \times \frac{1}{1000}\frac{\cancel{10^3 lb}}{\cancel{lb}} \times 54\frac{\cancel{hr}}{yr} \times 5.61\frac{lb}{\cancel{10^3 lb}} = \boldsymbol{403.8\frac{lb}{yr}}$$

$$\boldsymbol{E}_{\boldsymbol{NO_X-2801\frac{lb}{hr}}} = 2801\frac{\cancel{lb}}{\cancel{hr}} \times \frac{1}{1000}\frac{\cancel{10^3 lb}}{\cancel{lb}} \times 27\frac{\cancel{hr}}{yr} \times 9.11\frac{lb}{\cancel{10^3 lb}} = \boldsymbol{689.0\frac{lb}{yr}}$$

The other criteria pollutants are similarly calculated and presented in the following table:

FFR from Testing (lb/hr)	**Emissions (lb/yr)**							
	NO_x	**SO_x**	**CO**	**VOC**	**HAP**	**PM_{10}**	**$PM_{2.5}$**	**CO_2e**
685	5.9	20.3	1,213.6	41.4	37.5	150.4	66.6	59,810.4
915	203.6	72.5	1,839.4	94.9	88.3	409.1	139.7	213,047.4
1,333	403.8	79.2	639.2	9.4	6.5	642.8	500.3	232,780.4
2,801	689.0	83.2	298.0	5.3	3.0	201.2	127.1	244,567.9

Step 5 – Calculate total emissions from all fuel flow rates. Sum the individual emissions per fuel flow rate to give the total emissions from the TF34-GE-100A during testing.

For NO_X:

$$E_{NO_X} = 5.9\frac{lb}{yr} + 203.6\frac{lb}{yr} + 403.8\frac{lb}{yr} + 689.0\frac{lb}{yr}$$

$$\boxed{\boldsymbol{E_{NO_X} = 1,302.3\frac{lb}{yr}}}$$

Emissions from the other criteria pollutants are similarly calculated and presented in the following table:

Aircraft Engine	**Total Emissions (lb/yr)**							
	NO_x	**SO_x**	**CO**	**VOC**	**HAP**	**PM_{10}**	**$PM_{2.5}$**	**CO_2e**
TF34-GE-100A	1302.3	255.2	3990.2	151.0	135.3	1403.5	833.7	750,206.1

4.7 References

40 CFR 63 Subpart PPPPP, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 63-National Emission Standards for Hazardous Air Pollutants for Source Categories, Subpart PPPPP- National Emission Standards for Hazardous Air Pollutants for Engine Test Cells/Stands," U.S. Environmental Protection Agency

AFCEC 2016, "Air Emissions Guide for the Air Force Mobile Sources," Air Force Civil Engineer Center, Compliance Technical Support Branch, July 2016

DLA 2006, "Petroleum Quality Information System Fuels Data (2005)," Defense Logistics Agency (DLA), Defense Energy Support Center, Technology and Standardization Division, 2006

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5 FUEL DISPENSING (FDSP)

- *Fugitive Source*
- *Mobile Source* – When fuel is dispensed to mobile equipment.
- *Stationary Source* – Fuel spills and when dispensed to stationary equipment.

USAF policy does not consider fuel dispensing to on-road vehicles a stationary source of emissions. However, the regulator requires this category be included as a stationary source, contact the USAF air quality Subject Matter Expert (SME) for permission/guidance on emissions calculations. Subtract these emissions from the emissions calculated from a mobile AEI to avoid duplicate emissions

5.1 Introduction

Historically, "fuel dispensing" has referred to the refueling of vehicles at fuel service stations. Emissions from fuel dispensing are the result of vapors displaced as fuel is added to the fuel tank of the vehicle or equipment. The amount of vapor released to the atmosphere is a function of the gas and fuel tank temperatures, the vapor pressure of the fuel, the dispensing rate, and the presence of vapor emission control devices. The vapor that is emitted into the atmosphere is composed of both VOCs and HAPs and is considered fugitive in nature.

Previous source guides have stated that emissions from fuel dispensing operations result from three separate activities. These activities include the filling of underground storage tanks, the fueling of motor vehicles, and any resulting fuel spills that occur at fuel dispensing facilities. These emission sources have been historically regarded as stationary, but have been recently been changed to accurately classify the emission sources and reduce instances of duplicate reporting.

Emissions resulting from the filling of storage tanks, are no longer a part of the fuel dispensing chapter. **The process for calculating emissions resulting from the filling of storage tanks is described in the "Storage Tanks" section of this guide.** That section describes the estimation of emissions resulting from the loading of storage tanks at fuel service stations, and the loading of large tanks which service stationary internal combustion engines. **Emissions from the loading of smaller tanks, which are those with a diameter of less than 3 feet and a length less than 5 feet, are described in the "Fuel Transfer" section of this guide.**

Since emissions from fueling mobile equipment are the result of displaced vapors from the fuel tank of a mobile source, **the emissions generated from the refueling of vehicles are regarded as a mobile and are addressed in the *Air Emissions Guide for Air Force Mobile Sources*.** Section 5.2.2.3 of AP-42 states that air emissions from motor vehicle refueling are incorporated in what is now the MOVES model. Therefore, these emissions are already accounted for in the on-road vehicle EFs. Refer to the latest version of the *Air Emissions Guide for Air Force Mobile Sources* for the calculation of emissions from dispensing fuel to aircraft and non-road engines.

Fuel spills may refer to either the minor and inevitable fuel loss that occurs through vehicle refueling or from significant fuel spills resulting from transfer incidents. **The method for estimating emissions from minor spills during vehicle refueling is described under the "Fuel Transfer" section of this guide.** For guidance regarding estimating emissions from significant fuel spills, refer to the latest version of the *Air Emissions Guide for Air Force Transitory Sources.*

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6 FUEL TRANSFER (FLD, FDSP) – STATIONARY SOURCES

- *Fugitive Source*
- *Mobile Source* – When fuel is dispensed to mobile equipment.
- *Stationary Source* – Fuel spills and when dispensed to stationary equipment.

The USAF recommends that most emissions generated during the transfer (dispensing) of fuel into *on-road* vehicles be classified as mobile emissions. However, if the regulator requires this category be included as a stationary source, subtract those emissions from the mobile AEI and add them to the stationary AEI to avoid duplicate reporting

6.1 Introduction

Fuel transfer activities include the transfer of liquid fuel from bulk storage to outlets such as fuel service stations or smaller tanks and the subsequent dispensing of fuel into aircraft, mobile and stationary ICOMs and ECOMs, and *non-road* engines and equipment. **Note that the emissions generated from the filling of larger storage tanks, which are those with a diameter larger than three feet and a length greater than five feet, are calculated as described in the "Storage Tanks" section of this guide. Emissions from the filling of smaller tanks may be calculated using the methods outlined in this section. Additionally, the emissions generated from the fueling of mobile equipment are regarded as mobile sources of emissions and are described in the *Air Emissions Guide for Air Force Mobile Sources*.**

At USAF installations, fuel is transferred from large storage tanks into tanker trucks at fuel loading docks, also known as racks or fill stands. The tanker trucks distribute fuel to aircraft, tanks at fuel dispensing centers, non-road or stationary equipment, or smaller Petroleum, Oil, and Lubricant (POL) tanks. The primary source of evaporative emissions from fuel transfer are due to vapor displacement during fuel loading. These loading losses occur as the volume occupied by organic vapors in "empty" cargo tanks is supplanted by the liquid fuel loaded into the tank. The organic vapors are formed in the tank headspace through evaporation of residual product from previous loads. Vapors are also transferred to the tank in vapor balance systems as product is being unloaded, and vapors are generated in the tank as the new product is being loaded. **The emitted vapor is fugitive in nature and is comprised of both VOCs and HAPs**. This is illustrated in a simple control volume in Figure 6-1. The quantity of vapor emissions that are lost during a fuel transfer process depend on multiple factors that include loading method, vapor capturing unit efficiency, and fuel type.

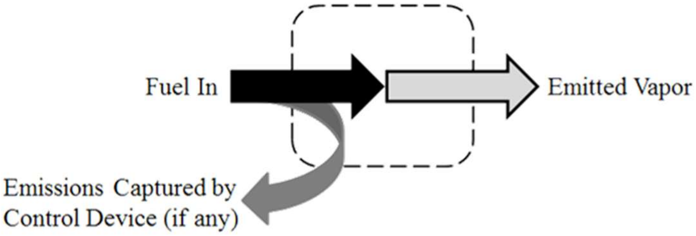


Figure 6-1. Simple Control Volume for Emissions from Fuel Transfer

The loading method used in the fuel transfer process has a significant effect on the amount of vapor emissions generated during the transfer activity. There are two main fuel loading methods: splash loading and submerged loading. The splash loading method involves the lowering of the fill pipe into the tank **above** the liquid level. The loading of the fuel using the splash method results in significant turbulence, which increases the amount of vapor released into the atmosphere. The alternative method, submerged loading, may be further subdivided into two techniques: 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 storage tank, **below** the liquid level. In the bottom loading method, a fill pipe is permanently attached to the bottom of the storage tank. In both cases, the fill pipe is below the liquid level so turbulence is minimized and vapor emissions are greatly reduced when compared to the splash loading method. Each method is shown in Figure 6-2.

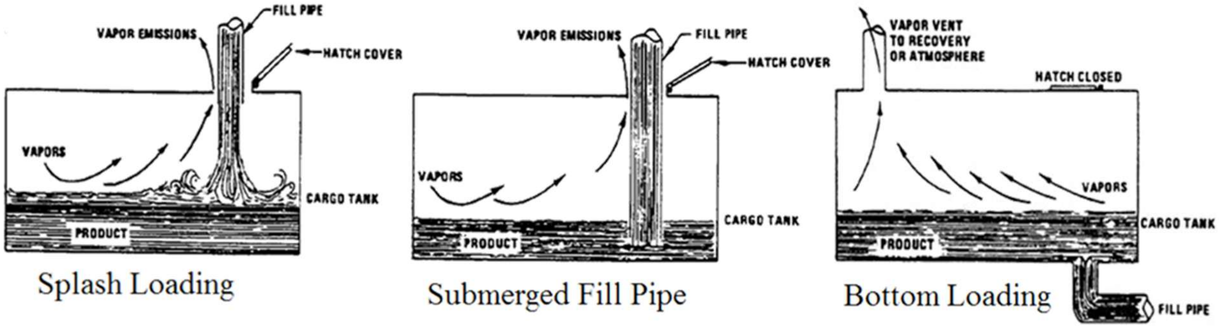


Figure 6-2. Splash Loading, Submerged Fill Pipe, and Bottom Loading Methods

There are several challenges to calculating evaporative emissions from fuel transfer activities. These challenges include the fact that there are several different fuels used on base, such as gasoline, diesel, or JP-8 fuel, each with different vapor pressures. Furthermore, there are multiple destinations for fuels on base that may make it more difficult to gather data or determine what emissions are classified as mobile or stationary. To simplify how each base should calculate fuel transfer emissions, a diagram of the typical destinations of fuel on base is provided in Figure 6-43.

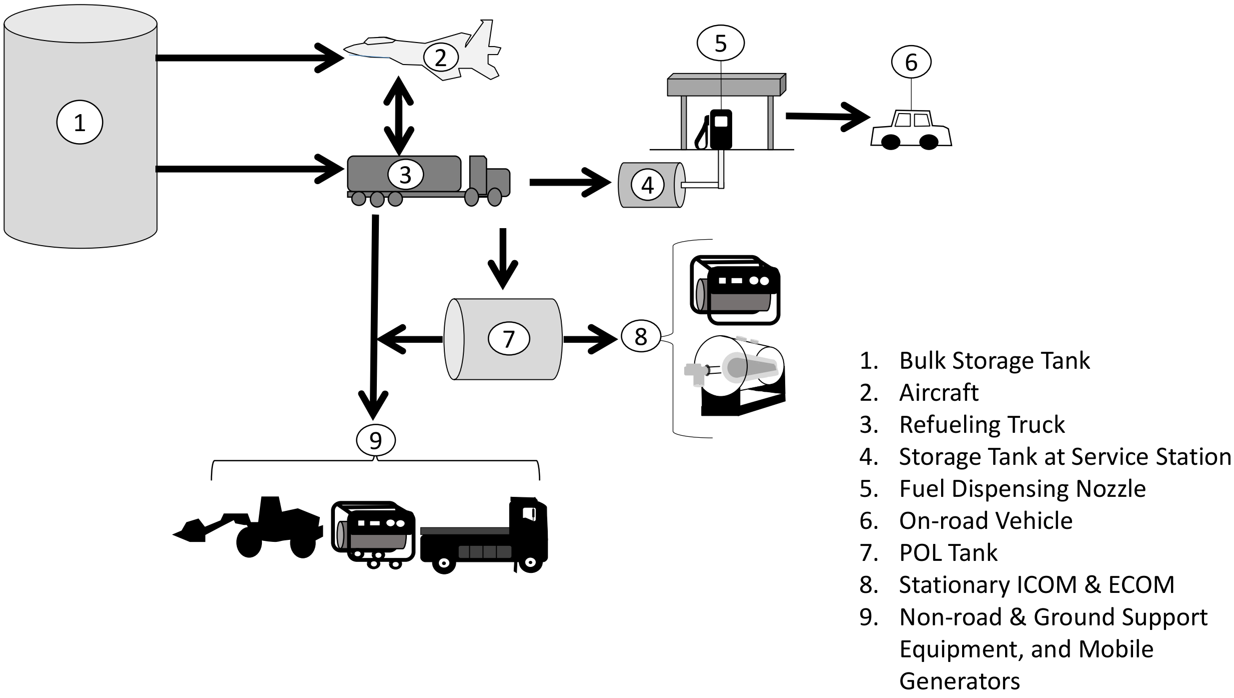
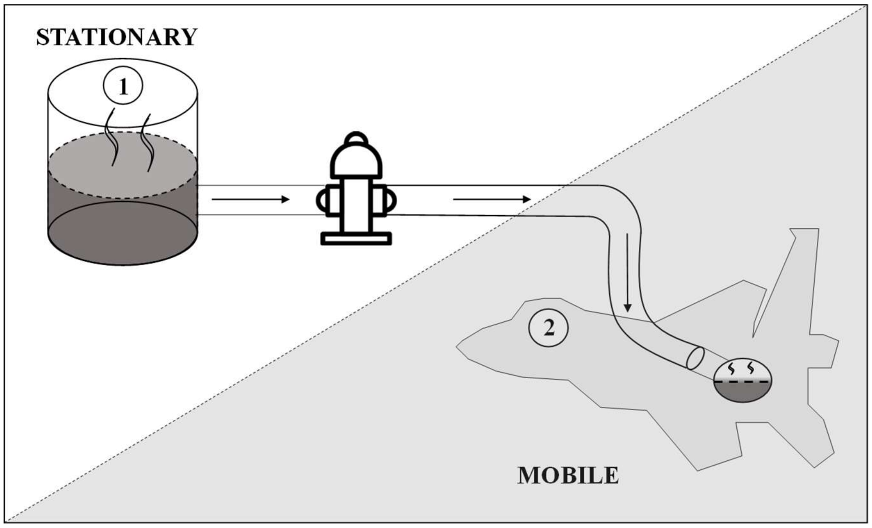


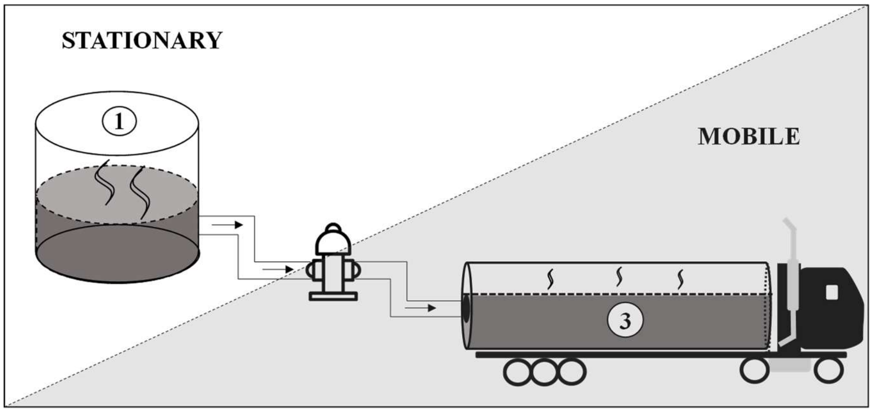
Figure 6-3. Typical On-Base Fuel Transfer Activities and Destinations

Figure 6-3 illustrates the potential fuel transfer pathways for fuels used at a USAF installation. The transfer of the fuel into different equipment results in the generation and release of pollutant emissions. The classification (mobile vs. stationary) of these pieces of equipment, determines if the emissions generated are regarded as mobile or stationary sources. It is important to note that **significant** fuel spills may occur at any point in the fuel transfer process, which will contribute to VOC and HAP emissions as the fuel evaporates. However, since these are uncommon occurrences, emissions from fuel spills are addressed in the *Air Emissions Guide for Air Force Transitory Sources*. During the fuel transfer processes involving storage tanks, emissions generated from breathing and/or working losses are estimated using the total fuel throughput in a year for each tank. These emissions are not broken down by each specific stage or pathway. Emissions generated by these losses are estimated using the methodology of EPA’s TANKS modeling program which is an emissions estimate program. The TANKS program is in APIMS tanks emission calculation module. The specific pathways illustrated in Figure 6-43 are described below and categorized as either mobile (shaded) or stationary (not shaded) sources of emissions.



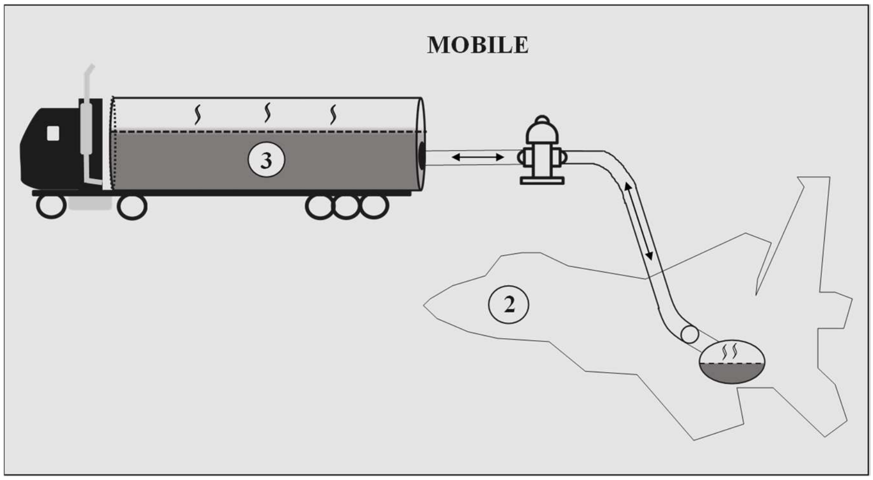
1→2 This figure illustrates fuel transferred to refuel an aircraft from a bulk storage tank via a hydrant system. The vapors displaced within the storage tank as the liquid level lowers or rises are known as "working losses". Vapors generated in the space above the stored liquid are known as "breathing losses". These emissions result in **stationary** emissions of pollutants and are calculated as described in the "Storage Tanks" section of this guide.

Mobile emissions are generated from the displaced vapor in the aircraft fuel tank. These emissions are calculated as directed by the *Air Emissions Guide for Air Force Mobile Sources* and should be reported in a mobile AEI.

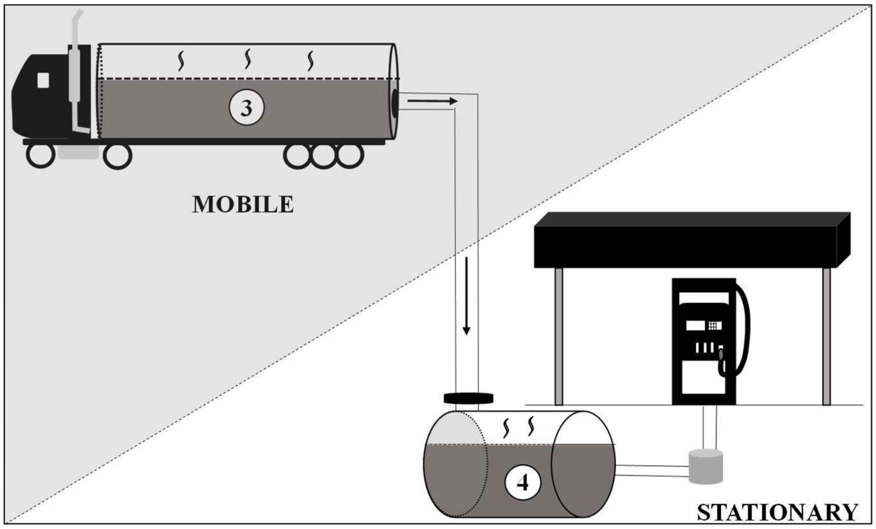


1→3 In this figure, the **stationary** source of emissions is the storage tank producing working losses and breathing losses from the liquid fuel. These emissions, previously calculated by the now incompatible EPA's TANKS modeling program, can now be calculated with either ACAM or APIMS. This is described in the "Storage Tanks" section of this guide or with Equation 6-2 if the tank size is below the minimum dimensions required to run the modeling program.

The **mobile** emissions from loading fuel into refueling trucks are generated from the displaced vapor in the fuel truck. The mobile emissions should be reported in a mobile AEI and are calculated as directed by the *Air Emissions Guide for Air Force Mobile Sources.*



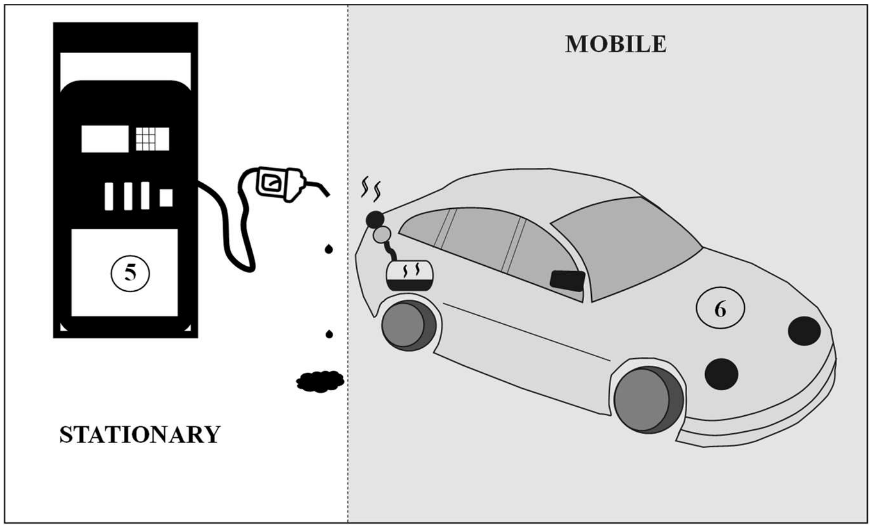
2↔3 This figure illustrates the fueling or defueling of an aircraft via a refueling truck. Both pieces of equipment are **mobile.** All emissions generated from these activities (which come from displaced vapors in the refueling truck or aircraft fuel tanks) should be reported in a mobile AEI and calculated as directed by the *Air Emissions Guide for Air Force Mobile Sources*.



3→4 This figure illustrates the loading of fuel from a refueling truck into a storage tank at a fuel service station. The **stationary** emissions from the refilling of a storage tank at a fuel dispensing location include breathing and working losses from the storage tank. These emissions, previously calculated by the now incompatible EPA's TANKS modeling program, can now be calculated with either ACAM or APIMS. This is described in the "Storage

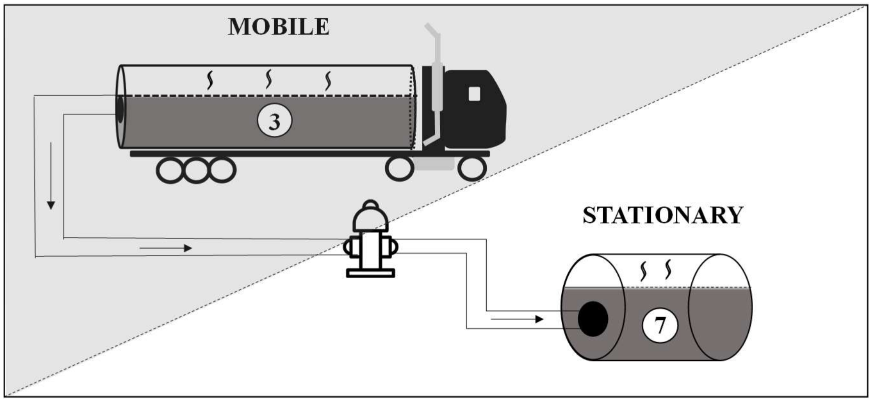
Tanks" section of this guide or with Equation 6-2, if the tank size is below the minimum dimensions required to run the modeling program.

Likely, the only substantial emissions coming from the mobile source (refueling truck) would be the emissions generated from any significant fuel spills. Emissions from significant fuel spills are addressed in the *Air Emissions Guide for Air Force Transitory Sources*.



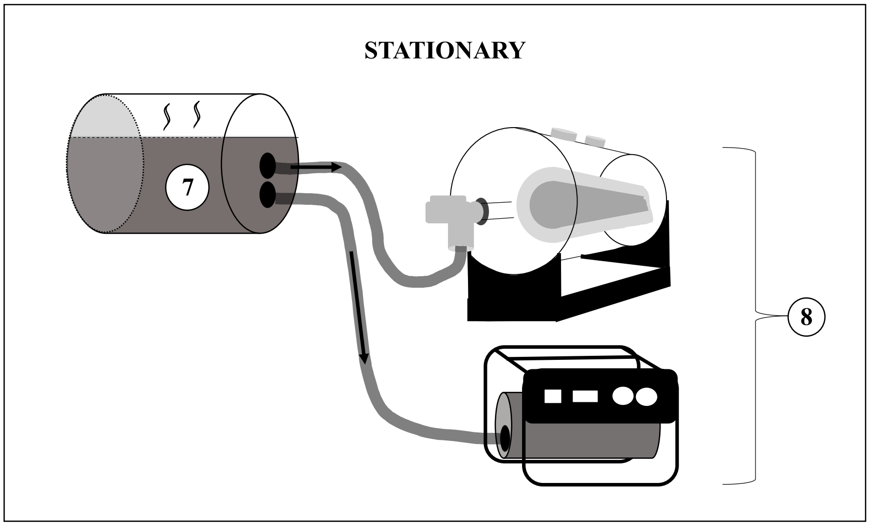
5→6 This figure illustrates the refueling of a vehicle at a service station. The **stationary** emissions are the result of the evaporation of spilled fuel from the fuel nozzle whose calculations are described in Equation 6-3. Another source of stationary emissions come from the working losses of the storage tank as the fuel level is lowered. Therefore, depending on the tank size, the emissions are estimated with ACAM or APIMS, or with Equation 6-2.

The **mobile** emissions are generated from the displaced vapors in the vehicle fuel tank. The displaced vapor emissions should be included in a mobile AEI and are already calculated by the EPA's Motor Vehicle Emission Simulator (MOVES) model used to determine on-road vehicle emissions. AP-42 states that the motor vehicle refueling emissions equation is incorporated into the MOBILE model, which has been integrated into the MOVES model. The MOVES model, which is the current model used for estimating emissions for on-road vehicles, allows for disabling of the refueling emissions calculation if these emissions are included in a stationary AEI rather than in a mobile AEI. **This should only be done if the regulator requires this category be included as a stationary source.**



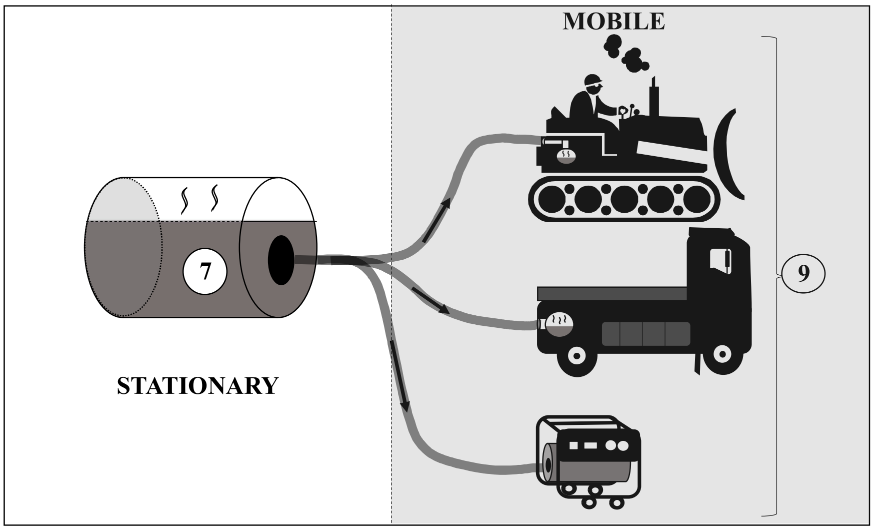
3→7 This point in the fuel transfer pathway describes the loading of fuel from a refueling truck into a storage tank. The **stationary** emissions include the breathing and working losses from smaller storage tanks on base. Provided that these tanks have a diameter of at least three feet and minimum length of five feet, these emissions are calculated using either the ACAM or APIMS program as described in the "Storage Tanks" section of this guide. If the tank has dimensions smaller than what is described above, the emissions are calculated using Equation 6-2 provided later in this chapter.

Likely, the only emissions generated from the mobile source (refueling truck) are from any significant fuel spills which are addressed in the *Air Emissions Guide for Air Force Transitory Sources*.



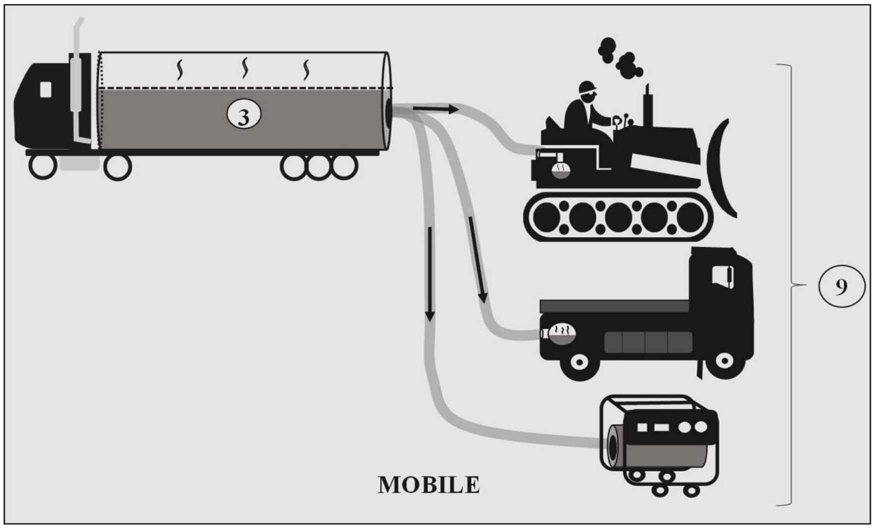
7→8 This figure illustrates the loading of fuel from a storage tank into a stationary ICOM piece of equipment, such as a generator, or ECOM equipment, such as a boiler. The **stationary** emissions from the fuel outlet, the storage tank, are the result of any significant fuel spills and breathing/working losses generated. The losses are calculated either using either the ACAM or APIMS program, or using the equation provided later in this chapter.

Emissions from fuel spills are addressed in the *Air Emissions Guide for Air Force Transitory Sources*. The **stationary** emissions from the fuel loading inlet, the stationary ICOM or ECOM equipment, are generated from the displaced vapor in the fuel tanks. Emissions calculations for these equipment pieces are described later in this chapter.



7→9 During this fuel transfer activity, fuel is moved from a storage tank to a mobile piece of equipment, such as non-road equipment, Ground Support Equipment (GSE), or a mobile generator. The **stationary** emissions from the storage tank are the result of any significant fuel spills and breathing/working losses generated. The losses are calculated using either the ACAM or APIMS program, or using the equation provided later in this chapter while fuel spill emissions are addressed in the *Air Emissions Guide for Air Force Transitory Sources*.

The **mobile** emissions from the fuel loading inlet (non-road and ground support equipment or mobile generator) are produced by the displaced vapor in the fuel tanks, and should be recorded in only the mobile AEI. Emissions are calculated as described in the *Air Emissions Guide for Air Force Mobile Sources*. Care should be taken to avoid duplicate reporting.



3→9 This figure illustrates the transfer of fuel from a **mobile** fuel loading outlet (refueling truck) into either non-road equipment, GSE, or a mobile generator, **all** of which are considered **mobile** sources. Emissions are calculated as described in the *Air Emissions Guide for Air Force Mobile Sources* and should be reported in a mobile AEI.

6.2 NSPS and NESHAP Applicability

40 CFR 60 Subpart XX, *Standards of Performance for Bulk Gasoline terminals,* defines bulk gasoline terminals as any gasoline facility receiving gas by pipeline having a throughput greater than 75,700 liters per day. This regulation applies to all loading racks that deliver gasoline to fuel trucks. According to this regulation, any facility whose construction or modification commenced after December 17, 1980 is required to have a vapor collection system to collect the TOC vapors while loading fuel trucks. Additionally, these standards impose emission limits and regulations regarding the vapor documentation of the trucks loaded at the facility. To verify that the installation adheres to these rules, refer to 40 CFR 60 Subpart XX for detailed information.

In addition to the performance standards that are required of the bulk gasoline terminals, there are also NESHAPs promulgated in 40 CFR 63 Subparts R and BBBBBB. Subpart R, *National Emission Standards for Gasoline Distribution Facilities (Bulk Gasoline Terminals and Pipeline Breakout Stations),* applies to facilities that are classified as major sources. This section outlines the standards for loading racks and alternative means of emissions limitation. Subpart BBBBBB, *National Emission Standards for Hazardous Air Pollutants for Source Category: Gasoline Distribution Bulk Terminals, Bulk Plants, and Pipeline Facilities,* applies to area source gasoline distribution bulk terminals. This Subpart also outlines the national emission limitations and management practices for HAP emissions, including requiring monthly leak inspections and requiring submerged fill method for all tanks with a capacity equal to or more than 250 gallons.

6.3 Emission Factors

The loading losses are the primary source of evaporative emissions from the loading of fuel tanks. These losses are the result of organic vapors within a tank that are displaced to the atmosphere as the tank is loaded with fuel. Calculation of these emissions requires the use of a saturation factor, which refers to the ratio of the saturated value of the expelled vapor to the unsaturated value. These values vary based on the loading parameters, such as the recent loading history of a cargo carrier and are an important factor in determining loading losses. A tank that is filled with only one type of fuel, or fuels with similar chemical characteristics, is said to be practicing “dedicated normal service.” When loading vapors are returned to the loading terminal after the fuel is unloaded to a storage tank, it is known as “dedicated vapor balance service”. Section 5.2 of AP-42 provides fuel loading saturation factors (S) which are provided in Table 6-1.

Table 6-1. Fuel Loading Saturation Factors

Loading Method	Loading Parameters	S Factor
Submerged Loading	Clean Tank	0.50
	Dedicated Normal Service	0.60
	Dedicated Vapor Balance Service	1.00
Splash Loading	Clean Tank	1.45
	Dedicated Normal Service	1.45
	Dedicated Vapor Balance Service	1.00

SOURCE: Section 5.2- “Transportation and Marketing of Petroleum Liquids," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, June 2008.

The vapor emissions resulting from fuel transfer are a function of the vapor pressure of the fuel, which is indicative of the evaporation rate of a liquid. The vapor pressures for each fuel and their respective vapor molecular weights are provided in Table 6-2.

Table 6-2. Vapor Pressures for Various Fuels

Petroleum Liquid	Liquid Molecular Weight (lb/lb-mol)	Vapor Molecular Weight (lb/lb-mol)	True Vapor Pressure (psia)						
			40°F	50°F	60°F	70°F	80°F	90°F	100°F
Crude Oil RVP 5[a]	207	50	1.8	2.3	2.8	3.4	4	4.8	5.7
Gas RVP 6	92	69	1.9	2.37	2.93	3.6	4.38	5.29	6.35
Gas RVP 7	92	68	2.3	2.9	3.5	4.3	5.2	6.2	7.4
Gas RVP 7.8	92	68	2.59	3.21	3.94	4.79	5.79	6.96	8.3
Gas RVP 8	92	68	2.67	3.3	4.04	4.92	5.94	7.13	8.5
Gas RVP 8.3	92	68	2.79	3.44	4.22	5.13	6.19	7.42	8.83
Gas RVP 9	92	67	3.06	3.77	4.61	5.59	6.74	8.06	9.58
Gas RVP 10	92	66	3.4	4.2	5.2	6.2	7.4	8.8	10.5
Gas RVP 11	92	65	3.87	4.75	5.77	6.96	8.34	9.92	11.74
Gas RVP 11.5	92	65	4.09	5	6.07	7.31	8.75	10.41	12.29
Gas RVP 12	92	64	4.29	5.24	6.36	7.65	9.15	10.86	12.82
Gas RVP 13	92	62	4.7	5.7	6.9	8.3	9.9	11.7	13.8
Gas RVP 13.5	92	62	4.93	6.01	7.26	8.71	10.38	12.29	14.46
Gas RVP 15	92	60	5.58	6.77	8.16	9.77	11.61	13.71	16.09
Diesel	188	130	3.10E-03	4.50E-03	6.50E-03	9.00E-03	1.20E-02	1.60E-02	2.20E-02
JP-8/Jet A[b]	162	130	1.58E-02	2.19E-02	3.01E-02	4.08E-02	5.48E-02	7.27E-02	9.54E-02

SOURCE (unless otherwise stated): TANKS, Version 4.09d, U.S. Environmental Protection Agency, October 2005.

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

b) SOURCE: "JP-8 Volatility Study," Southwest Research Institute, March 2001. Vapor pressures calculated using the composite data calculation, an average flash point temperature of 118.238°F, and atmospheric pressure of 760mmHg. Flash point temperature average provided by "Petroleum Quality Information System Fuels Data (2005)," Defense Logistics Agency, Defense Energy Support Center, Technology and Standardization Division, 2006.

6.4 Control and Capture Efficiencies

The structure of equipment and presence of vapor recovery systems can help reduce vapor losses throughout fuel transportation. Control efficiencies for the vapor recovery units range from 90 to over 99 percent. However, only 70 to 90 percent of the displaced vapors are captured by the control device, due to leakage from both the tank truck and collection system. Therefore, there are various efficiency values to choose from depending on what capture system is used in addition to the control techniques practiced. The assorted values are given in Table 6-3 for the typical capture efficiencies, and Table 6-4 for the typical fuel transfer control efficiencies.

Table 6-3. Typical Fuel Truck Capture Efficiencies

Fuel Truck Capture System	Capture Efficiency (%)
Untested	70.0
EPA standards (NSPS Subpart XX) leak test	98.7
MACT-level annual leak test	99.2
Trucks with installed blower system	100.0[(a)]

SOURCE (Unless otherwise stated): Section 5.2-"Transportation and Marketing of Petroleum Liquids," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, June 2008.

a) SOURCE: "Tank Truck Loading of Crude Oil or Condensate," Texas Commission on Environmental Quality (TCEQ), <http://www.tceq.texas.gov/assets/public/permitting/air/NewSourceReview/oilgas/tank-truck-load.pdf>.

Table 6-4. Typical Fuel Transfer Control Efficiencies

Control Techniques		Control Efficiency (%)
Flares(a)	Compounds ≤ 3 Carbon atoms	99.0
	Other Organic Compounds	98.0
Thermal Oxidizers(b)		99.0
Carbon Systems(c)		98.0
Vapor Recovery Units		100.0

SOURCE: TCEQ. "Tank Truck Loading of Crude Oil or Condensate," Texas Commission on Environmental Quality (TCEQ), <http://www.tceq.texas.gov/assets/public/permitting/air/NewSourceReview/oilgas/tank-truck-load.pdf>.

a) Flares must meet 40 CFR 60.18 requirements of minimum heating value of waste gas and a maximum flare tip velocity.

b) Must be designed for the variability of the waste gas stream and basic monitoring which consists of temperature monitor that indicates the device is achieving a satisfactory minimum temperature.

c) Must have an alarm system that will prevent break through.

6.5 Emissions Calculation

Emissions of concern from fuel transfer are VOCs and HAPs. The total VOC emissions from fuel transfer is the sum of the emissions from vapor displacement and emissions from evaporated fuel due to spills, if any, and is shown in Equation 6-1.

$$\boldsymbol{E(Total)_{VOC} = E(Vapor)_{VOC} + E(Spills)_{VOC}}$$

Equation 6-1

Where,

E(Total)$_{VOC}$ = Total annual VOCs emitted from fuel transfer activities (lb/yr)
E(Vapor)$_{VOC}$ = Annual VOC emissions due to vapor displacement (lb/yr)
E(Spills)$_{VOC}$ = Annual VOC emissions due to evaporated fuel from spills (lb/yr)

6.5.1 VOC Emissions Calculations from Vapor Displacement

VOC emissions created by vapor displacement are calculated as follows:

$$E_{VOC} = Q \times \frac{1}{1000} \times 12.46 \times \frac{S \times P \times M}{T} \times \left\{1 - \left[\left(\frac{Cap}{100}\right) \times \left(\frac{CE}{100}\right)\right]\right\}$$

Equation 6-2

Where,

EVOC = Annual emissions of VOCs (lb/yr).
Q = Annual quantity of fuel transferred into the tanks (gal/yr).
1000 = Factor converting gallons to 10^3 gallons (gal/10^3 gal)
12.46 = Equation constant (°R lb-mol/psia 10^3 gal).
S = Saturation factor. This is provided in Table 6-1.
P = True vapor pressure of fuel (psia). This is provided in Table 6-2.
M = Vapor molecular weight of the fuel (lb/lb-mol). This is provided in Table 6-2.
T = Temperature of bulk liquid loaded (°R).
Cap = Capture efficiency of the loading terminal (%). This is provided in Table 6-3.
CE = Efficiency of the control device (%). This is provided in Table 6-4.
100 = Factor for converting a percent to a fraction (%).

A detailed control volume for fuel loading activities is provided in Figure 6-4.

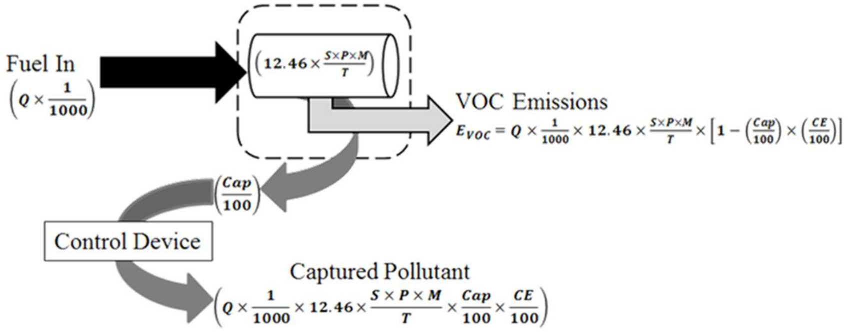


Figure 6-4. Fuel Transfer Control Volume

6.5.2 VOC Emissions Calculations from Fuel Spills

In addition to emissions generated from the displacement of fuel vapor, fuel transfer activities will inevitably lead to spilled fuel, which also serves as a VOC emissions source as the fuel evaporates. This section is concerned with the calculation of emissions from fuel spills that result from the filling of on-road vehicle gas tanks, **not the significant spills** that may occur periodically and are reported to base Environmental Management or the Hazardous Materials Response Team. Emissions resulting from fuel spills of significant magnitude are calculated using the methodology as described in the "Spills and Releases" section of the *Air Emissions Guide for Air Force Transitory Sources*.

Emissions from smaller-scale fuel spills, such as those at fuel service stations, have been studied to determine a representative Spillage Factor (SF) that is typical across all service stations. For gasoline, AP-42 states this value is equivalent to 0.7 pounds for every thousand gallons of gasoline dispensed. Compared to gasoline, diesel is typically denser with significantly lower vapor pressures, therefore, diesel evaporative losses are considered negligible. However, the same SF used for gasoline is used for diesel and is recognized as very conservative. For emissions estimates, a value of 0.7 pounds per thousand gallons of fuel dispensed may be used unless more accurate estimates are available.

With the amount of fuel dispensed at the fuel service station known, the VOC emissions from the evaporated fuel from spills are estimated as follows:

$$\boldsymbol{E_{VOC} = Q \times \frac{1}{1000} \times SF}$$

Equation 6-3

Where,

E

E_{VOC} = VOC emissions from evaporated fuel spills (lb/yr)
SF = Spillage factor. The typical value is 0.7 (lb/10^3 gal)
Q = Annual quantity of fuel dispensed at service station (gal/yr)

6.5.3 HAP Speciation

The calculation of HAPs emitted from fuel transfer activities is directly proportional to both the amount of VOCs emitted and the weight percent of the HAP in the fuel. Contact the fuel supplier for specific information regarding the weight percent of HAPs in fuels commonly used at USAF installations. In the absence of available data, Table 6-5 provides the typical weight percent of individual HAPs found in several fuels used at USAF installations.

Table 6-5. HAP Speciation of Fuels Commonly Used at USAF Installations

Compound	Typical wt. %					
	Diesel		Gasoline		JP-8/Jet A(a)	
	Liquid Phase	Vapor Phase(b)	Liquid Phase	Vapor Phase(b)	Liquid Phase	Vapor Phase(b)
Anthracene	2.83E-03(c)	---	---	---	---	---
Benzene	8.00E-04	1.96E-01	1.80E+00	6.18E-01	3.38E-02	1.58E+00
1,3-Butadiene	---	---	2.00E-04(c)	1.62E-03	---	---
Cumene (Isopropylbenzene)	---	---	5.00E-01	7.79E-03	1.81E-01	3.83E-01
Dibenzofuran	1.64E-02(c)	---	---	---	---	---
Ethylbenzene	1.30E-02	3.10E-01	1.40E+00	4.67E-02	1.59E-01	7.20E-01
Fluorene	2.94E-02(c)	---	---	---	3.44E-03	---
Hexane	1.00E-04	3.98E-02	1.00E+00	5.57E-01	---	---
Isooctane (2,2,4-Trimethyl Pentane)	---	---	4.00E+00	7.11E-01	1.23E-03	2.97E-02
Naphthalene	3.39E-01(c)	2.15E-01	1.74E-01(c)	1.54E-04	2.68E-01	3.23E-02
Phenanthrene	3.22E-02(c)	---	---	---	---	---
Phenylbenzene (1,1'-biphenyl)	---	---	---	---	6.78E-02	---
Pyrene	3.62E-02(c)	---	---	---	1.00E-05	---
Toluene	3.20E-02	2.30E+00	7.00E+00	7.05E-01	2.19E-01	3.00E+00
Xylenes	2.90E-01	7.19E+00	7.00E+00	2.43E-01	1.19E+00	5.61E-02

SOURCE (Unless otherwise stated): Data taken from USEPA 2005, TANKS, Version 4.09d, U.S. Environmental Protection Agency, October 2005. wt. % = weight percent.

a) SOURCE: "JP-8 Composition and Variability," Armstrong Laboratory, Environics Directorate, Environmental Research Division, May 1996. An average density of 6.67 pounds per gallon (lb/gal) was used for unit conversion.

b) The vapor phase speciation data was estimated using the liquid phase speciation data and equations found in Section 7.1.4 of AP-42, Fifth Edition, Volume I last updated November 2006. Physical properties for fuels used for calculations can be found in Table 6-2.

c) SOURCE: SPECIATE, Version 4.4, U.S. Environmental Protection Agency, February 2014.

"---" No data available

Speciation of HAP emissions is becoming increasingly more important for all emission sources. HAP emissions from fuel transfer activities are determined by taking the product of the total VOCs emitted and the weight fraction of the individual HAP in the fuel as shown:

$$E_{HAP} = E_{VOC} \times \left(\frac{WP_{HAP}}{100}\right)$$

Equation 6-4

Where,

E_{HAP} = Total HAP emitted from fuel transfer activities (lb/yr)
E_{VOC} = Total VOCs emitted due to fuel transfer activities (lb/yr)
WP_{HAP} = Weight percent of HAP in the fuel (%). **Note**- Use the vapor-phase weight % for emissions from vapors.
100 = Factor converting weight percent to weight fraction (%)

6.6 Information Resources

The gasoline terminal supervisor should be contacted for information regarding fuel transfer activities. This includes the annual throughput, method of tank filling, fuel type, and presence of vapor recovery control systems. If a vapor recovery system is used for the loading of fuel into tanker trucks, then the base CE or the applicable manufacturer will need to be contacted to obtain the control efficiency of the vapor recovery unit.

6.7 Example Problem

Approximately 4,450,000 gal of JP-8 was transferred from tanker trucks to stationary generators during the previous year. All fuel transfer was performed using the submerged fill pipe method with dedicated vapor balance service and a vapor recovery system with 95 percent control efficiency. The tanker trucks are not required to pass an annual leak test. 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 degrees Fahrenheit (°F) or 520 degrees Rankin (°R). Calculate the annual VOC emissions and benzene emissions associated with fuel transfer operations on base.

<u>Step 1</u> – **Record the saturation factor, vapor pressures, vapor molecular weights, and capture/control efficiencies.** Based on the loading method employed, the saturation factor is **1.00** (from Table 6-1). Since the fuel used was JP-8, the vapor pressure at 60°F and vapor molecular weight may be found in Table 6-2. The vapor pressure and molecular weight are **0.0301 psia** and **130 lb/lb-mol,** respectively. The tanker trucks are not required to pass an annual leak test which means that, according to Table 6-3, the capture efficiency of the vapor recovery system is **70.0%**.

Step 2 – **Calculate VOC emissions.** Using Equation 6-2, the data provided in the problem statement, the data collected in Step 1 above, and assuming no spillage, VOC emissions are calculated as follows:

$$E_{VOC} = Q \times \frac{1}{1000} \times 12.46 \times \frac{S \times P \times M}{T} \times \left\{1 - \left[\left(\frac{Cap}{100}\right) \times \left(\frac{CE}{100}\right)\right]\right\}$$

$$E_{VOC} = 4{,}450{,}000\,\frac{\cancel{gal}}{yr} \times \frac{1}{1000}\left(\frac{10^3 gal}{\cancel{gal}}\right) \times 12.46\,\frac{°R\ lb{-}mol}{psia\ 10^3 gal} \times \frac{1.00 \times 0.0301\ psia \times 130 \frac{lb}{lb{-}mo}}{520°R} \times \left\{1 - \left[\left(\frac{70.0\cancel{\%}}{100\cancel{\%}}\right) \times \left(\frac{95.0\cancel{\%}}{100\cancel{\%}}\right)\right]\right\}$$

$$E_{VOC} = 4{,}450\,\frac{10^3 gal}{yr} \times 12.46\,\frac{°R\ lb{-}m}{psia\ 10^3 gal} \times \frac{1.00 \times 0.0301\ psia \times 130 \frac{lb}{lb{-}m}}{520°R} \times \{1 - [(0.7) \times (0.95)]\}$$

$$E_{VOC} = 4{,}450\,\frac{10^3 gal}{yr} \times 12.46\,\frac{°R\ lb{-}m}{psia\ 10^3 gal} \times \frac{1.00 \times 0.0301\ psia \times 130 \frac{lb}{lb{-}mol}}{520°R} \times \{1 - [0.665]\}$$

$$E_{VOC} = 4{,}450\,\frac{10^3 gal}{yr} \times 12.46\,\frac{\cancel{°R\ lb{-}mol}}{\cancel{psia}\ 10^3 gal} \times 0.007525\,\frac{\cancel{psia}\ lb}{\cancel{°R\ lb{-}mol}} \times \{0.335\}$$

$$E_{VOC} = 4{,}450\,\frac{\cancel{10^3 gal}}{yr} \times 0.0937615\,\frac{lb}{\cancel{10^3 gal}} \times \{0.335\}$$

$$\boxed{\boldsymbol{E_{VOC} = 139.8\,\frac{lb}{yr}}}$$

Step 3 – **Record benzene weight percent.** According to Table 6-5, the estimated vapor-phase weight percent of benzene in JP-8 fuel is **1.58%.**

Step 4 – **Calculate the total benzene emissions.** Using the total VOCs emitted as calculated in Step 2, the weight percent of benzene in JP-8 as recorded in Step 3, and Equation 6-4, the total benzene emissions are calculated as follows:

$$E_{HAP} = E_{VOC} \times \left(\frac{WP_{HAP}}{100}\right)$$

$$E_{Benzene} = 139.8\,\frac{lb}{yr} \times \left(\frac{1.58\cancel{\%}}{100\cancel{\%}}\right)$$

$$E_{Benzene} = 139.8\,\frac{lb}{yr} \times 0.0158$$

$$\boxed{\boldsymbol{E_{Benzene} = 2.21\,\frac{lb}{yr}}}$$

6.8 References

40 CFR 60 Subpart XX, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New Stationary Sources, Subpart XX-Standards of Performance for Bulk Gasoline Terminals," U.S. Environmental Protection Agency

40 CFR 63 Subpart R, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 63-National Emission Standards for Hazardous Air Pollutants for Source Categories, Subpart R-National Emission Standards for Gasoline Distribution Facilites (Bulk Gasoline Terminals and Pipeline Breakout Stations)," U.S. Environmental Protection Agency

40 CFR 63 Subpart BBBBBB, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 63-National Emission Standards for Hazardous Air Pollutants for Source Categories, Subpart BBBBBB-National Emission Standards for Hazardous Air Pollutants for Source Category: Gasoline Distribution Bulk Terminals, Bulk Plants, and Pipeline Facilities," U.S. Environmental Protection Agency

DLA 2006, “Petroleum Quality Information System Fuels Data (2005),” Defense Logistics Agency (DLA), Defense Energy Support Center, Technology and Standardization Division, 2006

Mayfield 1996, “JP-8 Composition and Variability,” Armstrong Laboratory, Environics Directorate, Environmental Research Division, May 1996

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TCEQ 2013, "Tank Truck Loading of Crude Oil or Condensate," Texas Commission on Environmental Quality (TCEQ), http://www.tceq.texas.gov/assets/public/permitting/air/NewSourceReview/oilgas/tank-truck-load.pdf

USEPA 2005, TANKS, Version 4.09d, U.S. Environmental Protection Agency, October 2005

USEPA 2006, Section 7.1-“Organic Liquid Storage Tanks," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, November 2006

USEPA 2008, Section 5.2-“Transportation and Marketing of Petroleum Liquids," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, June 2008

USEPA 2014, SPECIATE, Version 4.4, U.S. Environmental Protection Agency, February 2014

7 ABRASIVE BLASTING (ABCL)

- *Point Source* – When performed using an industrial (non-heating, ventilating, and air conditioning [HVAC]) ventilation system
- *Fugitive Source* – When not using an industrial (non-HVAC) ventilation system

7.1 Introduction

Abrasive blasting operations involve the use of a hard, abrasive material (e.g. sand, garnet, glass beads) being projected with high intensity onto a surface to remove paint and/or corrosion from an object. A high pressure pneumatic gun is used to blast the abrasive media at the equipment being stripped. Blasting operations are typically performed by the Corrosion Control, Vehicle Maintenance, Repair and Reclamation, and Aerospace Ground Equipment (AGE) shops. **Due to the nature of abrasive blasting operations, the primary pollutants of interest are PM_{10}, $PM_{2.5}$, and HAPs within the particulate.**

The material that makes up the coating (paint and primer) that is exhausted from blasting operations is in the form of particulate that may contain inorganic HAPs such as chromium, lead, or cadmium. The exhaust from these blasting operations is usually vented to a control system consisting of a Fabric Filter (FF) to remove particulate. A cyclone may precede the FF in the collection system to separate the larger blast media from the smaller particulate in the exhaust stream. The large beads are then recycled to the blasting system while the smaller particulate is vented to the baghouse where it is captured and collected in a bin for disposal. Samples of the collected waste material are regularly analyzed to confirm the material is not considered hazardous waste.

Abrasive blasting operations may take place in different locations on an installation depending on the size of the object being stripped. For example, an aircraft wheel is usually stripped in a cabinet. AGE is usually stripped in a booth, and aircraft are usually stripped in a hangar. Additionally, some bases may 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 building exteriors or water towers, and blasting of road surfaces. The location of the operation is important in making the distinction between fugitive and point source emissions. **Blasting operations performed indoors (cabinet, booth, hangar) typically utilize a non-HVAC industrial ventilation system, and are, therefore, considered point sources. Blasting of buildings outdoors without any ventilation system results in fugitive emissions.** This means that when making a major source determination, the PM from outdoor applications does not need to be estimated. However, under NESHAP, HAPs must be estimated for both indoor and outdoor abrasive blasting operations. A simple control volume for abrasive blasting operations is provided in Figure 7-1.

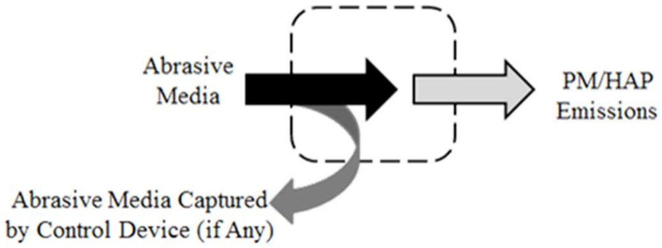

Figure 7-1. Simplified Abrasive Blasting Control Volume

7.2 NESHAP Applicability

Abrasive blasting operations for aerospace vehicles are subject to the NESHAP as outlined in 40 CFR 63 Subpart GG, *National Emission Standards for Aerospace Manufacturing and Rework Facilities*. These standards state that the removal of paint from aerospace vehicles must be performed in an enclosed area unless a closed-cycle system is used. Additionally, the NESHAP requirements for paint removal of aerospace vehicles state that the abrasive blasting system for new and existing sources must use a filter system with a minimum particulate removal efficiency as specified in 40 CFR 63.745. To verify that the abrasive blasting operations on the USAF installation adhere to the NESHAP requirements, consult 40 CFR 63 Subpart GG.

7.3 Emission Factors

Air emissions from abrasive blasting operations are dependent on the blasting media, wind speed, and emissions control efficiency. Currently, few EFs have been developed for abrasive blasting. Therefore, a mass balance method may be the most viable option for estimating emissions from these operations. PM EFs have been developed by AP-42 and the Air Pollution Control District of San Diego County, California. These EFs are presented in Table 7-1.

Calculating EFs for HAPs from abrasive blasting is considerably more difficult due to their dependence on the amount of material removed from the object being blasted. Additionally, the amount of material removed is negligible compared to the amount of abrasive material used. If necessary, site-specific data should be used to calculate HAP emissions. A chemical analysis of the waste material using the Toxicity Characteristic Leaching Procedure (TCLP) may determine the HAP concentration in the waste blast material. Analysis of waste material for HAPs is not encouraged since HAP concentrations are likely to be negligible.

Table 7-1. PM Emission Factors for Abrasive Blasting

Abrasive Media	Emission Factors (lb/10^3lb Blasting Media)	
	PM_{10}	$PM_{2.5}$[(a)]
Aluminum Oxide	7.50	6.89
Copper Slag	5.00	4.60
Garnet - Uncontrolled	4.00	3.68
Garnet - Controlled with Fabric Filter	0.59[(a,b)]	0.55
Glass Beads	7.50	6.89
Sand	13.00[(b)]	1.30[(b)]
Shot Peen	5.00	4.60
Steel Grit	3.80	3.49
Steel Shot	5.00	4.60
Walnut Shell	7.50	6.89
Misc. Blast Materials	5.00	4.60

SOURCE (unless otherwise stated): Air Pollution Control District County of San Diego. "Abrasive Blasting." 1999. *County of San Diego.* Document. 21 October 2013.

a) SOURCE: Krause, Mike and Steve Smith. "Methodology to Calculate Particulate Matter (PM) 2.5 and PM 2.5 Significance Thresholds." South Coast Air Quality Management District, 2006. Value calculated using the PM fractions given in this document.

b) SOURCE: United States Environmental Protection Agency. Section 13.2.6 -"Abrasive Blasting." *Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources*. Fifth edition. 1997.

7.4 Control Techniques

A variety of techniques are used to control pollutant emissions from abrasive blasting. Emissions from abrasive blasting are a function of the blast media used. Therefore, selecting a certain type of media may have a significant effect on the total particulate or HAP emissions. In addition, there are several control devices and techniques which are commonly implemented to contain the amount of particulate released into the atmosphere. Common control techniques include using a FF in blast enclosures, vacuum blasters, drapes, water curtains, wet blasting, and reclaim systems. Depending on the type of control system used, the control efficiency may range from 50 percent to over 96 percent. If the control efficiency for the device is known, then the emissions from the abrasive blasting using the appropriate media for uncontrolled emissions should be multiplied by the control efficiency of the device. If the efficiency is not known, then either the control device manufacturer should be contacted or a conservative estimate should be used.

7.5 Emissions Calculation

7.5.1 Calculations Using Mass Balance (Controlled Operations)

7.5.1.1 PM Emissions

Mass balance emissions calculations for abrasive blasting requires that the total mass of blast media used is known. This may be calculated if the blasting operation has a control device and the efficiency of that device is known or can be estimated. Using the total waste material collected and the control device efficiency, the total PM may be calculated. With this total, PM_{10} and $PM_{2.5}$ emissions are estimated using a "fractional concentration". **The "fractional concentration" of PM_{10} and $PM_{2.5}$ has been estimated to be 0.86 and 0.79, respectively** (Krause 2006). Calculation of PM emissions for abrasive blasting using mass balances is performed as follows:

$$\mathbf{E_{Pol} = (M_{Tot} - M_{Col}) \times C_{Pol}}$$

Equation 7-1

Where,

$\mathbf{E_{Pol}}$ = Annual emissions of pollutant (lb/yr)
$\mathbf{M_{Tot}}$ = Mass of abrasive media applied. This is estimated in Equation 7-2. (lb/yr)
$\mathbf{M_{Col}}$ = Mass of waste material collected by the fabric filter (lb/yr)
$\mathbf{C_{Pol}}$ = Fractional concentration of the pollutant. **0.86 for PM_{10} and 0.79 for $PM_{2.5}$**.

If the total mass applied in abrasive blasting operations is unknown, it may be estimated using the efficiency of the control device used to collect PM. This is shown in Equation 7-2.

$$\mathbf{M_{Tot} = \frac{M_{Col}}{CE/100}}$$

Equation 7-2

Where,

$\mathbf{M_{Tot}}$ = Mass of abrasive media applied (lb/yr)
$\mathbf{M_{Col}}$ = Mass of waste material collected by the fabric filter (lb/yr)
CE = Efficiency of control device (%)
100 = Factor for converting a percent to a fraction (%)

7.5.1.2 HAP Emissions

HAPs may be generated from abrasive blasting operations if the paint/coating being stripped contains an inorganic HAP such as chromium, lead, 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 FF. The chemical analysis of the waste material is typically accomplished by TCLP. The results of the total constituent analysis are typically provided in units of milligrams per kilogram (mg/kg) but may be converted into the appropriate fractional concentration to yield the HAP concentration (C_{HAP}). HAP emissions are calculated by substituting C_{HAP} for C_{Pol} into Equation 7-1. A more detailed control volume describing the calculation of emissions from abrasive blasting using the mass balance method is given in Figure 7-2 below.

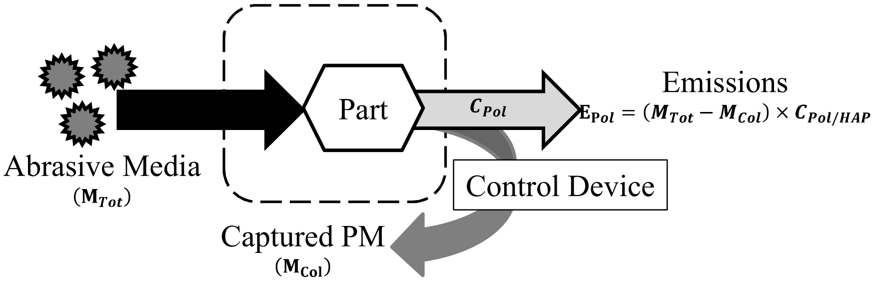

Figure 7-2. Abrasive Blasting Control Volume – Mass Balance Method

7.5.2 Calculations Using Emission Factors (Controlled or Uncontrolled Operations)

7.5.2.1 PM Emissions

As an alternative to the above method, emissions from both controlled and uncontrolled abrasive blasting operations may be calculated by using EFs. If the EF is available, the emissions from an abrasive blasting operation may be estimated by multiplying the EF by the amount (mass) of abrasive material used as shown below:

$$E_{Pol} = Q \times \frac{1}{1000} \times EF_{Pol} \times \left[1 - \left(\frac{CE}{100}\right)\right]$$

Equation 7-3

Where,

E_{Pol} = Emissions of pollutant from abrasive blasting (lb/yr)
Q = Annual blast media consumed (lb/yr)
1000 = Factor for converting pounds to 10^3 pounds (lb/10^3 lb)
EF_{Pol} = Emission factor (lb/10^3 lb of blast media used)
CE = Control Device Efficiency (%)
100 = Factor for converting a percent to a fraction (%)

A more detailed control volume describing the calculation of emissions from abrasive blasting using the EF method is given in Figure 7-3.

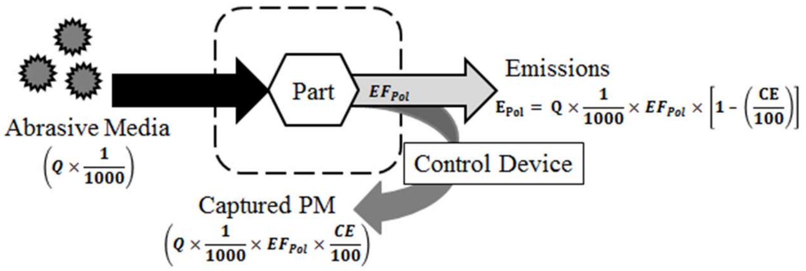

Figure 7-3. Abrasive Blasting Control Volume - Emission Factor Method

7.6 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, AGE, and CE). 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 (CEV). Additionally, information regarding the NESHAP requirements specific to aerospace vehicles may be found in 40 CFR 63 Subpart GG.

7.7 Example Problems

7.7.1 Problem # 1 – Mass Balance Method

The Corrosion Control Shop on base performs abrasive bead blasting on an aircraft in a large hangar. Exhaust from the hangar is ventilated and small particulate is sent to a baghouse. Shop records show that 3,275 lb of waste material was collected by the baghouse and disposed. Based on the manufacturer's estimates, the control efficiency of the baghouse for this material is 96 percent. A review of the SDS for the primer and paint used on the aircraft reveals that the primer contains zinc chromate. Since chromium compounds are HAPs, 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 parts per million (ppm) content is 940 mg/kg. Calculate both the PM_{10} and chromium emissions.

<u>Step 1</u> - **Convert the chromium content value into the correct fractional concentration.** The problem statement provided a chromium content in ppm (mg/kg). Conversion of this concentration into a fractional concentration is accomplished as follows:

$$\mathbf{C_{Cr}} = \frac{940 \frac{\cancel{mg}}{\cancel{kg}}}{1{,}000{,}000 \frac{\cancel{mg}}{\cancel{kg}}} = \mathbf{0.00094}$$

Step 2 – **Calculate the total mass of abrasive material applied.** The total abrasive material applied during this operation is a function of the efficiency of the control device and the amount of material collected by the control device. Total abrasive material applied may be calculated using Equation 7-2:

$$M_{Tot} = \frac{M_{Col}}{CE/_{100}}$$

$$\boldsymbol{M_{Tot}} = \frac{3{,}275.0\frac{lb}{yr}}{96\cancel{\%}/_{100\cancel{\%}}} = \mathbf{3{,}411.5}\,\boldsymbol{\frac{lb}{yr}}$$

Step 3 – **Calculate emissions.** Use Equation 7-1 to calculate the PM_{10} and chromium emissions based on the amount of waste material collected and the efficiency of the baghouse:

$$E_{Pol} = (M_{Tot} - M_{Col}) \times C_{Pol}$$

For PM_{10}:

$$E_{PM_{10}} = \left(3{,}411.5\,\frac{lb}{yr} - 3{,}275.0\,\frac{lb}{yr}\right) \times 0.86$$

$$E_{PM_{10}} = \left(136.5\,\frac{lb}{yr}\right) \times 0.86$$

$$\boxed{\mathbf{E_{PM_{10}}} = \mathbf{117.4}\,\boldsymbol{\frac{lb}{yr}}}$$

For Chromium:

$$E_{Cr} = \left(3{,}411.5\,\frac{lb}{yr} - 3{,}275.0\,\frac{lb}{yr}\right) \times 0.00094$$

$$E_{Cr} = \left(136.5\,\frac{lb}{yr}\right) \times 0.00094$$

$$\boxed{\mathbf{E_{Cr}} = \mathbf{1.28 \times 10^{-1}}\,\boldsymbol{\frac{lb}{yr}}}$$

7.7.2 Problem # 2 – Emission Factor Method

A USAF base used approximately 6,500 lb of sand during the year to perform abrasive blasting on various parts in a blasting booth. Calculate the annual PM_{10} emissions assuming a FF with 92 percent control efficiency is used.

Step 1 - Select and record the appropriate EF. Table 7-1 lists it as **13.00 lb/10^3 lb** for sand being used as the blasting media.

Step 2 – Determine PM_{10} emissions. Use Equation 7-3 to determine the PM_{10} emissions:

$$\mathrm{E_{Pol}} = \mathrm{Q} \times \frac{1}{1000} \times \mathrm{EF_{Pol}} \times \left[1 - \left(\frac{\mathrm{CE}}{100}\right)\right]$$

$$\mathrm{E_{PM_{10}}} = 6{,}500\,\frac{\mathrm{lb}}{\mathrm{yr}} \times \frac{1}{1000}\,\frac{10^3\mathrm{lb}}{\mathrm{lb}} \times 13.00\,\frac{\mathrm{lb}}{10^3\ \mathrm{lb}} \times \left[1 - \left(\frac{92\cancel{\%}}{100\cancel{\%}}\right)\right]$$

$$\mathrm{E_{PM_{10}}} = 6{,}500\,\frac{\cancel{\mathrm{lb}}}{\mathrm{yr}} \times \frac{1}{1000}\,\frac{10^3\mathrm{lb}}{\cancel{\mathrm{lb}}} \times 13.00\,\frac{\mathrm{lb}}{10^3\ \mathrm{lb}} \times [1 - 0.92]$$

$$\mathrm{E_{PM_{10}}} = 6.50\,\frac{\cancel{10^3\mathrm{lb}}}{\mathrm{yr}} \times 13.00\,\frac{\mathrm{lb}}{\cancel{10^3\ \mathrm{lb}}} \times (0.08)$$

$$\mathrm{E_{PM_{10}}} = 84.50\ \frac{lb}{yr} \times [0.08]$$

$$\boxed{\mathbf{E_{PM_{10}} = 6.76\ \frac{lb}{yr}}}$$

7.8 References

40 CFR 63 Subpart GG, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 63-National Emission Standards for Hazardous Air Pollutants for Source Categories, Subpart GG-National Emission Standards for Aerospace Manufacturing and Rework Facilities," U.S. Environmental Protection Agency

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8 CORROSION CONTROL COATINGS (MPLT, TMS)

- *Point Source* – When performed using an industrial (non-HVAC) ventilation system
- *Fugitive Source* – When not using an industrial (non-HVAC) ventilation system

8.1 Introduction

Due to the nature of their operation, a wide variety of parts and equipment found at USAF installations require surface coating. These coatings may be for decorative purposes, but are usually performed to improve the life or mechanical properties of the item being treated. Often, the surface treatments are applied to improve a part's resistance to corrosion. There are several types of corrosion control coating methods that may be performed at a USAF base including electroplating (both hard and decorative), chromic acid anodizing, and thermal metal spraying. **If an industrial (non-HVAC) system is used, electroplating, chromic acid anodizing, or thermal metal spraying may serve as point or fugitive sources of metallic HAP and PM emissions.** A graphic representation describing emissions from these processes is given in Figure 8-1.

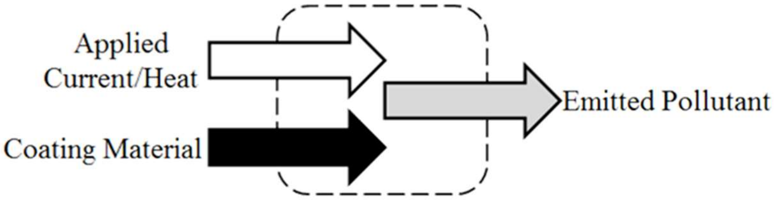

Figure 8-1. Simplified Corrosion Control Coatings Control Volume

8.1.1 Electroplating

Electroplating is the process of applying a coating layer to a surface through electrodeposition. In this process, the part to be coated is immersed in an electrolytic solution that contains the metal ions that will coat the part. When an electric current is applied to the solution, the metal ions of this coating source are oxidized and dissolve in the bath. The part acts as the cathode, attracting the metal ions and reducing them. The thickness of the metal layer which adheres to the part depends on the current density and plating time.

Emissions of concern from electroplating operations are PM (PM_{10} and $PM_{2.5}$) and HAPs. The amount of emitted pollutants is dependent on the composition of the electrolyte bath and the plating time. The plating time is a function of the cathode efficiency and current densities applied to the bath.

Some of the metals used for electroplating include brass, cadmium, chromium, copper, gold, lead, nickel, platinum, silver, tin, and zinc. Several of the metal ions pose an environmental threat since they are classified as HAPs and may react with other materials to form additional hazardous compounds. It is common for the electrolytic solution to contain harmful materials, such as cyanide, sulfuric acid, formaldehyde, and boric acid, among others. Emissions from electroplating operations result from misting of the electrolyte solution due to the evolution of gas bubbles or through mechanical agitation.

One of the most common and most regulated metals used in electroplating operations is chromium. Chrome electroplating is of particular importance from an environmental standpoint, and some air resource boards have developed several rules regarding its use. There are two types of chromium electroplating, hard and decorative. Hard chromium electroplating produces a relatively thick chromium layer and is performed to improve a material's physical properties or to build up surfaces that have been eroded by use. Decorative chromium plating results in a thin chromium layer that produces a bright surface with wear and tarnish resistance. Hexavalent chromium (Cr^{+6}), which is the most toxic form of chromium, is the most widely used for depositing chrome on metal. Trivalent chromium is sometimes used as an alternative to Cr^{+6}, because of lower operating costs and fewer environmental concerns. However, trivalent chromium is more sensitive to contamination than Cr^{+6}, and does not provide the full range of coating thickness options that Cr^{+6} provides.

8.1.2 Chromic Acid Anodizing

Chromic acid anodizing is another coating method that is commonly used on aluminum aircraft parts that are subject to high stress and corrosion. The process is similar to that of chrome electroplating, with some equipment differences. For chromic acid anodizing, the tank acts as the cathode while the aluminum part acts as the anode. Sidewall shields are used to reduce the possibility of 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 at a rate of 5 volts per minute, from 5 to 40 volts, and then 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 ampere/square foot (A/ft^2). The chromic acid anodizing process produces PM emissions made up entirely of chromic acid mist.

8.1.3 Thermal Metal Spraying

Thermal metal spraying is a process in which metal coatings are applied to critical or high strength parts. This coating method was developed as a more environmentally friendly alternative to electroplating. The purpose of thermal metal spraying may be for corrosion control, improved wear characteristics, thermal protection, electrical insulation or conduction, or just for aesthetics. The coating material used in thermal metal spraying may be in the form of a powder, rod, or wire that is heated and deposited in a molten or semi-molten condition onto the part being treated. Emissions of concern from thermal metal spraying are PM (PM_{10} and $PM_{2.5}$) and HAPs.

For thermal metal spraying processes, the method of application is dependent on the thickness of the coating to be applied or the properties of the part being coated. The different application methods include electric arc spray, flame spray, high velocity oxy-fuel (HVOF) spray, and plasma spraying. The coating precursor, "feedstock", is heated by chemical (combustion flame) or electrical (plasma or arc) methods.

In electric arc spraying, two conductive wires are fed into a spray gun and brought into close contact. A voltage is applied to the wires, which creates an electric arc that melts the tips of the wires. Air is directed through this point, projecting the molten material onto the part being coated. This method is ideal for applying thick coatings to any part or applying coatings to non-metallic materials at high spray rates.

Flame spraying, which is sometimes known as combustion spraying, uses a spray gun that combusts spray gas such as O_2 and acetylene. Powder or wire is fed through a combustion point where the temperatures are sufficiently high to melt the feedstock. The spray gas air stream projects the molten particles onto the part to be coated. This process may use non-conductive wires and has high transfer efficiency for materials with low melting points.

High velocity oxy-fuel (HVOF) spraying is a subset of flame spraying developed to produce high quality, specialty coatings. In HVOF, powder feedstock is added to the jet stream, which partially melts the powder particles and projects them onto the part being coated. The high velocity of the jet stream results in a dense coating with low porosity and strong adhesion, which may be applied to form a relatively thick coating with minimal thermal or metallurgical effects.

Plasma spraying is the most versatile thermal metal spraying application method since it utilizes a wide range of coatings, can be used on both small and large components, and can be used on almost any sprayable surface. This is partly because the substrate being coated does not experience a significant temperature increase as it is being coated. In plasma spraying, an electric arc is created in the spray gun. The electric arc is surrounded by a plasma forming gas such as an argon/helium or argon/hydrogen mixture. The gas expands due to the increased temperature and forms a jet stream as it leaves the nozzle of the spray gun. Powder particles are injected into the jet stream where the temperature is sufficiently high to melt them. Due to the high velocity of the jet stream, the molten material forms a strong bond to the substrate.

8.2 NESHAP Applicability

The use of HAPs as coating material for corrosion control processes has given rise to several NESHAPs to minimize the release of these pollutants into the atmosphere. 40 CFR 63 Subpart N, *National Emission Standards for Chromium Emissions from Hard and Decorative Chromium Electroplating and Chromium Anodizing Tanks*, outlines the record keeping and operating requirements of any facility which operates either a hard chromium or decorative chromium electroplating tank. Similarly, any facility that owns or operates a plating or polishing facility that is an area source of HAP emissions and performs non-chromium electroplating is subject to the standards described in 40 CFR 63 Subpart WWWWWW, *National Emission Standards for Hazardous Air Pollutants: Area Source Standards for Plating and Polishing Operations*. 40 CFR 63 Subpart GG, *National Emission Standards for Aerospace Manufacturing and Rework Facilities,* also applies to any facilities that are major sources for HAPs that manufacture or rework aerospace vehicles or components. Refer to 40 CFR 63 Subparts N, GG, and WWWWWW to verify that the facility complies with the standards outlined in these sections.

8.3 Emission Factors

Emissions from electroplating operations are dependent on the metal used in the process. EFs have been developed for chromium electroplating processes and are presented in Table 8-1. EFs are based on which type of electroplating is being applied, hard or decorative, as well as what control type is applicable, if present. If the electroplating shop performs electroplating operations using metals other than chromium, the appropriate EFs should be selected from Section 12.20 of AP-42.

Unlike the EFs for chromium electroplating, the EFs for chromic acid anodizing operations are in units of $lb/10^3hr\text{-}ft^2$. This is because the EFs are dependent on the tank surface area. The EFs for chromic acid anodizing are listed in Table 8-2.

During thermal metal spraying, both chromium and nickel are commonly applied to substrates for decorative and practical purposes. Due to their common use and harmful environmental effects, EFs for thermal metal spraying using nickel and chromium have been developed for each of the more common application methods. These EFs are in units of lb HAP/lb coating sprayed, and are provided in Table 8-3. Note that an EF for Cr^{+6} is given, and not for total chromium. Other common materials applied using thermal metal spraying include cadmium, lead, and manganese; however, EFs are not known to have been developed for these metals.

Table 8-1. Chromium and PM Emission Factors for Chromium Electroplating

Process	Control Type[(a)]	Emission Factor (lb/10^3 A-hr)		
		Chromium	PM_{10}[(b)]	$PM_{2.5}$[(b)]
Hard Chromium Electroplating SCC 3-09-010-18	Uncontrolled	1.71E-02	3.57E-02	3.57E-02
	MEX	2.00E-03	4.00E-03	4.00E-03
	PB	6.00E-03	1.26E-02	1.26E-02
	FS	2.29E-03	4.86E-03	4.86E-03
	FS and PB	4.29E-04	9.00E-04	9.00E-04
	PBS	3.00E-04	6.29E-04	6.29E-04
	PBS, FS, and PB	3.71E-05	7.86E-05	7.86E-05
	CBME	1.26E-03	2.57E-03	2.57E-03
	MPME	1.71E-04	3.71E-04	3.71E-04
	PBS and MPME	4.57E-07	9.57E-07	9.57E-07
	Composite MPME	5.43E-05	1.14E-04	1.14E-04
Decorative Chrome Electroplating SCC 3-09-010-28	Uncontrolled	4.71E-03	9.86E-03	9.86E-03
	FS	1.71E-05	3.57E-05	3.57E-05

SOURCE: Section 12.20 - “Electroplating," Compilation of Air Pollutant Emission Factors Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, July 1996. SCC = Source Classification Code.

a) Control Types include: MEX - Moisture Extractor, PB - Polypropylene Balls, FS - Fume Suppressant, PBS - Packed Bed Scrubber, CBME - Chevron Blade Mist Eliminator, and MPME - Mesh Pad Mist Eliminator.

b) Original source lists emission factors for total particulate matter (PM). Assumption is that total PM = PM_{10} = $PM_{2.5}$.

Table 8-2. Chromium and PM Emission Factors for Chromic Acid Anodizing

Control Type[(a)]	Emission Factor (lb/10^3 hr-ft^3)		
	Chromium	PM_{10}[(b)]	$PM_{2.5}$[(b)]
Uncontrolled	2.86E-01	6.00E-01	6.00E-01
PB	2.43E-01	5.14E-01	5.14E-01
FS	9.14E-03	1.86E-02	1.86E-02
FS and PB	3.57E-03	7.57E-03	7.57E-03
PBS	1.37E-03	2.86E-03	2.86E-03
PBS and FS	1.07E-04	2.29E-04	2.29E-04
MPME	7.29E-04	1.57E-03	1.57E-03
PBS and MPME	7.71E-05	1.57E-04	1.57E-04
WS, MEX, and HEPA filter	6.86E-05	1.43E-04	1.43E-04

SOURCE: Section 12.20 - "Electroplating", Compilation of Air Pollutant Emission Factors Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, July 1996.

a) Control types include: PB – Polypropylene balls, FS – Fume suppressant, PBS – Packed Bed Scrubber, MPME – Mesh Pad Mist Eliminator, WS – Wet Scrubber, MEX – Moisture Extractor, HEPA – High Efficiency Particulate Air.

b) Original source lists emission factors for particulate matter (PM). Assumption is that Total PM = PM_{10} = $PM_{2.5}$.

Table 8-3. Chromium and Nickel Emission Factors for Thermal Metal Spraying

Operation	Emission Factors (lb HAP/lb sprayed)	
	lb Cr^{+6}/lb Cr sprayed	lb Ni/lb Ni sprayed
Electric Arc Spray	6.96E-03	6.00E-03
Flame Spray	6.20E-03	1.10E-01
Single-Wire Flame Spray	4.68E-03	---
HVOF	6.20E-03	1.10E-01
Plasma Spray	1.18E-02	1.50E-01
Other Thermal Spraying	7.17E-03	9.40E-02

SOURCE: "Airborne Toxic Control Measure to Reduce Emissions of Hexavalent Chromium and Nickel from Thermal Spraying," California Environmental Protection Agency, 2011

"---" – No data available

8.4 Control Techniques

There are several types of control devices and techniques that have been implemented to reduce the amount of emissions from electroplating, especially given the common use of Cr^{+6}. Several control devices act as mist suppressants to reduce PM and HAP emissions. Mist suppressant controls include moisture extractors, blade and mesh pad mist eliminators, polypropylene balls, and both packed bed and wet scrubbers. Moisture extractors utilize a centrifuge to remove chromic acid mist from the bath exhaust. Chevron blade and mesh pad moisture eliminators work by allowing the vapor stream to pass through them. This results in the collection of the air-suspended liquid droplets that coalesce over time and flow back into the tank. Polypropylene balls reduce the amount of liquid surface area in the tank, which greatly reduces the amount of mist generated. Scrubbers are the most common control device for electroplating and chromic acid anodizing. The chromic acid air stream flows through the scrubber, which absorbs the gaseous component of chromic acid and removes excess liquid from the air stream.

In addition to mist suppression, there are fume suppressant controls that are often used. Fume suppressants may be subdivided into two categories; those that suppress surface misting and those that are wetting agents, which change the surface chemistry. Wetting agents reduce the surface tension of the plating baths, which results in a diminished "bursting" of the bubbles formed at the liquid surface, and a reduced amount of misting.

For thermal metal spraying, emissions may be controlled through the addition of filters, wet impingers, baghouses, or water curtains. Most likely, most emissions reductions for thermal metal spraying will come from add-on control devices. Common control devices include a water curtain, dry filters, or High Efficiency Particulate Air (HEPA) filters. Contact the manufacturer to determine the control efficiency of the device.

8.5 Emissions Calculation

8.5.1 Electroplating

To calculate emissions from hard and decorative chromium electroplating operations, the total annual energy input (A-hr) is multiplied by the appropriate EF, as shown below:

$$\boldsymbol{E_{Pol} = EI \times \frac{1}{1000} \times EF_{Pol}}$$

Equation 8-1

Where,

$\mathbf{E_{Pol}}$ = Annual emissions of pollutant (lb/yr)
EI = Total annual energy input (A-hr/yr)
1000 = Factor converting A-hr to 10^3 A-hr (A-hr/10^3 A-hr)
$\mathbf{EF_{Pol}}$ = Emission factor (lb/10^3A-hr)

A detailed control volume depicting emissions from electroplating is provided in Figure 8-2.

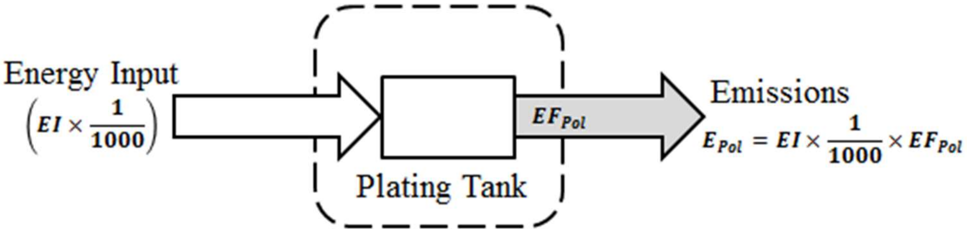

Figure 8-2. Electroplating Control Volume

8.5.2 Chromic Acid Anodizing

To calculate emissions from chromic acid anodizing operations, the total annual tank operating time and the tank surface area must be known. These values are multiplied by the appropriate EF, as shown in Equation 8-2.

$$E_{Pol} = OT \times \frac{1}{1000} \times SA \times EF_{Pol}$$

Equation 8-2

Where,

E_{Pol} = Annual emissions of pollutant (lb/yr)
OT = Total annual tank operating time (hr/yr)
1000 = Factor converting hr to 10^3 hr (hr/10^3 hr)
SA = Surface area of tank (ft^2)
EF_{Pol} = Emission Factors (lb/10^3 hr-ft^2)

A detailed control volume for chromic acid anodizing is provided in Figure 8-3.

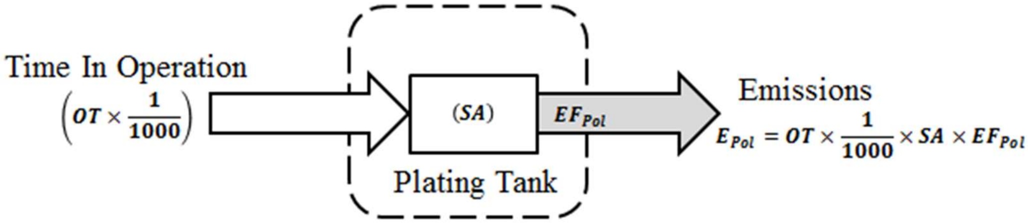

Figure 8-3. Chromic Acid Anodizing Control Volume

8.5.3 Thermal Metal Spraying

There are two methods for calculating emissions from thermal metal spraying. The first method uses a mass balance equation, while the second method uses EFs for emissions calculations. The two methods are described below.

8.5.3.1 Mass Balance Method for Calculating Particulate and Inorganic HAP Emissions

Particulate emissions calculations are more complex than organic HAP and VOC emissions due to the transfer efficiency and fallout percentage associated with each process. Transfer efficiency refers to the fraction of coating solids which adhere to the part surface. Overspray refers to those solids that are applied, but do not adhere to the surface of the part being treated. There are several variables that affect the transfer efficiency including the application method, the size and surface area of the part, and even the skill of the person applying the coating. Each shop should be able to provide assistance in determining the transfer efficiency for emissions estimation purposes. The fallout percent refers to the percent of solids in the overspray that fall to the floor prior to passing through the control device. The fallout value is a function of the application method, the size and surface area of the part, and the spray area ventilation rate. Contact the paint shops for assistance in estimating the fallout. However, if this information is unavailable a conservative assumption of 0 percent fallout may be made. The calculation is performed as follows:

$$\boldsymbol{E_{Pol} = Q \times \left(\frac{WP_{Pol}}{100}\right) \times \left[1 - \left(\frac{TE}{100}\right)\right] \times \left[1 - \left(\frac{FO}{100}\right)\right] \times \left[1 - \left(\frac{CE}{100}\right)\right]}$$

Equation 8-3

Where,

E_{Pol} = Pollutant Emissions (lb/yr)
Q = Quantity of coating applied (lb/yr)
WP_{Pol} = Weight percent of the pollutant in the coating (%)
100 = Factor converting percent to a fraction (%)
TE = Transfer efficiency (%)
FO = Fallout (%). **Use 0 if unknown.**
CE = Efficiency of the emission control device (%). **This is 0 if no device is present.**

A detailed control volume showing the emissions from thermal metal spraying is shown in Figure 8-4.

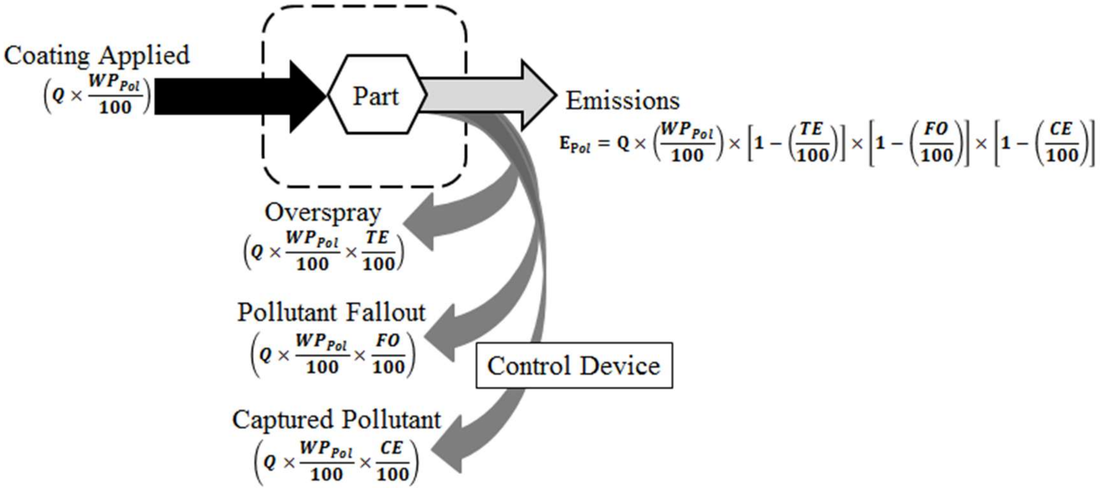

Figure 8-4. Thermal Metal Spraying Control Volume – Mass Balance Method

Note that if the fallout fraction is unknown, but the quantity of overspray recovered is known, then Equation 8-3 may be modified to calculate emissions as follows:

$$E_{Pol} = (Q_S - Q_R) \times \left(\frac{WP_{Pol}}{100}\right) \times \left[1 - \left(\frac{TE}{100}\right)\right] \times \left[1 - \left(\frac{CE}{100}\right)\right]$$

Equation 8-4

Where,

Q_S = Quantity of coating applied (lb/yr)
Q_R = Quantity of coating recovered – not from control device (lb/yr)

If emissions of a specific HAP are required and the weight percent is unknown, but the weight percent of the HAP containing compound is known, then the weight percent of the specific HAP may be determined using Equation 8-5.

$$WP_{HAP} = \frac{MW_{HAP}}{MW_{Cmpd}} \times WP_{Cmpd}$$

Equation 8-5

Where,

WP_{HAP} = Weight percent of the specific HAP in the coating (%)
MW_{HAP} = Molecular weight of HAP in the coating compound (g)
MW_{Cmpd} = Molecular weight of the HAP containing compound (g)
WP_{Cmpd} = Weight percent of the HAP containing compound in the coating (%)

8.5.3.2 Emission Factor Method

The EF method is less accurate than the mass balance equation and should be used when it is the only viable option. In addition to the diminished accuracy that comes with using EFs, the PM EFs for thermal spraying have not been developed directly for total PM, but rather, for speciation of HAPs within PM. EFs have been calculated to determine chromium, Cr^{+6}, and nickel emissions and are provided in Table 8-3. Emissions calculation using the EF method is performed as follows:

$$E_{Pol} = Q \times \left(\frac{WP_{Pol}}{100}\right) \times EF_{Pol} \times \left[1 - \left(\frac{CE}{100}\right)\right]$$

Equation 8-6

Where,

E_{Pol} = Pollutant emissions (lb/yr)
Q = Quantity of coating applied (lb/yr)
WP_{Pol} = Weight percent of the pollutant in the coating (%)
EF_{Pol} = Pollutant emission factor (lb/lb)
CE = Efficiency of the emission control device (%)

A more detailed control volume for thermal spraying using EFs is given in Figure 8-5.

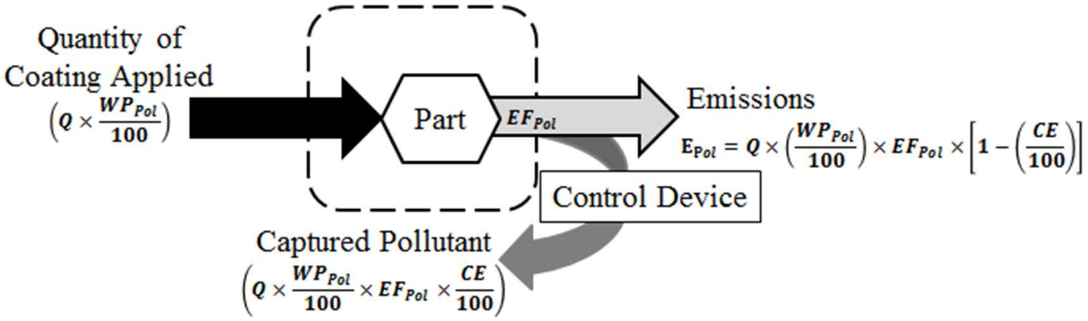

Figure 8-5. Thermal Metal Spraying Control Volume - Speciated Inorganic HAP Emission Factor Method

8.6 Information Resources

The base electroplating shop(s) may be contacted directly for all information required to calculate emissions from electroplating or chromic acid anodizing operations. Information on the quantity of coating material delivered to a shop should be available from records/databases maintained by the Hazardous Materials Pharmacy (HAZMART), or Enterprise Environmental, Safety & Occupational Health Management Information System (EESOH-MIS). Information may also be obtained from the product literature (e.g. SDS, container label, and technical specification sheets). If necessary, Bioenvironmental Engineering (BEE) should be able to provide a list of all shops on base that perform electroplating, anodizing, and/or thermal metal spraying.

The efficiency of any control device used may be obtained from product literature or directly from the manufacturer of the control device. For thermal metal spraying, the average transfer efficiency should be available from the paint shops. However, the manufacturer of the spray equipment may also be able to provide guidance. Note that transfer efficiency is directly correlated to the size and shape of the part being coated, so the manufacturer may need to know this information regarding the typical pieces being treated to provide a more accurate value. The most difficult value to obtain may be the fallout efficiency, which can be determined through on-site measurements. If required, a conservative emission calculation is possible by assuming this value to be equal to zero.

8.7 Example Problems

8.7.1 Problem #1 (Electroplating and Chromic Acid Anodizing)

A USAF base needs to calculate chromium emissions from two electroplating shops on base. Shop A performs hard chromium electroplating with polypropylene balls, and used approximately 1,260,000 A-hr during the year. Shop B performs chromic acid anodizing with a fume suppressant, and reports a total operating time of 5,600 hr for its tank. The surface area of the tank is 20 ft^2. Calculate the total chromium emissions from both processes at these shops.

__Step 1__ **- Select and record the appropriate emission factors.** EFs for electroplating and chromic acid anodizing may be found in Table 8-1 and Table 8-2, respectively. For shop A, the EF for chromium is **6.00E-03 lb/10^3 A-hr** and for shop B, the EF for chromium is **9.14E-03 lb/10^3 hr-ft^2**.

__Step 2__ **– Calculate chromium emissions for shop A**. Using the data given in the problem statement, the EFs recorded in Step 1, and Equation 8-1, the chromium emissions are calculated as follows:

$$E_{Pol} = EI \times \frac{1}{1000} \times EF_{Pol}$$

$$\boldsymbol{E(shop\ A)_{Cr}} = 1{,}260{,}000\ \frac{\cancel{A-hr}}{yr} \times \frac{1}{1000}\frac{\cancel{10^3 A-hr}}{\cancel{A-hr}} \times 0.006\frac{lb}{\cancel{10^3 A-hr}} = \mathbf{7.56}\,\boldsymbol{\frac{lb}{yr}}$$

Step 3 - Determine the chromium emissions from Shop B. Using the data given in the problem statement, the EFs recorded in Step 1, and Equation 8-2, the chromium emissions are calculated as follows:

$$E_{Pol} = OT \times \frac{1}{1000} \times SA \times EF_{Pol}$$

$$\boldsymbol{E(shop\ B)_{Cr}} = 5{,}600\frac{\cancel{hr}}{yr} \times \frac{1}{1000}\frac{\cancel{10^3 hr}}{\cancel{hr}} \times 20\cancel{ft^2} \times 0.00914\frac{lb}{\cancel{10^3 hr - ft^2}} = \mathbf{1.02}\frac{\boldsymbol{lb}}{\boldsymbol{yr}}$$

Step 4 - Calculate the total chromium emissions. Add chromium emissions from both shop A and shop B for the total as shown:

$$E(total)_{Cr} = E(shop\ A)_{Cr} + E(shop\ B)_{Cr}$$

$$E(total)_{Cr} = 7.56\ \frac{lb}{yr} + 1.02\ \frac{lb}{yr}$$

$$\boxed{\boldsymbol{E(total)_{Cr}} = \mathbf{8.58}\ \frac{\boldsymbol{lb}}{\boldsymbol{yr}}}$$

8.7.2 Problem #2 (Thermal Metal Spraying - Emission Factor Method)

A USAF base is interested in determining the amount of Cr^{+6} that was emitted in the previous year. The base has two spray booths that perform thermal spraying with one booth dedicated to plasma spraying and the other to HVOF spraying. After looking at shop records and the SDS for the materials sprayed, the quantity of material used, weight percent HAPs, and controls are recorded and provided below.

Booth	Control Device	Operation	Material	Quantity Used (lb/yr)	% Total Cr
Booth #1	HEPA Filter	Plasma Spray	Powder A	25	25
			Powder B	15	***
Booth #2	HEPA Filter	HVOF	Powder A	30	25

***Powder B does not have a weight percent provided for Cr, but does state that the powder is 95 percent chromium oxide (Cr_2O_3) by weight. Assuming the HEPA filter has an efficiency of 99 percent, calculate the amount of Cr^{+6} emitted the previous year.

<u>Step 1</u> – **Calculate the weight percent Cr in powder B.** The information has already been gathered and provided in the table above, but the weight percent Cr for powder B must be calculated. This is accomplished using Equation 8-5 as follows:

$$WP_{HAP} = \frac{MW_{HAP}}{MW_{Cmpd}} \times WP_{Cmpd}$$

$$WP_{Cr} = \frac{(52\times2)\frac{g}{mol}}{[(52\times2)+(16\times3)]\frac{g}{mol}} \times 95\%$$

$$WP_{Cr} = \frac{104\frac{\cancel{g}}{\cancel{mo}}}{152\frac{\cancel{g}}{\cancel{mol}}} \times 95\%$$

$$\boldsymbol{WP_{Cr}} = 0.684 \times 95\% = \mathbf{65}\%$$

<u>Step 2</u> – **Select and record the appropriate emission factors.** Using Table 8-3, the EFs for Cr^{+6} are stated as **1.18E-02** and **6.20E-03** lb Cr^{+6}/lb Cr for plasma spraying and HVOF, respectively.

<u>Step 3</u> – **Calculate Cr^{+6} emissions.** Using the control efficiency and the quantity of the coating applied as given in the problem statement, plus the EFs recorded in Step 2, the emissions of Cr^{+6} for each booth may be calculated using Equation 8-6.

$$E_{Pol} = Q \times \left(\frac{WP_{Pol}}{100}\right) \times EF_{Pol} \times \left[1 - \left(\frac{CE}{100}\right)\right]$$

For Booth #1:

<u>For Powder A:</u>

$$E_{Cr^{+6}} = 25\frac{lb}{yr} \times \left(\frac{25\cancel{\%}}{100\cancel{\%}}\right) \times 0.0118\frac{lb\ Cr^{+6}}{lb\ Cr} \times \left[1 - \left(\frac{99\cancel{\%}}{100\cancel{\%}}\right)\right]$$

$$E_{Cr^{+6}} = 25\frac{lb}{yr} \times 0.25 \times 0.0118\frac{lb\ Cr^{+6}}{lb\ Cr} \times [1 - (0.99)]$$

$$E_{Cr^{+6}} = 25\frac{lb}{yr} \times 0.25 \times 0.0118\frac{lb\ Cr^{+6}}{lb\ Cr} \times [0.01]$$

$$\boldsymbol{E_{Cr^{+6}}} = 6.25\frac{\cancel{lb}}{yr} \times 0.0118\frac{lb\ Cr^{+6}}{\cancel{lb\ Cr}} \times [0.01] = \mathbf{7.38E-04}\frac{\mathbf{lb}}{\mathbf{yr}}$$

<u>For Powder B:</u>

$$E_{Cr^{+6}} = 15\frac{lb}{yr} \times \left(\frac{65\cancel{\%}}{100\cancel{\%}}\right) \times 0.0118\frac{lb\ Cr^{+6}}{lb\ Cr} \times \left[1 - \left(\frac{99\cancel{\%}}{100\cancel{\%}}\right)\right]$$

$$E_{Cr^{+6}} = 15\frac{lb}{yr} \times \left(\frac{65\cancel{\%}}{100\cancel{\%}}\right) \times 0.0118\frac{lb\ Cr^{+6}}{lb\ Cr} \times [1 - (0.99)]$$

$$E_{Cr^{+6}} = 15\frac{lb}{yr} \times 0.65 \times 0.0118\frac{lb\ Cr^{+6}}{lb\ Cr} \times [0.01]$$

$$\boldsymbol{E_{Cr^{+6}}} = 9.75\frac{\cancel{lb}}{yr} \times 0.0118\frac{lb\ Cr^{+6}}{\cancel{lb\ Cr}} \times [0.01] = \mathbf{1.15}\boldsymbol{E} - \mathbf{03}\frac{\boldsymbol{lb}}{\boldsymbol{yr}}$$

For Booth #2:

$$E_{Cr^{+6}} = 30\frac{lb}{yr} \times \left(\frac{25\cancel{\%}}{100\cancel{\%}}\right) \times 0.0062\frac{lb\ Cr^{+6}}{lb\ Cr} \times \left[1 - \left(\frac{99\cancel{\%}}{100\cancel{\%}}\right)\right]$$

$$E_{Cr^{+6}} = 30\frac{lb}{yr} \times \left(\frac{25\cancel{\%}}{100\cancel{\%}}\right) \times 0.0062\frac{lb\ Cr^{+6}}{lb\ Cr} \times [1 - (0.99)]$$

$$E_{Cr^{+6}} = 30\frac{lb}{yr} \times 0.25 \times 0.0062\frac{lb\ Cr^{+6}}{lb\ Cr} \times [0.01]$$

$$\boldsymbol{E_{Cr^{+6}}} = 7.5\frac{\cancel{lb}}{yr} \times 0.0062\frac{lb\ Cr^{+6}}{\cancel{lb\ Cr}} \times [0.01] = \mathbf{4.65}\boldsymbol{E} - \mathbf{04}\frac{\boldsymbol{lb}}{\boldsymbol{yr}}$$

<u>Step 4</u> – Calculate total $\mathbf{Cr^{+6}}$ emissions. The total emissions are the sum of the Cr^{+6} from each coating in both booths.

$$E_{Cr^{+6}} = (0.000738 + 0.00115 + 0.000465)\frac{lb}{yr}$$

$$\boxed{\boldsymbol{E_{Cr^{+6}}} = \mathbf{2.35}\boldsymbol{E} - \mathbf{03}\frac{\boldsymbol{lb}}{\boldsymbol{yr}}}$$

8.8 References

40 CFR 63 Subpart N, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 63-National Emission Standards for Hazardous Air Pollutants for Source Categories, Subpart N- National Emission Standards for Chromium Emissions from Hard and Decorative Chromium Electroplating and Chromium Anodizing Tanks," U.S. Environmental Protection Agency

40 CFR 63 Subpart GG, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 63-National Emission Standards for Hazardous Air Pollutants for Source Categories, Subpart GG-National Emission Standards for Aerospace Manufacturing and Rework Facilities," U.S. Environmental Protection Agency

40 CFR 63 Subpart WWWWWW, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 63-National Emission Standards for Hazardous Air Pollutants for Source Categories, Subpart WWWWWW- National Emission Standards for Hazardous Air Pollutants Area Source Standards for Plating and Polishing Operations," U.S. Environmental Protection Agency

CARB 2011, "Airborne Toxic Control Measure to Reduce Emissions of Hexavalent Chromium and Nickel from Thermal Spraying," California Environmental Protection Agency, California Air Resources Board (CARB), 2011

USEPA 1996, Section 12.20-“Electroplating," Compilation of Air Pollutant Emission Factors Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, July 1996

9 DRY CLEANING (CLN)

- *Point Source*

9.1 Introduction

Most USAF installations offer some form of dry cleaning service. In most cases, the actual dry cleaning process is performed at off-site locations by contracted employees. However, there are some installations that perform dry cleaning on-base.

Dry cleaning involves the cleaning of fabrics (e.g., garments, draperies, leather goods) with a variety of solvents. As the industry has evolved, so has the process, and alternative dry cleaning solvents have been introduced. These new solvents include halogenated hydrocarbons, petroleum-based solvents, aqueous solvents, and liquid CO_2. Depending on the type of solvent used, the emissions of concern from dry cleaning are VOCs from petroleum solvents and/or organic HAPs such as perchloroethylene (PERC).

One type of previously used solvent, trichlorotrifluoroethane, is subject to the Montreal Protocol and is no longer manufactured or used. Petroleum solvents are flammable and may form explosive mixtures. Therefore, their use is limited to transfer machines where the solvent concentration in vapors does not build to high levels. While there are new technologies emerging, the most common type of solvent is a synthetic, halogenated hydrocarbon known as PERC.

Historically, there were two basic types of dry cleaning machines: transfer and dry-to-dry. In transfer machines, the fabrics are washed in one machine and manually transferred to another machine to dry. Emissions result from the evaporation of the solvent, which occurs both during the transfer and during the operation of the washer and dryer. Evaporated solvents are emitted into the air through the vents on the dry cleaning machines. Transfer units are older technologies that produce more emissions than dry-to-dry machines. New air quality standards, such as those regulated under the EPA's NESHAP program and those regulated under state or local programs, require that all transfer machines be replaced by dry-to-dry units. As a result, **there should not be any transfer units in operation at any USAF installation**. In the dry-to-dry process, both washing and drying take place in one machine that may either be vented or vent-less.

Due to the increase in air quality regulations and the high cost of synthetic halogenated solvents, most dry cleaning machines are equipped with control devices that capture and reduce emissions from air vents. Emissions control is also achieved through changes in operational practices to reduce fugitive emissions through Best Management Practices (BMPs). Examples of BMPs include storage of solvents and wastewater in tightly sealed containers, minimizing the length of time the door on any given dry cleaning machine is left open, and prompt detection and repair of any leaky valves, hose connections, or gaskets, as required under the EPA's 2008 Final Rule for all sources.

In addition to utilizing BMPs to control emissions, control devices can also be employed. 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. 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 performed on-site, the solvent is placed back into the pure solvent supply tank to be re-used. Control devices of this nature are required to be installed in all new dry cleaning machines. NESHAP and the EPA's 2008 Final Rule requirements for dry cleaning require leak detection and seal inspection programs. Additionally, monitoring and reporting programs, and some form of control device, such as the use of refrigerated condensers or carbon adsorbers are also required. **Dry cleaning facilities and equipment are considered point sources** and a simple control diagram for these operations is given in Figure 9-1.

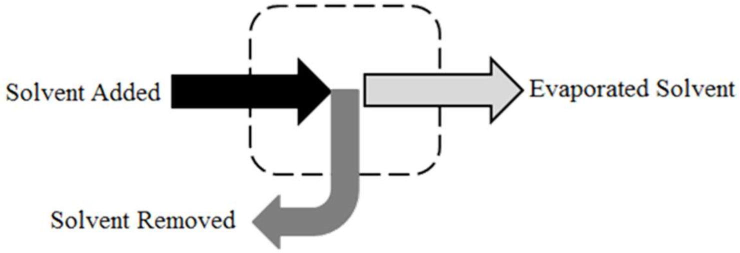

Figure 9-1. Simplified Control Volume for Emissions from Dry Cleaning

9.2 NSPS and NESHAP Applicability

The EPA has established NSPS for dry cleaning machines to reduce the amount of solvent vapor released to the atmosphere. According to 40 CFR 60 Subpart JJJ, *Standards of Performance for Petroleum Dry Cleaners*, any dryer installed after December 14, 1982 must be a solvent recovery dryer for those facilities which use petroleum based solvents. Similarly, any filter installed at a petroleum dry cleaning plant after this date must be a cartridge filter. Supplemental information regarding the recordkeeping requirements and performance standards for dry cleaning equipment may be found in 40 CFR 60 Subpart JJJ.

In addition to the required performance standards, some dry cleaning facilities are also required to observe NESHAP requirements as outlined in 40 CFR 63 Subpart M, *National Perchloroethylene Air Emission Standards for Dry Cleaning Facilities*. These standards outline the required system components for the operation of dry cleaning machines that use PERC. This standard also states that each new dry cleaning facility installed after September 22, 1993 must "eliminate any emission of perchloroethylene during the transfer of articles between the washer and dryer(s)" [40 CFR 63.322(b)(2)]. This mandate has essentially led to the elimination of transfer machines at dry cleaning facilities. To verify that the dry cleaning facility complies with the standards outlined in this NESHAP, refer to 40 CFR 63 Subpart M.

9.3 Emission Factors

Chapter 4, Section 1, of AP-42 provides EFs from dry cleaning processes. However, the EFs provided in Table 4.1-1 are for transfer processes that are no longer allowed, and for dry-to-dry processes using trichlorotrifluoroethane, which is no longer used. Therefore, the use of these EFs is no longer valid. Consequently, calculation of emissions from dry cleaning should be performed using a mass balance approach, rather than an EF approach.

9.4 Emissions Calculation

Emissions produced from dry cleaning operations are estimated using a mass balance method as shown by Equation 9-1 below:

$$\mathbf{E_{Solvent}} = [(\mathbf{V_{FS}} - \mathbf{V_{WS}}) - \mathbf{V_{CS}}] \times \mathbf{D}$$

Equation 9-1

Where,

$\mathbf{E_{Solvent}}$ = Annual emissions of solvent (lb/yr)
$\mathbf{V_{FS}}$ = Volume of fresh solvent added to the dry cleaning process (gal/yr)
$\mathbf{V_{WS}}$ = Volume of waste solvent removed from the process (gal/yr)
D = Density of solvent (lb/gal)
$\mathbf{V_{CS}}$ = Volume of solvent which is captured via carbon adsorption and not reintroduced back into the process (gal/yr)

A more detailed diagram of the emissions resulting from dry cleaning is given in Figure 9-2.

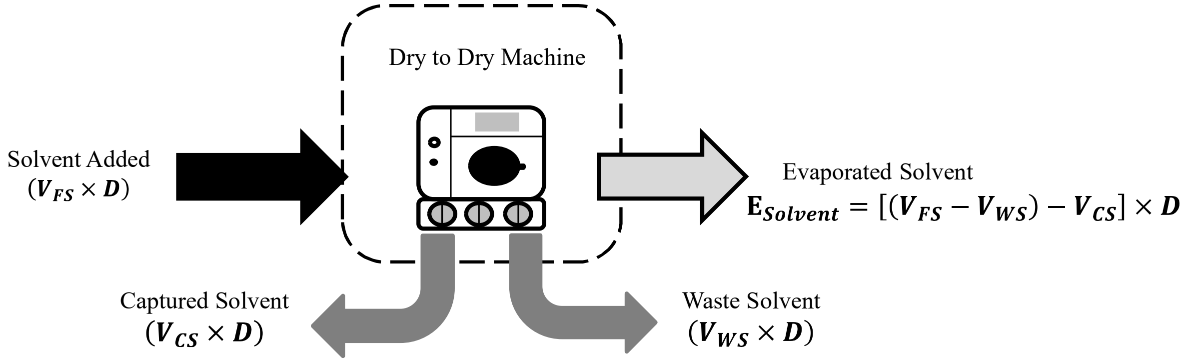

Figure 9-2. Detailed Control Volume for Emissions from Dry Cleaning

9.5 Information Resources

The volume of solvent used (V_{FS}), removed (V_{WS}), and recovered (V_{CS}), should be available from the personnel who operate the dry cleaning machines. Additionally, these personnel should also have the solvent density, which is also available from the SDS supplied by the solvent manufacturer. Information regarding emissions limits and reporting requirements for dry cleaning may be found in 40 CFR 60 Subpart JJJ and 40 CFR 63 Subpart M.

9.6 Example Problem

A dry cleaning facility has a single dry-to-dry machine that uses PERC. A total of 250 gal of fresh PERC was added to the process during the year while approximately 200 gal of waste solvent was removed from the process for off-site recycling. Emissions are controlled by a refrigerated condenser followed by a carbon adsorber. Approximately 25 gal of PERC was captured by the carbon adsorption material during the year and shipped off-site for reclamation. Calculate the PERC emissions using the mass balance method described above. (Note: Density of PERC is **13.5 lb/gal**)

Step 1 – **Calculate emissions from dry cleaning processes.** The problem states that the volume of PERC added (V_{FS}) was 250 gal, the amount removed (V_{WS}) was 200 gal, and the volume recovered (V_{CS}) was 25 gal. Use this data and Equation 9-1 to determine total PERC emissions.

$$\mathrm{E_{Solvent}} = [(\mathrm{V_{FS}} - \mathrm{V_{WS}}) - \mathrm{V_{CS}}] \times \mathrm{D}$$

$$\mathrm{E_{PERC}} = \left[\left(250\frac{gal}{yr} - 200\frac{gal}{yr}\right) - 25\frac{gal}{yr}\right] \times 13.5\frac{lb}{gal}$$

$$\mathrm{E_{PERC}} = \left[\left(50\frac{gal}{yr}\right) - 25\frac{gal}{yr}\right] \times 13.5\frac{lb}{gal}$$

$$\mathrm{E_{PERC}} = \left[25\,\frac{\cancel{gal}}{yr}\right] \times 13.5\,\frac{lb}{\cancel{gal}}$$

$$\boxed{\mathbf{E_{PERC}} = \mathbf{337.5}\ \frac{\mathbf{lb}}{\boldsymbol{yr}}}$$

9.7 References

40 CFR 60 Subpart JJJ, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New Stationary Sources, Subpart JJJ-National Perchloroethylene Air Emission Standards for Dry Cleaning Facilities," U.S. Environmental Protection Agency

40 CFR 63 Subpart M, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 63-National Emission Standards for Hazardous Air Pollutants for Source Categories, Subpart M-National Perchloroethylene Air Emission Standards for Dry Cleaning Facilities," U.S. Environmental Protection Agency

USEPA 1995, Section 4.1-"Dry Cleaning," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, January 1995

10 ELECTRONIC TRANSMISSIONS (ELEC)

- *Fugitive Source*

ONLY FOR MANDATORY GHG REPORTING IF REQUIRED TO REPORT

10.1 Introduction

USAF bases often have electrical transmission and distribution equipment insulated with sulfur hexafluoride (SF_6) or perfluorocarbons (PFCs). Typical equipment includes substations, circuit breakers, lines, switchgears, power transformers, and even components used in radar domes. The insulating gases have exceptional dielectric and arc-quenching properties to prevent electrical discharges and arcing from occurring. The equipment may be either hermetically sealed-pressure or closed-pressure. Hermetically sealed-pressure equipment does not require periodic refilling of the insulating gases, while closed-pressure equipment does. The amount of gas that the system is structurally engineered to hold is known as the Nameplate Capacity (NC) and is typically reported in pounds.

Sulfur hexafluoride (SF_6) is the most common gas used to insulate equipment. Electric power facilities constitute over 80 percent of SF_6 used in the United States, and currently there are no viable alternatives to SF_6. Other gases, such as perfluorocarbons (PFCs), are sometimes used either pure or mixed with SF_6 to decrease the cost of using pure SF_6. Selected GWPs of common gases used in electric power facilities are given in Table 10-1.

Table 10-1. Global Warming Potentials of Common Dielectric Gases

Pollutant	Global Warming Potential
Carbon Tetraflouride (PFC-14)	7,390
Hexafluoroethane (PFC-116)	12,200
Perfluorobutane (PFC-3-1-10)	8,860
Perfluorohexane (PFC-5-1-14)	9,300
Perfluoropropane (PFC-218)	8,830
Sulfur Hexafluoride	22,800

SOURCE: "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 98-Mandatory Greenhouse Gas Reporting, Subpart A-General Provision," U.S. Environmental Protection Agency.

Emissions of GHGs occur through leaks in the system and during equipment installation, testing, maintenance, and decommissioning. **The leaked gases are fugitive in nature** and are assumed to be 100 percent emitted into the atmosphere. **Note that this chapter only applies to USAF installations with mandatory GHG reporting facilities.** A graphic representation of the emissions from electronic transmission is provided in Figure 10-1.

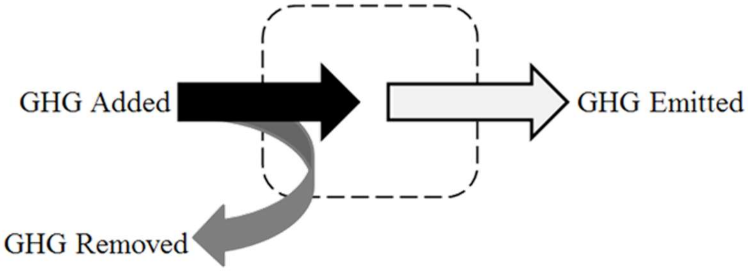

Figure 10-1. Simplified Electronic Transmission Control Volume

10.2 Greenhouse Gas Mandatory Reporting Rule

The EPA has established mandatory GHG reporting requirements for owners and operators of facilities that directly emit GHGs into the atmosphere. Regulations in 40 CFR 98.3, are for facilities that operate electrical transmission and distribution equipment using SF_6 and PFC with a total NC exceeding 17,820 pounds. These facilities are subject to the reporting rules outlined in 40 CFR 98 Subpart DD, *Electrical Transmission and Distribution Equipment Use*. Each facility subject to the reporting requirements as given in 40 CFR 98 Subpart DD must report the following:

- NC of equipment containing SF_6 and each PFC.
- Transmission miles.
- Distribution miles.
- Pounds of SF_6 and PFC stored in containers and **not** in equipment at the beginning and end of each year.
- Pounds of SF_6 and PFC purchased in bulk from distributors and those found in purchased equipment.
- Pounds of SF_6 and PFC returned to the facility after off-site recycling.
- Pounds of SF_6 and PFC sold to other entities, returned to suppliers, or sent off-site for recycling or destruction.

The EPA stipulates that the scale used to weigh the quantities listed above must be accurate to within ±2 pounds and periodically calibrated per manufacturer specifications. To verify that the facility complies with the reporting requirements stipulated by the EPA, refer to 40 CFR 98 Subpart DD for additional information.

10.3 Emissions Calculation

GHG emissions from electronic transmission and distribution are performed using a mass balance approach. Emissions calculations require the net difference in NC to be known and can be found by subtracting the NC of any retiring equipment from the NC of new equipment added to inventory. Note that the NC is specific for each gas.

$$NC_D = NC_N - NC_R$$

Equation 10-1

Where,

NC_D = Net annual difference in total nameplate capacity of equipment operated (lb/yr)
NC_N = Nameplate capacity of new equipment added to facility (lb/yr)
NC_R = Nameplate capacity of retiring equipment (lb/yr)

Emissions from all pertinent gases used to insulate an electric power transmission and distribution facility should then be calculated using a mass balance approach, as follows:

$$E_{Pol} = (Q_D + Q_A) - (Q_R + NC_D)$$

Equation 10-2

Where,

E_{Pol} = Annual emissions of greenhouse gas (lb/yr)
Q_D = Annual net decrease of greenhouse gas inventory stored in containers but not in equipment (lb/yr)
Q_A = Annual acquisitions of greenhouse gas from chemical producers or distributors, gas found in purchased equipment, and gas returned to the facility after off-site recycling (lb/yr)
Q_R = Annual removal of greenhouse gas either sold to other entities, returned to suppliers, sent off-site for recycling, or sent off-site for destruction (lb/yr)
NC_D = Annual net increase in total nameplate capacity of newer equipment added to inventory or replacing old equipment. Note this is proper equipment charge and not actual charge which may reflect leakage (lb/yr)

A detailed control volume depicting emissions of GHGs using electronic transmission and distribution equipment is provided in Figure 10-2.

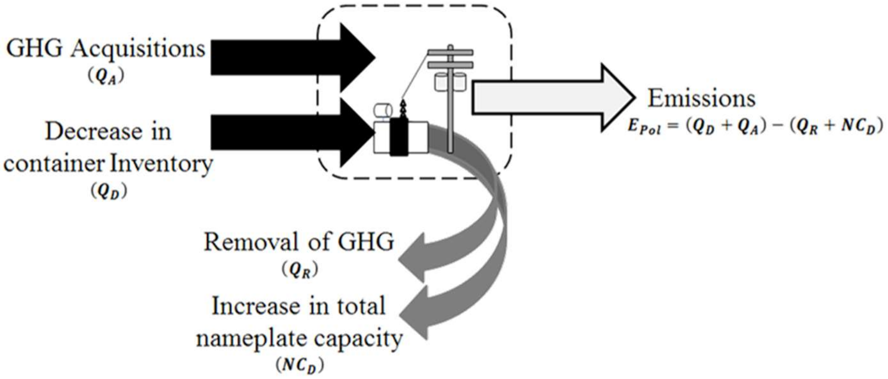

Figure 10-2. Electronic Transmission Control Volume

The emissions of GHGs in 100-year CO_2e are then calculated by multiplying the annual emissions of the pollutant from Equation 10-2 by their respective GWP from Table 10-1 and summing their totals, as shown:

$$E(CO_2e)_{GHG} = \sum_{i=1}^{n}\left(E_{Pol_i} \times GWP_{Pol_i} + \cdots + E_{Pol_n} \times GWP_{Pol_n}\right)$$

Equation 10-3

Where,

$\mathbf{E_{GHG}}$ = Annual GHG emissions in CO_2e (lb/yr)
$\mathbf{E_{Pol}}$ = Annual emissions of either SF_6 or PFCs (lb/yr)
$\mathbf{GWP_{Pol}}$ = 100-year GWP of selected GHG in CO_2e. This is provided in Table 10-1.

10.4 Information Resources

All information required for calculating emissions from electronic transmission facilities can be obtained through base CE. This includes NC, volume of gas in storage, volume of gas acquired, volume of gas disposed, and if applicable, any gas mixtures. GWPs of applicable GHGs can be found in 40 CFR 98 Subpart A.

10.5 Example Problem

A USAF base is mandated to calculate GHG emissions from the electric power facility on site. Base CE was contacted, and reports the total NC of all equipment was 11,500 lb last year, which increased to 11,800 lb this year. Additionally, they estimated that the amount of gas stored in containers decreased by 50 lb, while another 460 lb of gas had been purchased and 40 lb of gas was removed for disposal. Only SF_6 is used in the equipment at the facility. Calculate the GHG emissions from the operation of electrical transmission equipment for this facility.

<u>Step 1</u> - Record all information necessary to calculate emissions. The problem states that the net decrease of gas stored in containers (Q_D) was **50 lb**, the volume of gas acquired (Q_A) was **460 lb**, the volume of gas removed (Q_R) was **40 lb**, and the previous NC increased to **11,800 lb** from **11,500 lbs**. Also, according to Table 10-1, the GWP of SF_6 is **22,800**.

<u>Step 2</u> - Calculate the net increase in total nameplate capacity. Using the data recorded in Step 1 and Equation 10-1, the net increase in total NC is calculated as follows:

$$NC_D = NC_N - NC_R$$

$$\boldsymbol{NC_D} = 11{,}800\ \frac{lb}{yr} - 11{,}500\ \frac{lb}{yr} = \mathbf{300}\,\boldsymbol{\frac{lb}{yr}}$$

<u>Step 3</u> - Calculate the annual emissions of SF_6. Using the data given in Step 1 and Equation 10-2, the annual emissions of SF_6 are calculated as follows:

$$E_{Pol} = (Q_D + Q_A) - (Q_R + NC_D)$$

$$E_{SF_6} = \left(50\frac{lb}{yr} + 460\frac{lb}{yr}\right) - \left(40\frac{lb}{yr} + 300\frac{lb}{yr}\right)$$

$$\boldsymbol{E_{SF_6}} = \left(510\frac{lb}{yr}\right) - \left(340\frac{lb}{yr}\right) = \mathbf{170}\,\boldsymbol{\frac{lb}{yr}}$$

<u>Step 4</u> - Calculate the annual emissions of GHGs. Convert the annual emissions of SF_6 calculated in Step 3 into units of equivalent CO_2 (CO_2e) using the GWP of SF_6 gathered in Step 1 using Equation 10-3 as follows:

$$E(CO_2e)_{GHG} = \sum_{i=1}^{n}\left(E_{Pol_i} \times GWP_{Pol_i} + \cdots + E_{Pol_n} \times GWP_{Pol_n}\right)$$

$$E(CO_2e)_{GHG} = 170\frac{lb}{yr} \times 22800$$

$$\boxed{\boldsymbol{E(CO_2e)_{GHG} = 3{,}876{,}000\frac{lb}{yr}}}$$

10.6 References

40 CFR 98 Subpart A, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 98-Mandatory Greenhouse Gas Reporting, Subpart A-General Provision," U.S. Environmental Protection Agency

40 CFR 98 Subpart DD, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 98-Mandatory Greenhouse Gas Reporting, Subpart DD-Electrical Transmission and Distribution Equipment Use," U.S. Environmental Protection Agency

11 ETHYLENE OXIDE STERILIZERS (STER)

- *Point Source*

11.1 Introduction

Ethylene Oxide (EtO) is commonly used in the sterilization of medical equipment and surgical materials. Many hospitals and clinics on USAF bases have small, self-contained units for EtO sterilization. It is important to note that some facilities are beginning to use another method which utilizes ozone as a sterilizing agent. The ozone sterilization process takes United States Pharmacopeia (USP) grade O_2, water, and electricity, and energizes it to form ozone within the sterilizer. The ozone is then converted back into O_2 and water vapor by the end of the sterilization cycle, so is not considered a significant source of ozone emissions. Therefore, ozone sterilizers are not addressed within this guide and this section pertains only to EtO sterilizers.

EtO sterilization is ideal for heat and moisture sensitive equipment. However, EtO is highly flammable in the presence of as little as 3 percent air by volume. In 2010, new label restrictions required EtO sterilization to be performed in a single-chamber process. The sterilization process involves the use of a vacuum chamber that is a pressure vessel designed to safely handle EtO. Typical operating procedures involve five different stages: preconditioning/humidification, sterilant introduction, exposure, evacuation, and air washes. The sterilant of choice may either be 100 percent EtO or an EtO/gas mixture. Often, EtO sterilizers are operated in a closed loop system, which typically results in zero emissions.

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, but are not limited to, thermal oxidation (incineration), catalytic oxidation, and wet scrubbing. Although control techniques are designed to reduce EtO emissions, they could potentially break down EtO that may lead to other emissions of concern, such as GHGs. If the EtO sterilizer has a control device installed, the control device manufacturer may be contacted for more information regarding the emissions reduction efficiency. Additionally, if an EtO gas mixture is used, all constituents of the sterilant must be considered for emissions. **EtO sterilizers are point sources of emissions**. A simple control volume outlining emissions from the use of EtO sterilizers is provided in Figure 11-1.

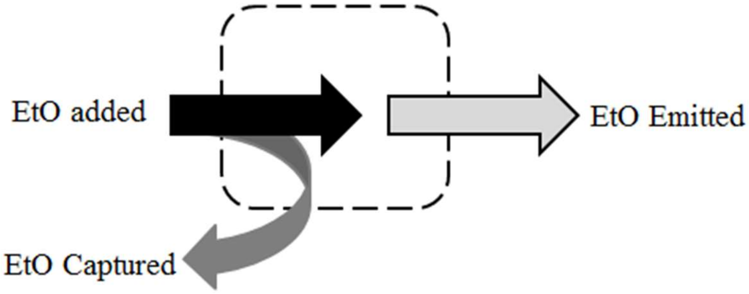

Figure 11-1. Simplified Control Volume for Emissions from EtO Sterilizers

11.2 NESHAP Applicability

The NESHAP requirements for EtO sterilizers are outlined in 40 CFR 63 Subpart WWWWW, *National Emission Standards for Hospital Ethylene Oxide Sterilizers*. This section states that any new or existing facility at a hospital that is an area source of HAP emissions must sterilize full loads of items having a common aeration time, except under medically necessary circumstances. This regulation also states the requirements to demonstrate compliance. For additional information, consult 40 CFR 63 Subpart WWWWW to verify that all facilities using EtO sterilizers comply with this NESHAP. Additionally, 40 CFR 63 Subpart O, *Ethylene Oxide Emissions Standards for Sterilization Facilities,* outlines the standards for EtO emissions for sterilization facilities. These standards are applicable to all sources using one ton in sterilization or fumigation operations. However, these standards do not apply to research laboratories or facilities whose primary purpose is to provide medical services to humans or animals. This standard stipulates that all sources using over one ton in sterilization must achieve at least 99 percent reduction in emissions from each sterilization chamber vent. Refer to 40 CFR 63 Subpart O for more information.

11.3 Control Techniques

Increased awareness of the dangers of exposure to EtO has led to advancements in sterilizer technology. These technologies include pulse-purging, in-chamber aeration, catalytic oxidizers, and acid scrubbers. These sterilizer techniques may reduce emissions to insignificant levels. It is important to note that some controls may be effective only on EtO and not diluent gases. Contact the manufacturer for more information regarding the control efficiencies of these devices.

11.4 Emissions Calculation

Emissions from EtO sterilizers are estimated using a mass balance approach. This approach assumes that all EtO not captured by the control device is released to the atmosphere. Using this method, emissions from the use of EtO sterilizers may be calculated as follows:

$$\boldsymbol{E_{Pol} = Q \times \frac{WP_{Pol}}{100} \times \left[1 - \left(\frac{CE}{100}\right)\right]}$$

Equation 11-1

Where,

E_{Pol} = Emissions of pollutant, typically only EtO unless a mixture is used (lb/yr)
Q = Quantity (mass) of sterilant used (lb/yr)
WP_{Pol} = Weight percent of the pollutant in the sterilant (%)
CE = Efficiency of control device (%). Note: CE is zero when no control device is used
100 = Factor to convert weight percent/percent efficiency to a decimal fraction (%)

A detailed control volume of EtO emissions is shown in Figure 11-2.

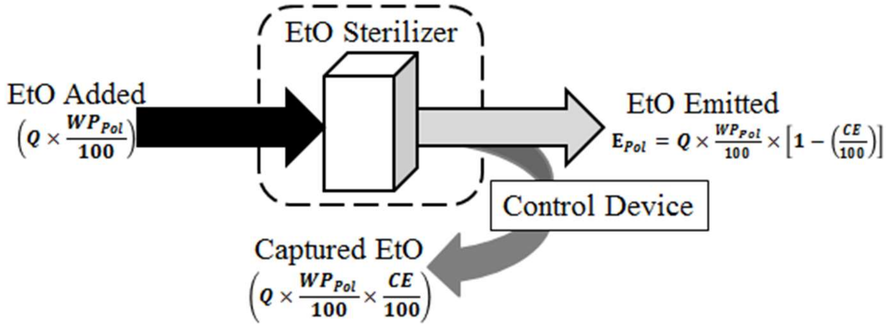

Figure 11-2. EtO Sterilizers Control Volume

11.5 Information Resources

Hospitals and/or clinics that use EtO sterilizers should have all the information needed to calculate EtO emissions. This includes the type and quantity of each sterilant used, type of sterilizing equipment used, and type of control device used. The control device manufacturer may need to be contacted to determine the control efficiency of the device. Additional information regarding the NESHAP requirements may be found in 40 CFR 63 Subpart WWWWW and Subpart O.

11.6 Example Problem

The USAF 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 percent EtO and 90 percent CO_2, by weight. According to hospital records, 235 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, using no control device. Calculate the annual emissions of EtO, and the annual emissions of CO_2.

<u>Step 1</u> – Calculate emissions using mass balance approach. Using the data provided in the problem statement, there is sufficient information to calculate the emissions for each pollutant using Equation 11-1.

$$E_{Pol} = Q \times \frac{WP_{Pol}}{100} \times \left[1 - \left(\frac{CE}{100}\right)\right]$$

<u>For EtO:</u>

$$E_{EtO} = 235\frac{lb}{yr} \times \frac{10\%}{100\%} \times \left[1 - \left(\frac{0\%}{100\%}\right)\right]$$

$$E_{EtO} = 235\frac{lb}{yr} \times \frac{10\cancel{\%}}{100\cancel{\%}} \times [1]$$

$$E_{EtO} = 235\frac{lb}{yr} \times 0.10 \times [1]$$

$$\boxed{\boldsymbol{E_{EtO} = 23.5\frac{lb}{yr}}}$$

<u>For CO_2:</u>

$$E_{CO_2} = 235\frac{lb}{yr} \times \frac{90\%}{100\%} \times \left[1 - \left(\frac{0\%}{100\%}\right)\right]$$

$$E_{CO_2} = 235\frac{lb}{yr} \times \frac{90\cancel{\%}}{100\cancel{\%}} \times [1]$$

$$E_{CO_2} = 235\frac{lb}{yr} \times 0.90 \times [1]$$

$$\boxed{\boldsymbol{E_{CO_2} = 211.5\frac{lb}{yr}}}$$

11.7 References

40 CFR 63 Subpart O, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 63-National Emission Standards for Hazardous Air Pollutants for Source Categories, Subpart O-Ethylene Oxide Emissions Standards for Sterilization Facilities," U.S. Environmental Protection Agency

40 CFR 63 Subpart WWWWW, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 63-National Emission Standards for Hazardous Air Pollutants for Source Categories, Subpart WWWWW-National Emission Standards for Hospital Ethylene Oxide Sterilizers," U.S. Environmental Protection Agency

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12 FIRE FIGHTER TRAINING (FIRE)

- *Fugitive Source*

12.1 Introduction

Training of military fire fighters involves the use of live fires fueled by liquid propane, JP-8, JP-4, or specially designed fire fighter training fuels, such as Tekflame or E-III, to create a realistic fire scenario. Most training of USAF fire fighters is accomplished at the Department of Defense (DoD) Louis F. Garfield Fire Training Academy located at Goodfellow AFB, TX. However, a few other USAF installations have smaller scale fire fighter training facilities that are used for periodic refresher training. The training performed at Goodfellow and the other USAF installations is performed in live fire training pits, which usually include a mock-up metal structure, such as an aircraft, vehicle, or building.

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 fire fighter training include PM_{10}, $PM_{2.5}$, CO, NO_X, SO_2, and VOC. EFs 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. Additionally, since fire fighter training may also involve the burning of wooden pallets or hay, emissions will also vary depending on the item being burned. **Emissions from fire fighter training are considered fugitive**. A graphic representation of emissions from fire fighter training is provided in Figure 12-1.

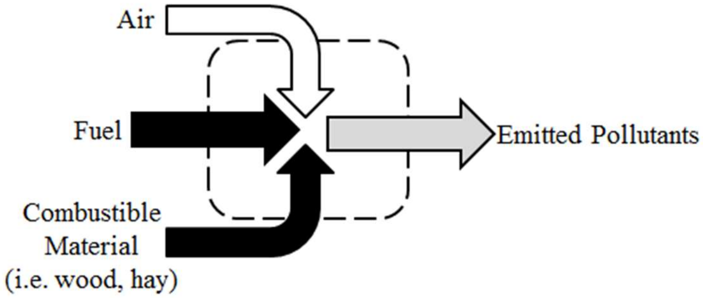

Figure 12-1. Simplified Control Volume for Emissions from Fire Fighter Training

12.2 Emission Factors

EFs for fire fighter training are dependent on the type of fuel used and material burned. There is limited information regarding EFs from firefighter training, specifically regarding HAPs and GHGs. This guide only provides an EF for one HAP – formaldehyde, which is provided alongside the criteria pollutant EFs in Table 12-1. GHG EFs were taken from subpart C of Title

40 Part 98 of the CFRs which gives the HHV and default EFs for general stationary fuel combustion sources. These EFs are given in Table 12-2.

Table 12-1. Criteria and HAP Emission Factors for Burned Fuel During Fire Fighter Training

Fuel	Emission Factors (lb/10^3gal)						
	NO_X	CO	SO_X	VOC	PM_{10}	$PM_{2.5}$[a]	Formaldehyde
Propane	55.7	15.4	0.02[b]	24.0[c]	9.5[d]	9.5	0.7
JP-8	10.0	296.1	6.8[b]	584.5[c]	193.9[d]	193.9	7.0
Tekflame[e]	3.7	68.3	0.04	49.6	33.3	33.3	---

SOURCE (unless otherwise stated): "Emissions Testing of Fire Fighter Training Facility Final Technical Report," Environmental Quality Management (EQM), 1998.

a) $PM_{2.5}$ is conservatively assumed to equal PM_{10}.

b) SOURCE: “Air Quality Procedures for Civilian Airports and Air Force Bases," U.S. Department of Transportation, Federal Aviation Administration (FAA) Office of Environment and Energy (AEE), April 1997.

c) Source provides total hydrocarbons emission factor. This is used as a conservative estimate of volatile organic compounds (VOC).

d) Source provides particulate matter (PM) emission factor. A conservative assumption of PM = PM_{10} = $PM_{2.5}$ was made.

e) SOURCE: Kenney, Michael, et al, "Aviation Emissions and Air Quality Handbook, Version 3." Federal Aviation Administration (FAA), 2014.

“---” - No data available.

Table 12-2. GHG Emission Factors for Burned Fuel During Fire Fighter Training

Fuel	Emission Factors (lb/10^3gal)			
	CO_2	CH_4	N_2O	CO_2e[a]
Propane	12,613	0.60	0.12	12,664
JP-8	21,494	0.89	0.18	21,570
Tekflame[b]	21,494	0.89	0.18	21,570

SOURCE: "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 98-Mandatory Greenhouse Gas Reporting, Subpart C-General Stationary Fuel Combustion Sources," U.S. Environmental Protection Agency.

a) CO_2e calculated by summing the product of the default emission factors for CO_2, N_2O, and CH_4 and their respective Global Warming Potentials (GWP). The GWP for CO_2, N_2O, and CH_4 are 1, 298, and 25 respectively.

b) JP-8 emission factors used as a surrogate for Tekflame.

Total emissions from fire fighter training also include those emissions from the material that is being burned. A separate set of EFs for burning items such as wood and hay have been calculated. For fire fighter training, hay or wooden pallets may be used to sustain fires for an appropriate amount of time. EFs for these items are given in Section 2.5 of AP-42 regarding the open burning of agricultural materials. The criteria pollutant and GHG EFs are provided in Table 12-3 and Table 12-4 respectively.

Table 12-3. Criteria Pollutant Emission Factors for Burned Materials During Fire Fighter Training

Material	Emission Factors (lb/ton)				
	NO_X	CO	VOC[a]	PM_{10}[b]	$PM_{2.5}$[b]
Hay[c]	4.5[e]	139.0	17.0	32.0	32.0
Wood Pallets[d]	4.0	140.0	19.0	17.0	17.0

SOURCE: Section 2.5- “Open Burning," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, October 1992.

a) Source provides total organic compounds (non-methane) emission factor. This is used as a conservative estimate of volatile organic compounds (VOC).
b) Source provides total particulate emission factor. A conservative assumption of particulate matter (PM) = PM_{10} = $PM_{2.5}$ was made.
c) Emission factors are assumed to be head fire burning.
d) “Unspecified” forest residues used to select emission factors.
e) SOURCE: Reid, Stephen B., et al, “Research and Development of Planned Burning Emission Inventories for the Central States Regional Air Planning Association, Final Report.” Sonoma Technology, Inc., July 2004.

Table 12-4. GHG Emission Factors for Burned Materials During Fire Fighter Training

Material	Emission Factors (lb/ton)			
	CO_2	CH_4[a]	N_2O	CO_2e[b]
Hay	2,149	5.0	0.1	2,297
Wood Pallets	3,615	5.7	0.1	3,799

SOURCE (unless otherwise stated): "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 98-Mandatory Greenhouse Gas Reporting, Subpart C-General Stationary Fuel Combustion Sources," U.S. Environmental Protection Agency.

a) SOURCE: Section 2.5 - “Open Burning", Compilation of Air Pollutant Emission Factors Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, January 1995. "Unspecified Forest Residues" used for wood pallets.
b) CO_2e calculated by summing the product of the default emission factors for CO_2, N_2O, and CH_4 and their respective Global Warming Potentials (GWP). The GWP for CO_2, N_2O, and CH_4 are 1, 298, and 25 respectively. "Agricultural Byproducts" and "Wood and Wood Residuals" used for hay and wood pallets respectively.

12.3 Emissions Calculation

For enhanced accuracy, if agricultural materials are used and their composition and mass is known, then the appropriate EF may be selected. EFs for the burning of various agricultural products are given in Sections 2.5 and 13.1 of AP-42. Generally, emissions from fire fighter training operations can be calculated as follows:

$$E_{Pol} = \sum (Q \times EF_{Pol})$$

Equation 12-1

Where,

E_{Pol} = Annual emissions of pollutant (lb/yr)
Q = Annual quantity of fuel or material burned (10^3 gal/yr or ton/yr)
EF_{Pol} = Emission factor (lb/10^3 gal or lb/ton)

A detailed control volume for emissions from fire fighter training is provided in Figure 12-2.

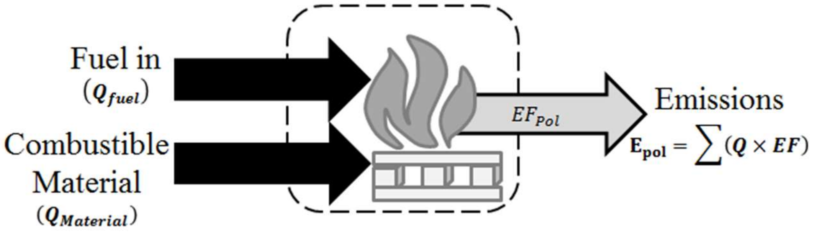

Figure 12-2. Fire Fighter Training Control Volume

12.4 Information Resources

The quantity of fuel and material burned is available from the Aircraft Rescue and Firefighting department, airport operator, or base operations section. For Goodfellow AFB, this information can be obtained from the DOD Louis F. Garfield Fire Training Academy.

12.5 Example Problem

Approximately 24,000 gal of liquid propane and approximately 800 gal of JP-8 were used in a two-month period for two fire training pits. Additionally, approximately 8,500 lb of hay and 4,500 lb of wood pallets were also burned throughout the year. Calculate the emission of CO, SO_X, and PM_{10} for the year.

<u>Step 1</u> **- Select and record EFs**. Table 12-1 provides the EFs for the fuel. For propane, the CO, SO_X, and PM_{10} are **15.4, 0.02, and 9.5 lb/10^3 gal,** respectively. For JP-8, the EFs for CO, SO_X, and PM_{10} are **296.1, 6.8, and 193.9 lb/10^3 gal,** respectively. Table 12-3 provides the EFs for the hay and pallets that were burned. SO_X emissions are typically a function of the sulfur content of fuel used, therefore SO_X EFs are not given in Table 12-3. For hay, the CO and PM_{10} EFs are **139 and 32 lb/ton**. For the wood pallets, the CO and PM_{10} EFs are **140 and 17 lb/ton**.

<u>Step 2</u> – Convert the fuel and material quantity into the appropriate units. The fuel EFs are in units of lb/10^3gal. The material EFs are in units of lb/ton, so for accurate calculations, the quantities must be converted into the correct units as follows:

<u>For Fuels:</u>

$$Q_{Propane} = \frac{24{,}000\frac{\cancel{gal}}{yr}}{1{,}000\frac{\cancel{gal}}{10^3 gal}} = \mathbf{24\frac{10^3 gal}{yr}}$$

$$Q_{JP-8} = \frac{800\frac{\cancel{gal}}{yr}}{1{,}000\frac{\cancel{gal}}{10^3 gal}} = \mathbf{0.8\frac{10^3 gal}{yr}}$$

<u>For Material:</u>

$$Q_{Hay} = \frac{8{,}500\frac{\cancel{lb}}{yr}}{2{,}000\frac{\cancel{lb}}{ton}} = \mathbf{4.25\frac{ton}{yr}}$$

$$Q_{Pallets} = \frac{4{,}500\frac{\cancel{lb}}{yr}}{2{,}000\frac{\cancel{lb}}{ton}} = \mathbf{2.25\frac{ton}{yr}}$$

<u>Step 3</u> – Calculate emissions for each pollutant. Use the EFs recorded in Step 1 and Equation 12-1 as follows:

$$\mathrm{E_{Pol}} = \mathrm{Q} \times \mathrm{EF}_{Pol}$$

<u>For Propane:</u>

$$\mathbf{E_{CO}} = 24\frac{\cancel{10^3\mathrm{gal}}}{\mathrm{yr}} \times 15.40\frac{\mathrm{lb}}{\cancel{10^3\mathrm{gal}}} = \mathbf{369.60\frac{lb}{yr}}$$

$$\mathbf{E_{SO_X}} = 24\frac{\cancel{10^3\mathrm{gal}}}{\mathrm{yr}} \times 0.02\frac{\mathrm{lb}}{\cancel{10^3\mathrm{gal}}} = \mathbf{0.48\frac{lb}{yr}}$$

$$\mathbf{E_{PM_{10}}} = 24\frac{\cancel{10^3\mathrm{gal}}}{\mathrm{yr}} \times 9.50\frac{\mathrm{lb}}{\cancel{10^3\mathrm{gal}}} = \mathbf{228.00\frac{lb}{yr}}$$

<u>For JP-8:</u>

$$\mathbf{E_{CO}} = 0.8\frac{\cancel{10^3\mathrm{gal}}}{\mathrm{yr}} \times 296.10\frac{\mathrm{lb}}{\cancel{10^3\mathrm{gal}}} = \mathbf{236.88\frac{lb}{yr}}$$

$$\mathbf{E_{SO_X}} = 0.8\frac{\cancel{10^3\mathrm{gal}}}{\mathrm{yr}} \times 6.80\frac{\mathrm{lb}}{\cancel{10^3\mathrm{gal}}} = \mathbf{5.44\frac{lb}{yr}}$$

$$\mathbf{E_{PM_{10}}} = 0.8\frac{\cancel{10^3 \text{gal}}}{\text{yr}} \times 193.90\frac{\text{lb}}{\cancel{10^3 \text{gal}}} = \mathbf{155.12}\,\boldsymbol{\frac{lb}{yr}}$$

For Hay:

$$\mathbf{E_{CO}} = 4.25\frac{\cancel{\text{ton}}}{\text{yr}} \times 139\frac{\text{lb}}{\cancel{\text{ton}}} = \mathbf{590.75}\,\boldsymbol{\frac{lb}{yr}}$$

$$\mathbf{E_{PM_{10}}} = 4.25\frac{\cancel{\text{ton}}}{\text{yr}} \times 32\frac{\text{lb}}{\cancel{\text{ton}}} = \mathbf{136.00}\,\boldsymbol{\frac{lb}{yr}}$$

For Wood Pallets:

$$\mathbf{E_{CO}} = 2.25\frac{\cancel{\text{ton}}}{\text{yr}} \times 140\frac{\text{lb}}{\cancel{\text{ton}}} = \mathbf{315.00}\,\boldsymbol{\frac{lb}{yr}}$$

$$\mathbf{E_{PM_{10}}} = 2.25\frac{\cancel{\text{ton}}}{\text{yr}} \times 17\frac{\text{lb}}{\cancel{\text{ton}}} = \mathbf{38.25}\,\boldsymbol{\frac{lb}{yr}}$$

Step 4 -Calculate total emissions. Add the emissions from the fuels and material burned as shown:

For CO:

$$\mathrm{E_{CO}} = 369.60\frac{\text{lb}}{\text{yr}} + 236.88\frac{\text{lb}}{\text{yr}} + 590.75\frac{lb}{yr} + 315.00\frac{lb}{yr}$$

$$\boxed{\mathbf{E_{CO}} = \mathbf{1,512.23}\ \frac{\mathbf{lb}}{\boldsymbol{yr}}}$$

For SO_X:

$$\mathrm{E_{SO_X}} = 0.48\frac{lb}{yr} + 5.44\frac{lb}{yr}$$

$$\boxed{\mathbf{E_{SO_X}} = \mathbf{5.92}\ \frac{\mathbf{lb}}{\boldsymbol{yr}}}$$

For PM_{10}:

$$\mathrm{E_{PM_{10}}} = 228.00\frac{lb}{yr} + 155.12\frac{lb}{yr} + 136.00\frac{lb}{yr} + 38.25\frac{lb}{yr}$$

$$\boxed{\mathbf{E_{PM_{10}}} = \mathbf{557.37}\ \frac{\mathbf{lb}}{\boldsymbol{yr}}}$$

12.6 References

40 CFR 98 Subpart C, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 98-Mandatory Greenhouse Gas Reporting, Subpart C-General Stationary Fuel Combustion Sources," U.S. Environmental Protection Agency

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USEPA 1995, Section 2.5-“Open Burning," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, January 1995

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13 GENERAL CHEMICAL USE (CHEM, LAB, NDI, PHAT, DEGR, WSR, CLN, SEAD, FIBR, GSOL)

- *Point Source* – When performed using an industrial (non-HVAC) ventilation system
- *Fugitive Source* – When an industrial (non-HVAC) ventilation system is not used

13.1 Introduction

General chemical use includes a wide variety of items that are point sources of air emissions that are not specifically addressed in any other section of this guide. The chemicals that fall into this category are typically items commercially purchased in small quantities, such as household cleaners, adhesives, or sealants, and includes lab chemicals and solvents used for degreasing or non-destructive inspections. Most general chemicals are typically exempt from regulatory consideration under federal, state, and local air pollution control agency air quality regulations. However, these agencies should be consulted prior to excluding the sources that comprise this category. Information pertaining to the composition of general chemicals may be obtained from the base's SDS database, other product literature, or from the manufacturer, and made available if requested by state regulators.

The primary pollutants of concern associated with general chemical use are VOCs, organic HAPs, and occasionally PM from vapor displacement as the product evaporates. As a result, some organic chemical products, and most inorganic chemical products that have extremely low vapor pressures (e.g., <0.1 mm Hg), are considered insignificant and are usually not addressed in an AEI. Examples include heavy lubricants/oils, greases, hydraulic fluids, glycol deicers, and non-solvent (aqueous) cleaners. **Emissions from general chemical use may be either point or fugitive, depending on if an industrial ventilation (non-HVAC) system is used.** Figure 13-1 provides a graphical representation of emissions from general chemical use.

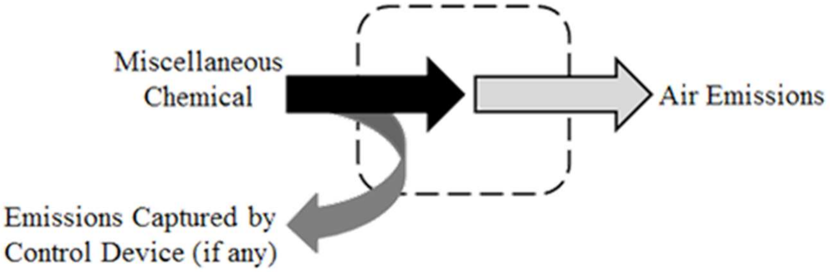

Figure 13-1. Simplified Control Volume for Emissions from General Chemical Use

13.1.1 Laboratory Chemicals (LAB)

Chemical laboratories are commonly found at USAF 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 various reagents. Vapors are most often a result of activities such as pouring/pipetting, heating solvents or having uncovered beakers and containers. Disposal methods vary according to the type of chemical used, and may range from placing chemicals into a sanitary sewer to shipping them off-site as hazardous waste.

Typically, air emissions occur as the chemical reagents are used or prepared underneath a fume hood. Some fume hoods vent the air through a filter, which recovers emitted pollutants to allow for their disposal while other fume hoods vent pollutants directly into the atmosphere. **The main pollutants of concern are the VOCs and/or volatile HAP ingredients in liquid reagents.**

To quantify emissions from laboratory chemicals, the volume of chemicals consumed must be considered a “loss”. As such, the chemical is assumed to be emitted directly into the atmosphere. To calculate air emissions, determine the original quantity of chemical from the previous inventory and add any amount of chemical that may have been purchased or otherwise added to the inventory. Then, subtract the amount of unused chemical remaining in inventory, any chemical still in use in any solutions or mixtures, all forms of the chemical disposed of as waste, and any non-waste amount(s) that were shipped off-site. The result is the maximum amount of the specified chemical that could have potentially been emitted into the air during the inventory period.

13.1.2 Non-Destructive Inspection (NDI)

USAF 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 such as inspection penetrants, penetrant removers, penetrant developers, alcohol cleaners (e.g., isopropyl, denatured ethanol, methanol), and other cleaning compounds. **The primary pollutants of concern from the use of these chemicals are VOCs and organic HAPs.** ODCs may also be a concern, as some inspection chemicals may contain methyl chloroform, a known ODC.

Generally, there are two methods used at NDI shops to inspect and clean mechanical parts. The first method involves placing chemicals into a tank in which the parts to be inspected are submerged/soaked. These chemicals are periodically replaced as they become dirty or no longer meet specifications. Any waste chemicals are collected and sent off-site for disposal. Pollutants are emitted as the chemicals vaporize when loaded into the tank, during use within the tank, and as they evaporate from the parts removed from the tank. To quantify these emissions, the volume of chemical removed from the tank during the year may be subtracted from the volume of chemical added to the tank during the year. This difference (gal/yr) is assumed to completely evaporate into the air. The resultant emissions are a function of the volume evaporated and the density of the chemical.

The second method involves the application of chemicals onto parts with the use of a spray can or bottle. Emissions from this technique are conservatively estimated by assuming the entire amount of chemical applied is emitted to the atmosphere. To calculate the emissions of a pollutant for the spraying method, the volume of chemical used is multiplied by its density and the weight percent of the pollutant in the chemical.

13.1.3 Printing Operations (PHAT)

Some USAF installations may perform large scale printing for mass distribution. There are six basic processes of the printing industry including: web offset lithography, web letterpress, flexography, rotogravure, screen, and plate-less. **The emissions of concern from printing operations include VOCs and HAPs which result from the evaporation of inks and solvents used during the printing process.** The amount of emissions produced is a function of the printing process, the ink formulation and coverage, the press size and speed, and the operating time.

Web offset lithography is commonly used for large volume applications since printing can occur at high speeds and on both sides of a page. The process involves the use of plates that have an image area that is receptive to ink (lipophilic) and repellant to water (hydrophobic) while the non-image area is ink repellant (lipophobic) and receptive to water (hydrophilic). The image is applied to a rubber “blanket” and onto the substrate. The ink used in the process may be either quickset, which dries by absorption on the substrate, or heatset which requires the application of high temperatures to dry. The heat is applied using a dryer operating at around 400 - 500°F. The dryers may be either hot air or direct flame.

Web letterpress printing is the oldest form of moveable type printing and is declining in use as printers continue to adopt faster printing methods. In web letterpress printing, an image area is raised and the ink is directly transferred from the image surface to the substrate. Pressure is applied at varying amounts on the substrate depending on the image and its size. The greater the pressure, the smaller and darker an ink dot becomes. This process is time consuming and expensive as multiple adjustments must be continuously made to get the image impression correct.

Flexography printing is essentially a modernized form of letterpress printing. The primary differences are that flexography uses a rubber image carrier and uses alcohol-based inks. Flexography is widely used for printing on food packaging since this method is suitable for printing on a variety of non-porous substrates.

Rotogravure printing utilizes a copper-plated steel cylinder as an image carrier. The image is engraved on this image carrier which then rotates in an ink trough or fountain. The ink is picked up on the engraved area while a "doctor blade" removes the excess from the non-image area. The substrate is fed between the image carrier cylinder and an impression cylinder which produces enough pressure to allow the image to transfer onto the substrate.

For screen printing, an image is first made in a silk screen that serves as a stencil. The silk screen stencil is composed of a woven mesh that allows or restricts the flow of ink based on the presence or absence of openings in the mesh. The screen is placed on the substrate and ink is applied. The ink which flows through the openings on the mesh forms the image on the substrate.

Plate-less printing has several advantages over traditional printing operations. Some advantages are that plate-less printing often operates with solvent-free ink, it does not require solvent washes, and can be performed for quick print applications. Plate-less printing requires sophisticated computer software and hardware that may result in a high initial investment cost, thus limiting the use of plate-less printing to in-plant and quick printing applications.

13.1.4 Solvent Cleaning Equipment (DEGR)

Solvent cleaning equipment is commonly used by USAF maintenance organizations to remove grease, oils, lubricants, soils, waxes, carbon deposits, fluxes, tars, and other contaminants from a variety of parts and equipment, such as aircraft, automobiles, and AGE. To a smaller extent, solvent cleaning equipment may also be found within the CE organization and in workplaces associated with communications and electronics maintenance.

There are two types of solvents that may be used: water-based solvents and organic solvents. Water-based solvents have fewer environmental concerns, as they contain fewer VOCs than organic solvents. However, organic solvents are still used in cleaning operations in which water-based solvents are not feasible. **The emissions of concern from solvent cleaning equipment using organic solvents include VOCs and organic HAPs**.

Organic solvents may be composed of non-halogenated compounds and/or halogenated compounds. Common non-halogenated solvents include aliphatic petroleum distillates, alcohols, ketones, and glycol ethers. Common halogenated solvents include methylene chloride, PERC, trichloroethylene, methyl chloroform, carbon tetrachloride, and chloroform. Many of these components found in organic solvents may be classified as a VOC, HAP, or both. However, the EPA has identified several organic compounds that may not be considered a VOC due to their negligible photochemical reactivity. The complete list of these compounds may 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, batch vapor, in-line cold, and in-line vapor cleaning machines. The difference between a "batch" type and an "in-line" type of solvent cleaning 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 to continuously clean parts. Since in-line machines are typically used for very large cleaning operations, they are not normally found at USAF installations. Cold cleaning machines use liquid, non-boiling solvent to clean or dry parts, while vapor cleaning machines boil liquid solvent to generate solvent vapor to clean or dry parts. The most common type of machine found is the batch cold cleaning machine, although some installations may also use batch vapor cleaning machines.

Batch cold cleaning machines provide the simplest and least expensive method of cleaning. These types of machines typically use non-halogenated solvents at room temperature or heated to a temperature below the solvent's boiling point. The parts are usually cleaned manually and then placed in the tank to soak until adequately cleaned. The solvent is drained from the parts for at least 15 seconds (or until dripping has stopped) before removing. The cover of the machine is intended to be securely closed whenever parts are not being handled in the cleaner.

Batch vapor cleaning machines heat the solvent to a temperature that is at or above the solvent's boiling point. These types of machines typically use halogenated solvents, due to their low flammability and higher vapor density. The most common type of batch vapor cleaning machine is an open-top vapor cleaner which is designed to generate and contain solvent vapors. As the solvent boils, the denser solvent vapors rise and displace the air within the tank. Coolant is circulated in condensing coils at the top of the tank, creating a controlled vapor zone. Parts are lowered into the vapor zone, and are cleaned when the solvent vapors condense onto the surface of the parts. Cleaning is often enhanced by either spraying the parts with the hot solvent or by immersing the parts in the solvent. Most batch vapor cleaning machines are equipped with a lip-mounted ventilation system that carries solvent vapors away from the operating personnel. The vapors may then be passed through a control device prior to being vented into the atmosphere.

Emissions associated with solvent cleaning equipment may occur from a variety of sources. These sources include solvent bath evaporation, spray evaporation, agitation, diffusion, convection, solvent carryout, and ventilation/exhaust systems. Emissions from many of these sources may be significantly reduced by regularly employing the use of a cover. To quantify these emissions, start with any solvent purchased or otherwise added during the year, and subtract any waste solvent, including solvent disposed of, recycled, or reclaimed. Although the waste product includes contaminants and is not pure solvent, for emission estimation purposes, the waste product may be considered pure solvent and subtracted from the total amount of solvent used.

13.1.5 Waste Solvent Reclamation (WSR)

Waste solvent reclamation is used as a pollution prevention initiative on some bases to 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. 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 these processes include VOCs, organic HAPs, and PM (when considering incinerator stacks)**. A description of each process follows.

Solvent storage and handling involves the storage of solvents both before and after reclamation. Solvents are stored in containers of varying size ranging from 55-gallon drums to 20,000-gallon tanks. To prevent solvent vapors from creating excessive pressure buildup, such storage tanks are typically of either fixed or floating-roof design and may include a venting system or a vacuum inside the fixed roof tanks. The handling of waste solvents typically involves loading the solvent into process equipment and filling drums and tanks prior to transport and storage.

Initial treatment involves one of two different methods: vapor recovery or mechanical separation. Vapor recovery involves the removal of solvent vapors from a gas stream to prepare for further reclaiming operations, while mechanical separation removes undissolved solid contaminants from liquid solvents. There are multiple vapor recovery methods that can be used, the selection of which is highly dependent on the properties of the solvent (i.e. miscibility, vapor composition and concentration, boiling point, reactivity, solubility, etc.). Vapor recovery methods include condensation, adsorption, and absorption.

Distillation is the process that removes dissolved impurities and separates solvent mixtures, taking the initial treatment process one step further. The separation of dissolved impurities is accomplished by simple batch, simple continuous, or steam distillation. The mixed solvents are separated by multiple simple distillation methods, such as batch or continuous rectification.

Purification is the process by which water is removed from the solvent by decanting or salting. Decanting is accomplished with immiscible solvent and water which, when condensed, form separate liquid layers, either of which can be drawn off mechanically. With salting, solvent is passed through a calcium chloride bed and water is removed by absorption. If necessary, reclaimed solvents are stabilized during the purification process.

Waste disposal is the incineration, landfilling, or deep well injecting of the materials separated from the solvents during the initial treatment and distillation processes. The composition of this waste varies depending on the original use of the solvent. However, according to Section 4.7 of

AP-42, up to 50 percent of this waste is un-reclaimed solvent. The remaining solvent consists of components such as oils, greases, waxes, detergents, pigments, metal fines, dissolved metals, organics, vegetable fibers, and resins.

VOC emissions can be calculated using a mass balance approach by subtracting the mass of waste material disposed and the mass of solvent reclaimed from the mass of the waste solvent that was distilled. Note that in some cases, the mass of waste solvent distilled and/or the mass of waste material disposed of annually may not be known. In such cases, the mass can be calculated by multiplying the annual volume by the density. Density, in turn, can be estimated by weighing out known volumes of other components, such as oils and greases, in the waste material since the composition of the waste includes many other components in addition to the solvent itself. The same also applies to calculations for determining the mass of reclaimed solvent.

There is an alternate means of calculating emissions that utilizes EFs. However, the mass balance approach should be the primary approach for calculation of Waste Solvent Reclamation emissions. For more information on emissions calculations using developed EFs, refer to Chapter 4.7 Waste Solvent Reclamation of AP-42.

13.1.6 Hand-Wipe Cleaning (HCLN)

Hand-wipe cleaning involves the use of cleaning solvents to remove contaminants from a surface by hand. Typically, at a USAF installation, this is performed on aircraft and aircraft components, making the use of solvents for this purpose subject to emissions standards. These standards are outlined in 40 CFR 63 Subpart GG, *National Emission Standards for Aerospace Manufacturing and Rework Facilities*. **The emissions generated from this source results from the evaporation of the cleaning solvent which may contain a significant amount of VOCs**. As with other sources that comprise the General Chemical Use category, the solvents should be stored in a closed container prior to use and stored in a sealed, nonabsorbent container at all times.

13.1.7 Sealants and Adhesives (SEAD)

Sealants and adhesives are used to bond two substrates together. They are used in a variety of applications including, but not limited to, the manufacture or repair of aircraft and aircraft parts, engines, HVAC systems, and on-road vehicles. The primary difference between sealants and adhesives is that sealants are more commonly used as a bonding agent between two substrates with different physical properties. This is because sealants are not as strong as adhesives but are more elastic, allowing for more flexibility between substrates with different thermal coefficients of expansion. **The use of both sealants and adhesives results in the emission of VOCs and organic HAPs**.

Sealants are often used to seal small openings and are effective in waterproofing processes. In the aerospace industry, sealants are commonly used for sealing fuel tanks, or repairing aircraft airframes or windshields. Sealants may also be exploited for their electrical conductivity or thermal and acoustical insulation properties. There are many types of sealants ranging from relatively high strength resins to low strength waxes and putties such as silicone.

Adhesives may be categorized as either reactive or non-reactive. Reactive adhesives are those that harden through chemical reaction while non-reactive adhesives do not. Reactive adhesives may be multi-part, which require the mixing of two compounds that chemically react and harden, or single-part, which harden through chemical reactions with heat, radiation, or moisture. Non-reactive adhesives include solvent based drying adhesives that harden as the solvent evaporates.

13.1.8 Fiberglass (FIBR)

Fiberglass is used in a variety of applications due to its light weight and high strength as well as its ability to be molded into complex shapes. Fiberglass is made of plastic reinforced with thin glass filaments that are woven together. Storage tanks and on-road vehicles may be partially comprised of fiberglass, but on an USAF installation, the most common use of fiberglass is likely to be aircraft repair. **The primary emissions from fiberglass manufacture are VOCs, such as styrene, which are emitted as the solvent evaporates and the resin dries.**

13.1.9 General Solvent Use (GSOL)

Solvents used on base that do not fall into the categories listed above (or any other section of this guide) may fall into the general solvent use source category. Sources that fall into this category are typically base-specific. Care should be taken to verify the volume of solvent used for this purpose is easy to distinguish from the volume used in any of the other source categories provided above to avoid duplicate emissions calculations. Contact the air quality SME for any guidance as necessary.

13.2 NSPS and NESHAP Applicability

For processes that fall under the general chemical use category, several standards have been enacted to limit the emissions of pollutants into the atmosphere. NSPS applicable to publication rotogravure printing is given in 40 CFR 60 Subpart QQ, *Standards of Performance for the Graphic Arts Industry: Publication Rotogravure Printing*. This standard states that no facility that performs rotogravure printing may emit more than 16 percent of the total mass of VOC and water used during an averaging period. This standard applies to any facility whose construction, modification, or reconstruction occurred after October 28, 1980, and describes the requirements of the performance tests needed to verify compliance with this standard. For more information regarding this standard, refer to 40 CFR 60 Subpart QQ.

Some general chemicals and applications may have applicable NESHAP requirements, provided in the CFRs. For example, 40 CFR 63 Subpart T, *National Emission Standards for Halogenated Solvent Cleaning*, applies to any solvent cleaning machine that uses either methylene chloride, PERC, trichloroethylene, 1,1,1-trichloroethane, carbon tetrachloride, or chloroform in excess of 5 percent by weight as a cleaning/drying agent. For these solvent cleaning machines, this NESHAP describes the operating requirements and emission limits. Also, 40 CFR 63 Subpart GG, *National Emission Standards for Aerospace Manufacturing and Rework Facilities*, outlines the operating and reporting requirements for the manufacturing and rework of aerospace vehicles and components. These activities may include cleaning and/or chemical milling. Additionally, 40 CFR 63 Subpart KK, *National Emission Standards for the Printing and Publishing Industry*, applies to any facility that performs publication rotogravure, product and packaging rotogravure, or web flexographic printing and is a major source of HAPs. The standard limits emissions of organic HAPs to 8 percent or less of the total VOC used monthly. It is important to note that the NESHAP requirements listed here may not be all inclusive and the appropriate regulatory agency should be contacted to ensure compliance. Consult the CFRs, including 40 CFR 63 Subparts T, GG and KK, for more information and to verify that the USAF installation complies with these standards.

13.3 Control Techniques

Air emissions control equipment may or may not be installed on any of the apparatus involved in the processes that fall under the category of general chemical use. Some processes, such as solvent degreasing, may have one or more control devices working in combination to reduce air emissions, including condensers or carbon adsorption systems. The condenser equipment works to apply a cooler air “blanket” to limit the vaporization of the solvent. Carbon adsorption is the process in which the liquid or gaseous solvent, or solvent components, adhere to the surface of the carbon adsorbent. Air emission controls are specific to the process, so it may be necessary to contact the personnel involved in the process. Additionally, contact the control device manufacturer to get specifics on emission controls and their respective efficiencies involved in the process.

13.4 Emissions Calculation

Emissions from general chemical use is estimated by using a material mass balance approach. The product of the total volume of the chemical used and the weight percent of the pollutant of interest is taken as follows to calculate annual emissions of pollutants:

$$E_{Pol} = (Q_A - Q_R - Q_C) \times \left(\frac{WP_{Pol}}{100}\right)$$

Equation 13-1

Where,

E_{Pol} = Annual emissions of pollutant (lb/yr)
Q_A = Annual mass of chemical used/added to process (lb/yr)
Q_R = Annual mass of chemical product removed for disposal (lb/yr)
Q_C = Annual mass of chemical captured by control device, and not reintroduced into the process, if applicable (lb/yr)
WP_{Pol} = Weight percent of the pollutant in the chemical product (%). **Assume this to be 100 for waste solvent reclamation.**
100 = Factor converting weight percent to weight fraction (%)

A more detailed representation explaining this process is provided in Figure 13-2.

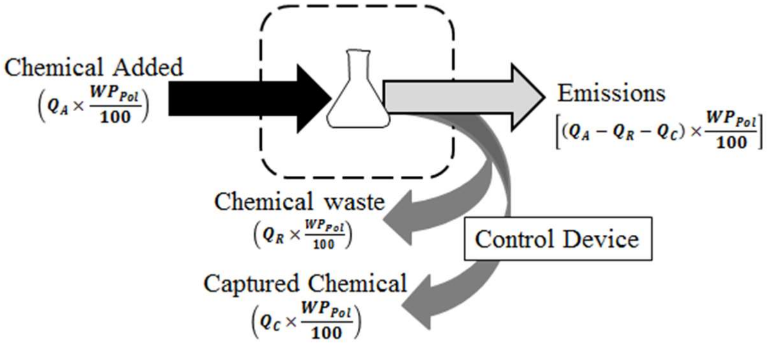

Figure 13-2. General Chemical Use Control Volume

If the mass of chemical captured by the control device cannot be measured on-site, this value may be estimated as needed. The annual mass of chemical captured by the control device, Q_c, is estimated using the control efficiency and capture efficiency of the control device as follows:

$$Q_C = (Q_A - Q_R) \times \left\{1 - \left[\left(\frac{Cap}{100}\right) \times \left(\frac{CE}{100}\right)\right]\right\}$$

Equation 13-2

Where,

Q_C = Annual mass of chemical captured by control device, if applicable (lb/yr)
Q_A = Annual mass of chemical used/added to process (lb/yr)
Q_R = Annual mass of chemical product removed for disposal (lb/yr)
Cap = Capture efficiency of the capture device (%)
CE = Efficiency of the control device (%)

If the volume and not the mass of the chemical used during the year is known, the mass may be calculated using the chemical density or specific gravity as follows:

$$\boldsymbol{Q_X = (V_X \times D) = (V_X \times SG \times 8.33)}$$

Equation 13-3

Where,

Q_X = Annual mass of chemical used, disposed, or captured (lb/yr)
V_X = Annual volume of chemical used, disposed, or captured (gal/yr)
D = Density of the chemical (lb/gal)
SG = Specific gravity of the chemical
8.33 = Density of water (lb/gal)

13.5 Information Resources

Most of the information necessary to calculate emissions from general chemical use may be obtained from EESOH-MIS, HAZMART, BEE, or from the applicable supply office. Information may include chemical name, stock number, manufacturer of applicable chemicals, identity of shops using the chemicals, and quantity used by each shop. If necessary, the shops that use the chemicals may be contacted for additional information. For solvent cleaning equipment, a commercial contract service may be used for solvent supply and removal. In these cases, the commercial contract service should have records indicating the quantity of fresh solvent delivered and the quantity of waste solvent picked up.

Information pertaining to the composition (VOC and HAP content) and density of chemicals can be obtained from the SDS, other product literature, the commercial vendor (if applicable), or from the chemical manufacturer. Information on a solvent can usually be obtained from the government supply center from which it was purchased. Contact the appropriate government supply center, such as the Defense Logistics Agency (DLA) or the General Services Administration (GSA) for more information regarding the chemicals purchased.

13.6 Example Problem

Air emissions for selected chemical products have been requested from the local regulatory agency. According to the EESOH-MIS on base, the chemicals have been used in the following quantities during the year:

Product	**V_A (gal/yr)**	**V_R (gal/yr)**	**V_C (gal/yr)**	**Density (lb/gal)**	**VOC wt.%**	**HAP wt.%**
General Machinery Cleaner	120.0	24.0	20.0	6.5	84%	50% Methanol 15% Toluene
Contact Adhesive	22.0	0.0	0.0	6.6	65%	30% n-Hexane 20% Toluene

Calculate the total VOC and HAP emissions from these chemicals.

Step 1 – **Calculate the mass of chemical used.** Using the chemical densities and the volumes given in the problem statement, the mass of the chemicals used is calculated using Equation 13-3 as shown:

$$Q_X = (V_X \times D)$$

For the General Machinery Cleaner:

$$\boldsymbol{Q_A} = 120.0\frac{\cancel{gal}}{yr} \times 6.5\frac{lb}{\cancel{gal}} = \boldsymbol{780.0\frac{lb}{yr}}$$

$$\boldsymbol{Q_R} = 24.0\frac{\cancel{gal}}{yr} \times 6.5\frac{lb}{\cancel{gal}} = \boldsymbol{156.0\frac{lb}{yr}}$$

$$\boldsymbol{Q_C} = 20.0\frac{\cancel{gal}}{yr} \times 6.5\frac{lb}{\cancel{gal}} = \boldsymbol{130.0\frac{lb}{yr}}$$

For the Contact Adhesive:

$$\boldsymbol{Q_A} = 22.0\frac{\cancel{gal}}{yr} \times 6.6\frac{lb}{\cancel{gal}} = \boldsymbol{145.2\frac{lb}{yr}}$$

$$\boldsymbol{Q_R} = 0.0\frac{\cancel{gal}}{yr} \times 6.6\frac{lb}{\cancel{gal}} = \boldsymbol{0.0\frac{lb}{yr}}$$

$$\boldsymbol{Q_C} = 0.0\frac{\cancel{gal}}{yr} \times 6.6\frac{lb}{\cancel{gal}} = \boldsymbol{0.0\frac{lb}{yr}}$$

Step 2 - **Calculate the VOC emissions.** Use Equation 13-1, the mass of chemicals calculated in Step 1, and the data provided in the problem statement as follows:

$$E_{pol} = (Q_A - Q_R - Q_C) \times \left(\frac{WP}{100}\right)$$

For the General Machinery Cleaner:

$$E(Cleaner)_{VOC} = (780.0 - 156.0 - 130.0)\frac{lb}{yr} \times \left(\frac{84\cancel{\%}}{100\cancel{\%}}\right)$$

$$\boldsymbol{E(Cleaner)_{VOC}} = (494)\frac{lb}{yr} \times (0.84) = \mathbf{415.0}\,\boldsymbol{\frac{lb}{yr}}$$

For the Contact Adhesive:

$$E(Adhesive)_{VOC} = (145.2 - 0.0 - 0.0)\frac{gal}{yr} \times \left(\frac{65\cancel{\%}}{100\cancel{\%}}\right)$$

$$\boldsymbol{E(Adhesive)_{VOC}} = (145.2)\frac{lb}{yr} \times (0.65) = \mathbf{94.4}\,\boldsymbol{\frac{lb}{yr}}$$

Step 3 – **Calculate the total VOC emissions from general chemical use.** Sum the VOCs emitted from the two compounds calculated above:

$$E_{VOC} = \sum\left(E_{VOC_{\mathrm{i}}} + \cdots + E_{VOC_n}\right)$$

$$E_{VOC} = 415.0\frac{lb}{yr} + 94.4\frac{lb}{yr}$$

$$\boxed{\boldsymbol{E_{VOC}} = \mathbf{509.4}\,\boldsymbol{\frac{lb}{yr}}}$$

Step 4 - **Calculate the HAP emissions**. Use Equation 13-1 to calculate the HAP constituent emissions as follows:

$$E_{pol} = (Q_A - Q_R - Q_C) \times \left(\frac{WP}{100}\right)$$

For the General Machinery Cleaner:

$$E_{Methanol} = (780.0 - 156.0 - 130.0)\frac{lb}{yr} \times \left(\frac{50\cancel{\%}}{100\cancel{\%}}\right)$$

$$\boldsymbol{E_{Methanol}} = (494.0)\frac{lb}{yr} \times (0.5) = \mathbf{247.0}\,\boldsymbol{\frac{lb}{yr}}$$

$$E_{Toluene} = (780.0 - 156.0 - 130.0)\frac{lb}{yr} \times \left(\frac{15\cancel{\%}}{100\cancel{\%}}\right)$$

$$\boldsymbol{E_{Toluene}} = (494.0)\frac{lb}{yr} \times (0.15) = \mathbf{74.1}\,\boldsymbol{\frac{lb}{yr}}$$

For the Contact Adhesive:

$$E_{n-Hexane} = (145.2 - 0 - 0)\frac{lb}{yr} \times \left(\frac{30\cancel{\%}}{100\cancel{\%}}\right)$$

$$\boldsymbol{E_{n-Hexane}} = (145.2)\frac{lb}{yr} \times (0.3) = \mathbf{43.6}\,\boldsymbol{\frac{lb}{yr}}$$

$$E_{Toluene} = (145.2 - 0 - 0)\frac{lb}{yr} \times \left(\frac{20\cancel{\%}}{100\cancel{\%}}\right)$$

$$\boldsymbol{E_{Toluene}} = (145.2)\frac{lb}{yr} \times (0.2) = \mathbf{29.0}\,\boldsymbol{\frac{lb}{yr}}$$

<u>Step 5</u> - Calculate the total HAP emissions. The total HAP emissions from general chemical use are the sum of the HAP constituents calculated in Step 4 as shown:

$$E_{HAP\ (Total)} = \sum\left(E_{HAP_{\mathrm{i}}} + \cdots + E_{HAP_n}\right)$$

$$E_{HAP\ (Total)} = \left(247.0\frac{lb}{yr} + 74.1\frac{lb}{yr} + 43.6\frac{lb}{yr} + 29.0\frac{lb}{yr}\right)$$

$$\boxed{\boldsymbol{E_{HAP\ (Total)}} = \mathbf{393.7}\,\boldsymbol{\frac{lb}{yr}}}$$

13.7 References

40 CFR 60 Subpart QQ, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New Stationary Sources, Subpart QQ-Standards of Performance for the Graphics Arts Industry: Publication Rotogravure Printing," U.S. Environmental Protection Agency

40 CFR 63 Subpart T, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 63-National Emission Standards for Hazardous Air Pollutants for Source Categories, Subpart T-National Emission Standards for Halogenated Solvent Cleaning," U.S. Environmental Protection Agency

40 CFR 63 Subpart GG, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 63-National Emission Standards for Hazardous Air Pollutants for Source Categories, Subpart GG-National Emission Standards for Aerospace Manufacturing and Rework Facilities," U.S. Environmental Protection Agency

40 CFR 63 Subpart KK, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 63-National Emission Standards for Hazardous Air Pollutants for Source Categories, Subpart KK-National Emission Standards for the Printing and Publishing Industry," U.S. Environmental Protection Agency

USEPA 1995a, Section 4.6-“Solvent Degreasing," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, January 1995

USEPA 1995b, Section 4.7-“Waste Solvent Reclamation," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, January 1995

USEPA 1995c, Section 4.9.1-“General Graphic Printing," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, January 1995

USEPA 1995d, Section 4.9.2-“Publication Gravure Printing," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, January 1995

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14 INCINERATORS (INCN)

- *Point Source*

14.1 Introduction

There are several types of incinerators likely to be found on USAF installations including classified waste incinerators, medical waste incinerators, and air curtain incinerators. Other incinerators, such as municipal solid waste incinerators and sewage sludge incinerators, can potentially be large sources of air emissions, but are not typically found at USAF installations. These types of refuse are typically shipped off-site for incineration and are, therefore, not addressed in this guide. If needed, refer to Sections 2.1 and 2.2 of AP-42 for guidance on air emissions calculations for municipal waste and sewage sludge incinerators. Air curtain incinerators, due to their nature of operation, are not covered in this section. Information regarding air curtain incinerators may be found in the *Air Emissions Guide for Air Force Transitory Sources*. **Classified waste and medical waste incinerators act as point sources, releasing criteria pollutants, HAPs, and GHGs into the air**. A simple control volume depicting emissions from incinerators is provided in Figure 14-1.

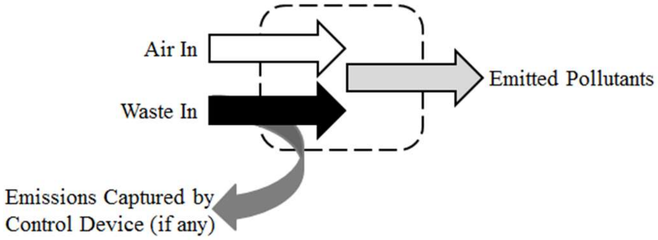

Figure 14-1. Simplified Control Volume for Emissions from Incinerator Use

14.1.1 Classified Waste Incinerators

Many USAF installations use a classified waste incinerator as a means of disposing classified information. This information is typically in the form of paper documents, plastic (microfiche) sheets, or computer tapes/discs. The EPA has not developed EFs specific to classified waste incinerators. For emissions estimation purposes, “industrial/commercial” incinerator EFs may be used as surrogate EFs for classified waste incinerators. Classified waste incinerators may be further subdivided based on if they are multiple chamber or single chamber design.

14.1.2 Medical Waste Incinerators

Medical waste incinerators are used to burn wastes produced by hospitals, clinics, veterinary facilities and medical research facilities. The wastes burned may include both infectious (i.e., red bag) wastes as well as non-infectious (e.g., general housekeeping) wastes. There are three major types of medical waste incinerators used: controlled-air incinerators, excess-air incinerators, and rotary kiln incinerators. The number of medical incinerators has decreased greatly and most of the remaining incinerators are likely to be of the controlled-air type.

14.1.2.1 Controlled-Air Medical Waste Incinerators

Controlled-air incineration involves the sequential combustion of waste in two separate chambers. The primary chamber, sometimes referred to as the ignition chamber, accepts the waste and the combustion process starts in a starved-air atmosphere. The amount of combustion air fed to the primary chamber is strictly regulated, and is usually fed as underfire air. The incineration of the waste occurs in three steps: volatilization of the moisture, vaporization of the volatiles, and combustion of the fixed carbon remaining in the waste. The combustion gases containing the volatile combustible materials are subsequently directed to the secondary chamber, which is regulated to provide an excess-air combustion condition. The introduction of these gases into the secondary combustion chamber produces turbulence, and promotes good mixing of the combustion gases and the combustion air. The burning of the combustion gases under high temperature, excess O_2, and high turbulent conditions promotes complete combustion.

Controlled-air incinerators are designed to operate in one of three modes: single batch, intermittent-duty (multiple batch), or continuous operation. In the single batch mode, the incinerator is loaded with one batch of waste per day and allowed to cool after the waste is completely burned. Once cooled, the ash is removed and another batch of waste is loaded into the incinerator. When operating in the intermittent-duty mode, a batch of waste is initially loaded into the incinerator and allowed to burn. Once this initial batch is burned down, the incinerator is recharged with one or more additional batches of waste. After two or more batches of waste are burned, the incinerator is cooled down and the ash removed so the incinerator may be used again. Continuous-duty incinerators can be operated continuously for an indefinite period; however, they 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.

14.1.2.2 Excess-Air Medical Waste Incinerators

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. Combustion in an excess-air incinerator occurs in two (or more) combustion chambers, all of which operate under excess-air conditions. 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 and into a mixing chamber where it is mixed with secondary air before it proceeds into the secondary combustion 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.

Excess-air incinerators are typically designed for single batch or intermittent-duty operation. Therefore, they do not have an automatic, continuous ash removal system that would make continuous operation possible. Consequently, the incinerator must be shut down at routine intervals (e.g., daily) for ash removal.

14.1.2.3 Rotary-Kiln Medical Waste Incinerators

A rotary-kiln incinerator also utilizes a primary chamber to heat and volatilize the waste, and a secondary chamber where the combustion of the volatile fraction is completed. The primary combustion chamber consists of an inclined rotating cylindrical chamber. Waste is fed through the higher end of the chamber by a mechanical feed system, and as the kiln rotates and the solids tumble, the inclination of the chamber allows the waste to slowly move down towards the discharge end. An auxiliary burner within the kiln maintains the desired combustion temperature to volatilize the moisture, vaporize the volatiles, and ignite the waste. The volatile gases pass into the secondary chamber where the combustion of the gases is completed under excess-air conditions.

Due to the nature of the rotary-kiln incinerator, they are typically operated in a continuous mode with a semi-continuous to continuous waste feed input. Consequently, a rotary kiln typically has a mechanical waste feed system and a system for continuous ash removal. Rotary-kiln incinerators are few in number and unlikely to be found at USAF installations. For more information regarding rotary-kiln incinerators, refer to Section 2.3 of AP-42.

14.1.3 Air Curtain Incinerators

Air curtain incinerators, which are also known as trench combustors, apply a curtain of air across the top of an open pit where open burning occurs. The purpose of the air curtain is to reduce particulate emissions while improving combustion efficiency. EFs for air curtain incinerators have been developed and are presented in AP-42. **However, since air curtain incineration is generally used as an alternative to open burning and open burning is regarded as a non-routine, short term source, both air curtain incineration and open burning are regarded as transitory sources of air emissions. EFs for air curtain incinerators, therefore, may be found in the *Air Emissions Guide for Air Force Transitory Sources*.**

14.2 NSPS and NESHAP Applicability

Increased scrutiny regarding the air pollution created by incinerators has led to development of strict regulations. There are several NSPSs required by the EPA applicable to incinerators. Emission standards have been established for steam-generating units which include solid waste incinerators with a heat recovery. These standards are codified in 40 CFR 60 Subpart Db, *Standards of Performance for Industrial, Commercial, Institutional Steam Generating Units*. This CFR outlines the emission standards based on size of the steam-generating unit and year of construction, modification, or reconstruction. 40 CFR 60 Subparts AAAA through FFFF each outline the performance standards for solid waste incinerators based on their size and date of construction, modification, or reconstruction. Different standards apply to medical waste incinerators and can be found in 40 CFR 60 Subpart Ce, *Emission Guidelines and Compliance Times for Hospital/Medical/Infectious Waste Incinerators.* This CFR provides the operator training, waste management, and inspection guidelines for each medical waste incinerator constructed or modified in the stated time. Another standard applicable to medical waste incinerators is found in 40 CFR 60 Subpart Ec, *Standards of Performance for New Stationary Sources: Hospital/Medical/Infectious Waste Incinerators.* This CFR outlines the emission limits and compliance testing requirements for those incinerators constructed within the stated time.

It should be noted that, while not covered in this guide, there are several NSPS applicable to both municipal solid waste and sewage sludge incinerators. 40 CFR 60 Subpart Cb, *Emissions Guidelines and Compliance Times for Large Municipal Waste Combustors that Are Constructed on or Before September 20, 1994*, outlines the standards required for incinerators capable of combusting more than 250 tons per day of municipal solid waste. However, there are several exemptions to this standard, so this CFR should be reviewed to determine if a source is subject to this standard. Similarly, 40 CFR 60 Subparts Ea and Eb describe the standards applicable to municipal waste incinerators capable of burning more than 250 tons per day based on the year of construction, modification, or reconstruction. Refer to 40 CFR 60 Subparts Ea and Eb for more information if needed.

In addition to the new source performance standards, any facility operating a hazardous waste incinerator is also subjected to NESHAP. 40 CFR 63 Subpart EEE, *National Emission Standards for Hazardous Air Pollutants from Hazardous Waste Combustors*, outlines the emissions and operating limits for hazardous waste incinerators for both area and major sources. Refer to the appropriate regulation for more information to verify that any affected incinerator complies with these standards.

14.3 Control Techniques

There are several types of control devices available to minimize the quantity of pollutants emitted into the atmosphere. The most commonly used controls on incinerators limit the emission of particulate. Common control devices include Electrostatic Precipitators (ESPs), in-duct sorbent injections, spray dryers, and FFs. ESPs work by applying an electric charge to particulate in the exhaust gas air stream of an incinerator. An electric field forces the charged particulate to accumulate on a collection plate. Duct sorbent injection is used to reduce the amount of sulfur emitted. This control technology works by introducing an alkaline material that reacts with the acidic gas in the exhaust stream to form salts, which are collected before the flue gas is emitted into the atmosphere. Spray dryers are also used to control particulate emissions. They work by applying hot gas across a liquid medium which evaporates and allows suspended particles to flow to a particulate collection device.

14.4 Emission Factors

EFs have not been developed directly for incinerators that burn classified waste. When possible, on site measurements should be taken for the most accurate emissions calculations. In the absence of on-site test data, EFs applicable to "industrial/commercial" incinerators that burn refuse other than municipal waste should be used for emission calculations. The EFs for criteria pollutants are listed in the tables of Section 2.1 of AP-42 and are also provided below in Table 14-1, while the GHG EFs are given in Table 14-2.

Table 14-1. Criteria Pollutant Emission Factors for Classified Waste Incinerators

Combustor Type	Emission Factors (lb/ton)					
	NO_X	CO	SO_X	VOC[(a)]	PM_{10}[(b)]	$PM_{2.5}$[(b)]
Single Chamber	2.0	20.0	2.5	15.0	4.5	3.0
Multiple Chamber	3.0	10.0	2.5	3.0	2.1	1.4

SOURCE: Section 2.1- "Refuse Combustion," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, October 1996.

a) Emission factors based on values provided for total organic compounds in source document.

b) Source document provided emissions for total particulate matter (PM). These values calculated using typical PM fractions as given by Krause, Mike and Steve Smith, "Methodology to Calculate Particulate Matter (PM) 2.5 and PM 2.5 Significance Thresholds," South Coast Air Quality Management District, October 2006

.

Table 14-2. GHG Emission Factors for Classified Waste Incinerators

Combustor Type	Emission Factors (lb/ton)			
	CO_2	CH_4	N_2O	$CO_2e^{(a)}$
Single Chamber	1,990	0.7	0.1	2,035
Multiple Chamber	1,990	0.7	0.1	2,035

SOURCE: "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 98-Mandatory Greenhouse Gas Reporting, Subpart C-General Stationary Fuel Combustion Sources," U.S. Environmental Protection Agency.

a) CO_2e calculated by summing the product of the default emission factors for CO_2, N_2O, and CH_4 and their respective Global Warming Potentials (GWP). The GWP for CO_2, N_2O, and CH_4 are 1, 298, and 25 respectively. Emission factors and high heat values for "municipal solid waste" were used for calculation.

EFs are provided for medical waste incinerators with common control devices seen on USAF installations. Every effort should be taken to use site-specific emission control data for more accurate modeling. In the absence of on-site test data, the EFs developed by AP-42 may be used for emission calculations. These EFs are given in Section 2.3 of AP-42 and provided in Table 14-3. The EFs for GHGs were calculated using the default EFs and HHV for “municipal solid waste” under 40 CFR 98. These EFs are given in Table 14-4.

In addition to the criteria pollutant EFs, AP-42 provides speciated HAP EFs resulting from medical waste incineration. Again, it is preferable to use on-site test data if possible. Note that HAP EFs have not been developed for classified waste incinerators, so it may be necessary to select surrogate EFs to estimate these emissions. Review chapter 2 of AP-42 for guidance as needed. The speciated HAP EFs for medical waste incinerators are provided in Table 14-5.

Table 14-3. Criteria Pollutant Emission Factors for Medical Waste Incinerators

Pollutant	Uncontrolled (lb/ton)	Control Device Emission Factors (lb/ton)(a)								
		Low Energy WS with FF	Medium Energy WS with FF	FF	Low Energy WS	High Energy WS	DSI with FF	DSI with CI and FF	DSI with FF and Scrubber	DSI with ESP
NO_X	3.56E+00	---	---	---	---	---	---	---	---	---
CO	2.95E+00	---	---	---	---	---	---	---	---	---
SO_X(b)	2.17E+00	---	3.75E-01	8.45E-01	2.09E+00	2.57E-02	3.83E-01	7.14E-01	2.42E-02(c)	---
Pb	7.28E-02	---	1.60E-03	9.92E-05	7.94E-02	6.98E-02	6.25E-05	9.27E-05	5.17E-05	4.70E-03
VOC(d)	2.99E-01	---	---	6.86E-02	1.40E-01	1.40E-01	4.71E-02	---	---	---
PM_{10}	3.04E+00	6.54E-01	1.16E-01	---	2.09E+00	1.06E+00	---	---	1.93E+00	---
$PM_{2.5}$	2.02E+00	2.45E-02	4.35E-03	---	7.83E-02	4.00E-02	---	---	7.24E-02	---

SOURCE: Section 2.3- “Medical Waste Incineration," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, January 1995.

a) Control devices include: wet scrubber (WS), fabric filter (FF), dry sorbent injection (DSI), carbon injection (CI), and electrostatic precipitator (ESP).

b) Provided in source document as SO_2.

c) This value is the sum of SO_2 and SO_3 as provided in the source document.

d) Emission factors based on values provided for total organic compounds in source document.

e) Particulate matter (PM) values based on fraction cumulative mass percentages for size distribution of total particulate matter data as shown in Table 2.3- 15 of AP-42.

“---” – No data available. If needed, a conservative estimate may be made using the uncontrolled emission factors as surrogate emission factors.

Table 14-4. GHG Emission Factors for Medical Waste Incinerators

Control Type	Emission Factors (lb/ton)			
	CO_2	CH_4	N_2O	CO_2e(a)
Uncontrolled	1,990	0.702	0.092	2,035

SOURCE: "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 98-Mandatory Greenhouse Gas Reporting, Subpart C-General Stationary Fuel Combustion Sources," U.S. Environmental Protection Agency.

a) CO_2e calculated by summing the product of the default emission factors for CO_2, N_2O, and CH_4 and their respective Global Warming Potentials (GWP). The GWP for CO_2, N_2O, and CH_4 are 1, 298, and 25 respectively. Emission factors and high heat values for "municipal solid waste" were used for calculation.

Table 14-5. Speciated HAP Emission Factors for Medical Waste Incinerators

Pollutant	Uncontrolled (lb/ton)	Control Device Emission Factors (lb/ton)[a]								
		Low Energy WS with FF	Medium Energy WS with FF	FF	Low Energy WS	High Energy WS	DSI with FF	DSI with CI and FF	DSI with FF and Scrubber	DSI with ESP
Antimony	1.28E-02	---	3.09E-04	---	---	4.08E-04	2.10E-04	1.51E-04	---	---
Arsenic	2.42E-04	---	3.27E-05	3.95E-08	1.42E-04	3.27E-05	1.19E-05	1.46E-05	---	5.01E-05
Beryllium	6.25E-06	---	---	---	---	---	---	3.84E-06	---	---
Cadmium	5.48E-03	---	1.78E-04	---	6.97E-03	7.43E-02	2.46E-05	9.99E-05	1.30E-05	5.93E-04
Chlorinated Dibenzofurans (Total CDF)	7.15E-05	---	---	8.50E-06	4.92E-06	4.92E-06	1.47E-06	9.47E-08	---	---
Chlorine	1.05E-01	---	---	---	---	---	---	---	---	---
Chromium	7.75E-04	---	2.58E-04	2.15E-06	4.13E-04	1.03E-03	3.06E-04	1.92E-04	3.96E-05	6.58E-04
Hydrogen Chloride	3.35E+01	1.90E+00	2.82E+00	5.65E+00	1.00E+00	1.39E-01	1.27E+01	9.01E-01	9.43E-02	4.98E-01
Hydrogen Fluoride	1.49E-01	---	---	---	---	---	---	1.33E-02	---	---
Manganese	5.67E-04	---	---	---	4.66E-04	6.12E-04	---	---	---	---
Mercury	1.07E-01	---	3.07E-02	---	1.55E-02	1.73E-02	1.11E-01	9.74E-03	3.56E-04	1.81E-02
Nickel	5.90E-04	---	5.30E-04	---	3.28E-04	2.54E-03	4.54E-04	2.84E-04	---	4.84E-04
Polychlorinated Biphenyls	4.65E-05	---	---	---	---	---	---	---	---	---
2,3,7,8-TCDD	5.47E-08	---	---	6.72E-09	1.29E-10	1.29E-10	5.61E-10	8.23E-10	---	1.73E-10

SOURCE: Section 2.3- "Medical Waste Incineration," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, January 1995.

a) Control devices include: wet scrubber (WS), fabric filter (FF), dry sorbent injection (DSI), carbon injection (CI), and electrostatic precipitator (ESP).

"---" – No data available. If needed, a conservative estimate may be made using the uncontrolled emission factors as surrogate emission factors.

14.5 Emissions Calculation

Pollutant emissions from incinerator use are estimated by taking the product of the mass of waste burned and the appropriate EF for each pollutant. If estimating emissions from waste incineration in the presence of a control device, use the EF developed for that control device. As an alternative, or if an EF for that control device has not been developed, multiply the mass of waste burned and the uncontrolled EF by the efficiency of the control device. This calculation is described in Equation 14-1 below.

$$\boldsymbol{E_{Pol} = Q \times EF_{Pol} \times \left[1 - \left(\frac{CE}{100}\right)\right]}$$

Equation 14-1

Where,

E_{Pol} = Pollutant emissions (lb/yr)
Q = Quantity of waste combusted (tons/yr)
EF_{Pol} = Emission Factor (lb/ton)
100 = Factor converting percent to a fraction (%)
CE = Control device efficiency (%). **This is 0 if uncontrolled or if a controlled emission factor is used.**

A detailed control volume describing emissions from incinerator use is provided in Figure 14-2.

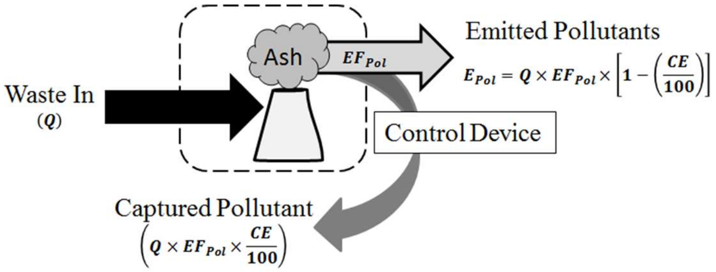

Figure 14-2. Incinerator Use Control Volume

14.6 Information Resources

Medical waste incinerators are typically operated by the base hospital/clinic. The medical facility manager should be contacted for specific information required for the calculation of emissions (e.g., type of incinerator, quantity of waste combusted). For information required to calculate emissions from classified waste incinerators, contact the base Information Systems office. If the incinerator has a control device installed, the manufacturer may need to be contacted to determine the control efficiency.

14.7 Example Problem

A USAF base needs to determine the PM_{10} emissions from the operation of their classified waste incinerator. The incinerator used was a multiple chamber device and burned 11,500 lb of classified waste during the year. If the PM_{10} control efficiency of the control device for this incinerator is given as 97 percent, determine the PM_{10} emissions from this operation.

Step 1 – **Convert the waste burned.** The total waste burned was provided in pounds, but emissions calculation requires that the total waste burned must be in tons. This unit conversion is accomplished as follows:

$$Q = \frac{11{,}500\,\frac{\cancel{lb}}{yr}}{2{,}000\,\frac{\cancel{lb}}{ton}} = \mathbf{5.75}\ \boldsymbol{\frac{ton}{yr}}$$

Step 2 – **Select and record the appropriate EF.** The EFs for classified waste incinerators are provided in Table 14-1. For a multiple chamber incinerator, the PM_{10} EF is given as **2.1lb/ton.**

Step 3 – **Calculate emissions.** Using the total amount of waste incinerated, the EF recorded in Step 2, the control device efficiency, and Equation 14-1, PM_{10} emissions are calculated as follows:

$$E_{\mathrm{Pol}} = Q \times EF_{Pol} \times \left[1 - \left(\frac{CE}{100}\right)\right]$$

$$E_{PM_{10}} = 5.75\ \frac{ton}{yr} \times 2.1\frac{lb}{ton} \times \left[1 - \left(\frac{97\%}{100\%}\right)\right]$$

$$E_{PM_{10}} = 5.75\frac{ton}{yr} \times 2.1\frac{lb}{ton} \times [1 - 0.97]$$

$$E_{PM_{10}} = 5.75\ \frac{\cancel{ton}}{yr} \times 2.1\frac{lb}{\cancel{ton}} \times [0.03]$$

$$\boxed{\boldsymbol{E_{PM_{10}} = 0.36\frac{lb}{yr}}}$$

14.8 References

40 CFR 60 Subpart Cb, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New Stationary Sources, Subpart Cb-Emissions Guidelines and Compliance Times for Large Municial Waste Combustors that are Constructed on or Before September 20, 1995," U.S. Environmental Protection Agency

40 CFR 60 Subpart Ce, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New Stationary Sources, Subpart Ce-Emissions Guidelines and Compliance Times for Hospital/Medical/Infectious Waste Incinerators," U.S. Environmental Protection Agency

40 CFR 60 Subpart Db, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New Stationary Sources, Subpart Db-Standards of Performance for Industrial-Commercial-Institutional Steam Generating Units," U.S. Environmental Protection Agency

40 CFR 60 Subpart Ea, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New Stationary Sources, Subpart Ea-Standards of Performance for Large Municipal Waste Combustors for which Construction is Commenced After December 20, 1989 and on or Before September 20, 1994," U.S. Environmental Protection Agency

40 CFR 60 Subpart Eb, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New Stationary Sources, Subpart Eb-Standards of Performance for Municipal Waste Combustors for which Construction is Commenced After September 20, 1994 or for Which Modification or Reconstruction is Commenced After June 19, 1996," U.S. Environmental Protection Agency

40 CFR 60 Subpart AAAA, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New Stationary Sources, Subpart AAAA-Standards of Performance for Small Municipal Waste Combustion Units for Which Construction is Commenced After August 30, 1999 or for Which Modification or Reconstruction is Commenced After June 6, 2001," U.S. Environmental Protection Agency

40 CFR 60 Subpart BBBB, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New Stationary Sources, Subpart BBBB-Emission Guidelines and Compliance Times for Small Municipal Waste Combustion Units Constructed on or Before August 30, 1999," U.S. Environmental Protection Agency

40 CFR 60 Subpart CCCC, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New Stationary Sources, Subpart CCCC-Standards of Performance for Commercial and Industrial Solid Waste Incineration Units," U.S. Environmental Protection Agency

40 CFR 60 Subpart DDDD, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New Stationary Sources, Subpart DDDD-Emissions Guidelines and Compliance Times for Commercial and Industrial Solid Waste Incineration Units," U.S. Environmental Protection Agency

40 CFR 60 Subpart EEEE, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New Stationary Sources, Subpart EEEE-Standards of Performance for Other Solid Waste Incineration Units for Which Construction is Commenced After December 9, 2004, or for Which Modification or Reconstruction is Commenced on or After June 16, 2006," U.S. Environmental Protection Agency

40 CFR 60 Subpart FFFF, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New Stationary Sources, Subpart FFFF-Emissions Guidelines and Compliance Times for Other Solid Waste Incineration Units that Commenced Construction on or Before December 9, 2004," U.S. Environmental Protection Agency

40 CFR 63 Subpart EEE, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 63-National Emission Standards for Hazardous Air Pollutants for Source Categories, Subpart EEE-National Emission Standards for Hazardous Air Pollutants from Hazardous Waste Combustors," U.S. Environmental Protection Agency

40 CFR 98 Subpart C, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 98-Mandatory Greenhouse Gas Reporting, Subpart C-General Stationary Fuel Combustion Sources," U.S. Environmental Protection Agency

Krause 2006, Krause, Mike and Steve Smith, "Methodology to Calculate Particulate Matter (PM) 2.5 and PM 2.5 Significance Thresholds," South Coast Air Quality Management District, October 2006

USEPA 1995, Section 2.3-"Medical Waste Incineration," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, January 1995

USEPA 1996, Section 2.1-“Refuse Incineration," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, October 1996

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15 LANDFILLS (LAND, MSW)

- *Fugitive Source*
- *(Potential) Point Source* – If Gas Collection System Used

15.1 Introduction

A landfill is a defined area of land, used explicitly to deposit wastes. Both active landfills (wastes currently being deposited) and closed landfills (wastes no longer being deposited) are significant sources of air pollution. While there are only a few active landfills at USAF installations, there are several USAF bases that have closed landfills on their property. **Both active and closed landfills serve as fugitive (and potentially) point sources of VOCs, HAPs, GHGs, and PM.**

Landfill waste includes, but is not limited to, Municipal Solid Waste (MSW), Construction and Demolition wastes (C&D), commercial and industrial organic wastes, and agricultural wastes. All landfills containing any organic wastes will generate and release gaseous emissions. Landfills are known to be the third largest human generated source of methane in the United States, therefore it is imperative to understand and control emissions from these sources.

Most landfills are equipped with some form of active or passive gas collection systems. Active collection systems employ the use of mechanical blowers or compressors to generate a pressure gradient to extract gases coming from landfills. Passive collection systems utilize the natural pressure gradient created by the generation of the landfill gases to mobilize the gas for collection. Typically, active gas collection systems will send the landfill gases to a control device such as a flare, turbine, or ICOM engine. Passive collection systems will vent the gases directly to the atmosphere without the use of any control device. USAF installations with active gas control technologies will commonly utilize a flare to combust the landfill gases. A control volume that describes the emissions from landfills is given in Figure 15-1.

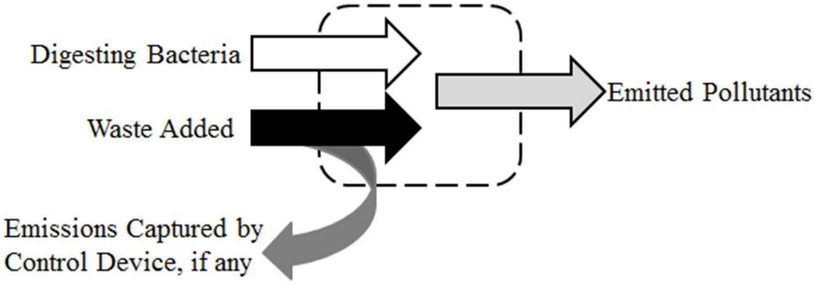

Figure 15-1. Simplified Control Volume for Emissions from Landfills

In general, a three-step process is followed when depositing waste into an active landfill. The waste is spread over an area, compacted, and then covered with a layer of soil. The covering of the waste is typically performed using heavy equipment (e.g., bulldozers, graders). Use of the heavy equipment results in the generation of fugitive dust emissions coming from the ground surface. Additionally, there may be a significant amount of emissions associated with the exhaust from the heavy equipment and other motorized vehicles used at the landfill site. **While estimating fugitive dust emissions at landfills is described below, both on-road and non-road equipment <u>exhaust</u> emissions are mobile sources of emissions, therefore they should not be included in a stationary AEI.**

MSW landfills primarily receive household wastes, but may also receive commercial solid waste, nonhazardous sludge, and industrial solid waste. MSW landfills are required to comply with the federal regulations promulgated under subtitle D of the Resource Conservation and Recovery Act (RCRA). These regulations describe location restrictions, detail emissions modeling and corrective actions, and provide design and operating criteria applicable to MSW landfills. The landfills subject to the regulations promulgated under RCRA are required to monitor methane emissions and prevent off-site migration for active landfills and for a period of 30 years after landfill closure. Details regarding these requirements are provided in 40 CFR 258, *Criteria for Municipal Solid Waste Landfills*. In Subpart C of this CFR, the operating criteria includes stating that owners and operators of all MSW landfills must not violate SIP requirements. Landfills are primarily the responsibility of state and local governments; therefore, stricter regulations may vary from state to state.

15.2 NSPS and NESHAP Applicability

Several NSPS have been developed to aid in the reduction of pollution from active and closed landfills. Emission guidelines for MSW landfills are provided in 40 CFR 60 Subpart Cc, *Emission Guidelines and Compliance Times for Municipal Solid Waste Landfills*. These standards are applicable to landfills whose construction, reconstruction, or modification commenced **before** May 30, 1991. According to this Subpart, landfills must have control devices installed to monitor and control the amount of NMOC released to the atmosphere. This requirement applies to any landfill with a design capacity greater than or equal to 2.5 million megagrams and 2.5 million cubic meters that also has a NMOC emission rate of at least 50 megagrams per year. For those landfills whose construction, reconstruction, or modification occurred **on or after** May 30, 1991, the air emissions standards are provided in 40 CFR 60 Subpart WWW, *Standards of Performance for Municipal Solid Waste Landfills*.

In addition to the NSPS described in part 60 of 40 CFR, there are also NESHAPs applicable to landfills. 40 CFR 63 Subpart AAAA, *National Emission Standards for Hazardous Air Pollutants: Municipal Solid Waste Landfills*, applies to any MSW classified as a major source of

HAPs or is an area source with a design capacity equal to or greater than 2.5 million megagrams and 2.5 million cubic meters that is estimated to produce 50 megagrams or more of NMOC annually. For more information regarding the requirements of the standards applicable to landfills, including reporting requirements and minimum control efficiencies, refer to 40 CFR 60 Subparts Cc and WWW, and 40 CFR 63 Subpart AAAA.

15.3 Greenhouse Gas Mandatory Reporting Rules

According to 40 CFR 98.2, any facility located in the United States or attached to the Outer Continental Shelf that has a municipal solid waste landfill that generates 25,000 metric tons or more of CO_2e per year is subject to the GHG reporting rules as outlined in 40 CFR 98. CH_4 generation from landfills as well as CH_4 destruction resulting from landfill gas collection and combustion systems are required to be reported. The calculation of the methane generated is described in detail in 40 CFR 98 Subpart HH, though the use of modeling software, as described below, may be used for this calculation. Note that the mandatory reporting rule applies to MSW landfills which generate 25,000 or more metric tons of CO_2e per year and accepted waste on or after January 1, 1980 unless: 1) The landfill did not receive waste on or after January 1, 2013; 2) The CH_4 generation was less than 1,190 metric tons in the 2013 reporting year; **and** 3) An annual report was not required under any requirement in 40 CFR 98 Subpart HH in any reporting year prior to 2013.

15.4 Control Techniques

The primary source of emissions at landfills comes from the generation of landfill gas. Collection and treatment of this gas is an important part of reducing the amount of pollutants emitted to the atmosphere. The most common technique for treating landfill gas is the use of combustion technologies such as flares, incinerators, boilers, gas turbines, and internal combustion engines. Combustion of landfill gas results in effectively destroying most of the organic compounds while converting CH_4 to CO_2, which has a significantly lower GWP. Typical control efficiencies of common control devices are provided in Table 15-1.

The disadvantage of combustion control is that the combustion of landfill gas may lead to the formation of NO_X, SO_X, CO, and PM. This gave rise to the development of non-combustion technologies. Non-combustion technologies may be classified as either energy recovery or gas-to-product conversion technologies. One example of an energy recovery technology is a Phosphoric Acid Fuel Cell (PAFC) which is a system that consists of a fuel cell processing system, fuel cell stacks, and a power conditioning system. Gas-to-products technologies convert landfill gas to natural gas, methanol, or purified CO_2 and CH_4 using several chemical reactions and/or purification techniques. Both types of non-combustion technologies require the landfill gas to first be pretreated to remove impurities. The non-combustion treatment still commonly results in the production of waste gases, which are often thermally destroyed with flares.

Table 15-1. Typical Control Efficiencies of Control Devices Used for Landfill Gas Destruction

Control Device	Constituent	Control Efficiency (%)	
		Average	Range
Boiler/Steam Turbine (SCC 5-01-004-23)	NMOC	98.0	96-99+
	Halogenated Species[(a)]	99.6	87-99+
	Non-Halogenated Species	99.8	67-99+
Flare[(b)] (SCC 5-01-004-10, 5-03-006-01)	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+

SOURCE: Section 2.4 - “Municipal Solid Waste Landfills," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, November 1998. SCC = Source Classification Code.

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 SO_2, CO_2, and hydrochloric acid.

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.

15.5 Emission Factors

VOC, HAP, and GHG emissions are calculated using the Landfill Gas Emissions Model (LandGEM). The use of EFs to calculate emissions from the decomposition of organic materials at municipal waste landfills is not recommended. However, at active sites, the calculation of fugitive dust emissions from the bulldozing and grading of waste overburden may be calculated based on equipment use and their respective EFs. Fugitive dust EFs at landfills are also a function of the soil moisture and silt content. EF equations are provided in Section 11.9 of AP-42. Using the geometric average for silt and moisture content and average grader speed, the EF equations were simplified and are provided in Table 15-2. For enhanced accuracy, refer to Table 11.9-1 of AP-42 and use on-site moisture content, silt content, or average grader speed.

Table 15-2. Fugitive Dust Emission Factors at Active Landfills

Operation	Emission Factors[(a)]		Units
	PM_{10}	$PM_{2.5}$	
Bulldozing	0.75	0.41	lb/hr
Grading	1.54	0.17	lb/VMT

SOURCE: Section 11.9 - "Western Surface Coal Mining," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, October 1998.

a) Particulate matter (PM) emission factors are calculated using the following average values: silt content (s) – 6.9, moisture content (M) – 7.9, and grader speed (S) – 7.1.

15.6 Emissions Calculation

15.6.1 Uncontrolled Emissions

The LandGEM is an automated tool developed by the EPA for estimating emissions from MSW landfills. The model is in the form of a Microsoft Excel™ spreadsheet, and can be used to estimate uncontrolled pollutants of concern. These pollutants of concern include CH_4, CO_2, NMOCs, and individual air pollutants from landfills by using a first order decay equation rate. However, according to the EPA, "CO_2 emissions from MSW landfills are not considered to contribute to global climate change because the carbon was contained in recently living biomass. The same CO_2 would be emitted because of the natural decomposition of the organic waste materials outside the landfill environment." Therefore, CO_2 emissions at landfills should be disregarded.

The model requires the user to input data such as the year the landfill opened and closed, the waste design capacity, and the annual waste deposited in the landfill. Also, the user may elect to change program defaults such as the values for CH_4 generation rate and generation capacity. The model generates a report detailing the uncontrolled emissions of individual pollutants over time and presents these pollutants as an AEI table for a user-specified year.

CH_4 emissions contribute a great amount to total GHG emissions, so another model designed to calculate CH_4 emission rates from landfills is CALMIM (California Landfill Methane Inventory Model). CALMIM is a field-validated, 1-dimensional transport and oxidation model that calculates annual **site-specific** landfill CH_4 emissions. CALMIM calculates the daily CH_4 flux from landfill cover based on United States Department of Agriculture (USDA) models for climate and soil microclimate. Unlike LandGEM, which is based on a first-order decay equation rate, CALMIM requires an extensive amount of site-specific information such as cover details and exact longitude and latitude coordinates to produce accurate emissions estimations. CALMIM is available for download through the USDA website.

15.6.2 Controlled Emissions

The LandGEM model does not directly calculate emissions from landfills that have control systems installed. However, the equations used to calculate controlled emissions rely upon the uncontrolled emissions generated by the LandGEM model. Most emissions control systems installed in landfills utilize combustion as a means of control. During the combustion process, much of the organic gases are converted to CO_2. **Air pollutant emissions resulting from the combustion of landfill gases are calculated using the methods described in the "External Combustion" section of this** guide**.** Emissions resulting from the fugitive release of gas not collected and combusted is a function of the efficiency of the collection and control system. If the capture efficiency of the collection system is not known, the EPA recommends an efficiency of 75 percent for estimation purposes. Controlled CH_4, NMOC, and speciated emissions can be calculated using a mass balance approach as follows:

$$\boldsymbol{E(Cont.)_{Pol} = E(Uncont.)_{Pol} \times \left[1 - \left(\frac{Cap}{100}\right) \times \left(\frac{CE}{100}\right)\right]}$$

Equation 15-1

Where,

E(Cont.)Pol = Annual **controlled** emissions of pollutant (lb/yr)
E(Uncont.)Pol = Annual **uncontrolled** emissions of pollutant (lb/yr)
Cap = Capture efficiency of collection system (%). **Assume 75% if unknown.**
100 = Factor for converting a percent to a fraction (%)
CE = Control efficiency of control device for pollutant (%)

A detailed control volume depicting the emissions from landfills with control devices in place is given in Figure 15-2.

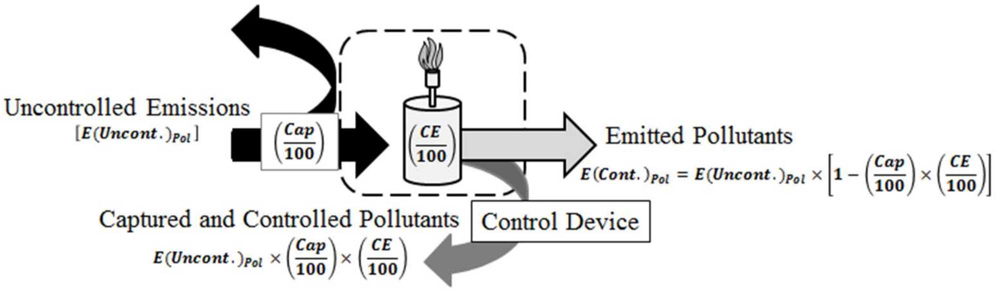

Figure 15-2. Landfill Control Volume – Controlled Emissions

15.6.3 Fugitive PM Emissions

Fugitive dust emissions at landfills result from the bulldozing and grading of municipal solid waste to minimize air space and make room for additional waste. Fugitive dust emissions are the sum of the fugitive dust emissions generated by both bulldozers and graders. Using the EFs provided in Table 15-2, fugitive dust emissions are calculated as follows:

$$\boldsymbol{E_{Pol} = [EF(Bulldozing)_{Pol} \times OT] + [EF(Grading)_{Pol} \times VMT]}$$

Equation 15-2

Where,

$\mathbf{E_{Pol}}$ = Annual emissions of pollutant (lb/yr)
$\mathbf{EF(Bulldozing)_{Pol}}$ = Bulldozing emission factor (lb/hr). This is provided in Table 15-2.
OT = Annual bulldozing operating time (hr/yr)
$\mathbf{EF(Grading)_{Pol}}$ = Grading emission factor (lb/VMT). This is provided in Table 15-2
VMT = Annual vehicle miles traveled by grader (miles/yr)

15.7 Information Resources

Base CE is typically responsible for operating and maintaining on-base landfills, and should be contacted to obtain specific landfill information. The annual average rainfall received by the base is required to determine the proper *k* value (CH_4 generation rate constant) to use when calculating uncontrolled emissions. Also, operating times and total vehicle miles travelled may be estimated using information provided by Base CE.

15.8 Example Problem

A USAF base has an inactive landfill that was closed in 2005. The landfill originally opened in 1993 and was used to dispose of residential (household) wastes only. Base CE estimates the landfill received an average of 50,000 tons (45,359 Mg) of waste per year. The landfill is equipped with a gas collection device (efficiency unknown) and a flare. The base is in an area that 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 xylenes for an emissions inventory for calendar year 2014.

Step 1 – Input data into LandGEM. 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**, *1993*, and the **Landfill Closure Year**, *2005*. Note that if the landfill were currently open, LandGEM could also calculate the estimated closure year if the two fields below the **Landfill Closure Year** are completed.

Under section 2: DETERMINE MODEL PARAMETERS, select *Inventory Conventional* for both the **CH_4 Generation Rate, k,** and the **Potential CH_4 Generation Capacity, L_o**. Select *Inventory No or Unknown Co-disposal* for **NMOC Concentration** and accept *CAA - 50 percent by volume* for **CH_4 Content**. Yearly precipitation and temperature averages are used to determine the CH_4 generation rate based on EPA Method 2E. For more details about the k value calculation as well as the refuse methane generation capacity, refer to 40 CFR 60 Appendix A-1.

Under section 3: SELECT GAS/POLLUTANTS, change **Gas/Pollutant #3** to *Xylenes – HAP/VOC*. 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 45,000 Mg/year for each year starting in 1993 and ending in 2005. 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.

Step 2 – Select and record calculated uncontrolled emissions. For AEI use, the INVENTORY tab will prepare a 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 Mg/year and 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 total landfill emissions for the inventory year. The objective of this problem is to determine the 2014 annual emissions from the landfill for NMOC and xylenes. Scroll down to the Results section of the REPORT tab and find the column labeled Xylenes – HAP/VOC and NMOC. Find 2014 year on the left side of the table and read across the table to the right. The Xylene emissions are **1.407E-01 Mg/year** and the NMOC emissions are **5.711E+00 Mg/year** for the year 2014.

Step 3 – Convert emissions into the appropriate units. The values provided by LandGEM are in units of Mg/yr, but calculations for controlled emissions require the units to be in lb/yr. Conversion of the units is performed as follows:

$$\boldsymbol{E(Uncont.)_{Xylenes}} = 0.1407\,\frac{\cancel{Mg}}{yr} \times 2204.62\,\frac{lb}{\cancel{Mg}} = \mathbf{310.19}\,\frac{\boldsymbol{lb}}{\boldsymbol{yr}}$$

$$\boldsymbol{E(Uncont.)_{NMOC}} = 5.711\,\frac{\cancel{Mg}}{yr} \times 2204.62\,\frac{lb}{\cancel{Mg}} = \mathbf{12,590.58}\,\frac{\boldsymbol{lb}}{\boldsymbol{yr}}$$

Step 4 – **Select and record the capture and control efficiencies.** Since the capture efficiency is unknown, a value of **75 percent is assumed**. The control efficiency of a flare however is given in Table 15-1. For xylenes, this efficiency is stated to be **99.7 percent** and **99.2 percent** for NMOC.

Step 5 – **Calculate controlled emissions.** Because this example landfill had a collection and control system, the capture and control efficiency of the system must be used to calculate the actual controlled emissions. This is accomplished by using the values converted in Step 3 and the capture and control efficiencies recorded in Step 4 in Equation 15-1 as follows:

$$E(Cont.)_{Pol} = E(Uncont.)_{Pol} \times \left[1 - \left(\frac{Cap}{100}\right) \times \left(\frac{CE}{100}\right)\right]$$

For Xylenes:

$$E(Cont.)_{Xylenes} = 310.19\frac{lb}{yr} \times \left[1 - \left(\frac{75\cancel{\%}}{100\cancel{\%}}\right) \times \left(\frac{99.7\cancel{\%}}{100\cancel{\%}}\right)\right]$$

$$E(Cont.)_{Xylenes} = 310.19\frac{lb}{yr} \times [1 - (0.75) \times (0.997)]$$

$$E(Cont.)_{Xylenes} = 310.19\frac{lb}{yr} \times [1 - (0.74775)]$$

$$E(Cont.)_{Xylenes} = 310.19\frac{lb}{yr} \times [0.25225]$$

$$\boxed{\boldsymbol{E(Cont.)_{Xylenes} = 78.25\frac{lb}{yr}}}$$

For NMOC:

$$E(Cont.)_{NMOC} = 12590.58\frac{lb}{yr} \times \left[1 - \left(\frac{75\cancel{\%}}{100\cancel{\%}}\right) \times \left(\frac{99.2\cancel{\%}}{100\cancel{\%}}\right)\right]$$

$$E(Cont.)_{NMOC} = 12590.58\frac{lb}{yr} \times [1 - (0.75) \times (0.992)]$$

$$E(Cont.)_{NMOC} = 12590.58\frac{lb}{yr} \times [1 - (0.744)]$$

$$E(Cont.)_{NMOC} = 12590.58\frac{lb}{yr} \times [0.256]$$

$$\boxed{\boldsymbol{E(Cont.)_{NMOC} = 3,223.19\frac{lb}{yr}}}$$

15.9 References

40 CFR 60 Subpart Cc, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New Stationary Sources, Subpart Cc-Emission Guidelines and Compliance Times for Municipal Solid Waste Landfills," U.S. Environmental Protection Agency

40 CFR 60 Subpart WWW, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New Stationary Sources, Subpart WWW-Standards of Performance for Municipal Solid Waste Landfills," U.S. Environmental Protection Agency

40 CFR 63 Subpart AAAA, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 63-National Emission Standards for Hazardous Air Pollutants for Source Categories, Subpart AAAA-National Emission Standards for Hazardous Air Pollutants: Municipal Solid Waste Landfills," U.S. Environmental Protection Agency

40 CFR 98 Subpart A, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 98-Mandatory Greenhouse Gas Reporting, Subpart A-General Provision," U.S. Environmental Protection Agency

40 CFR 98 Subpart HH, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 98-Mandatory Greenhouse Gas Reporting, Subpart HH-Municipal Solid Waste Landfills," U.S. Environmental Protection Agency

USDA-ARS, CALMIM, Version 5.1, California Landfill Methane Inventory Model, 2010

USEPA 1998a, Section 2.4-"Municipal Solid Waste Landfills," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, November 1998

USEPA 1998b, Section 11.9-"Western Surface Coal Mining," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, October 1998

USEPA 2005, LandGEM, Version 3.02, U.S. Environmental Protection Agency, May 2005

16 MUNITIONS OPEN BURN/OPEN DETONATION (OBOD)

- *Fugitive Source*

16.1 Introduction

Munitions open burn/open detonation is often utilized in the USAF as a means of disposing of bulk explosives, bulk propellants, small arms ammunition, high explosive incendiary (HEI) cartridges, bomb fuses, mines, flares/signals, and other bulk, obsolete, or unserviceable munitions and energetic materials. Incineration and the disassembly of these items is a more environmentally friendly alternative for disposal. However, due to safety and cost considerations, Open Burning/Open Detonation (OB/OD) is more commonly used for disposal of energetic materials.

Munitions and assembled energetic materials are defined as items in which the explosive material is contained within a metal casing. Munitions include small arms ammunition and HEI cartridges. 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).

OB/OD operations produce fugitive emissions and include criteria pollutants, organic and inorganic HAPs, and GHGs. Emissions are dependent upon the type and quantity of items that are burned or detonated. A graphical representation of the emissions from OB/OD is provided in Figure 16-1.

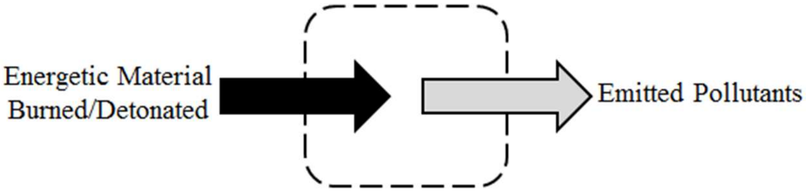

Figure 16-1. Simplified OB/OD Control Volume

16.2 Federal Standards

The EPA has established guidelines applicable to owners and operators of facilities that thermally treat waste explosives. These guidelines stipulate the minimum distance required between the detonation sites and the neighboring property. The required distance is dependent on the mass of explosives detonated. To verify that a facility complies with these guidelines, refer to the table in 40 CFR 265.382.

16.3 Emission Factors

The DOD has developed the Open Burn/Open Detonation Dispersion Model (OBODM) which contains a database of EFs for several munitions and explosives. More recently, however, the EPA has developed EFs for several munitions, assembled energetic materials, explosives, and propellants. These EFs have been published and are available in Chapter 15, "Ordnance Detonation," of AP-42. **This section does not provide EFs for cartridges. Refer to the "SMALL ARMS FIRING RANGE (MUN)" chapter for this data.** The criteria pollutant EFs for energetic materials are provided in Table 16-1, GHG EFs are provided in Table 16-2, and HAP EFs are given in Table 16-3.

The EFs are in units of pound of pollutant per item, but may be converted into units of pound of pollutant per pound Net Explosive Weight (NEW). Unit conversion is accomplished by dividing the EF (in pounds per item) by the NEW of the item. The default NEW value is provided in the tables for each munition. Alternatively, the composition and NEW for each energetic material may be obtained from the Army's Munitions Items Disposition Action System (MIDAS). The NEW is calculated by summing the energetic components in the munition. Note that MIDAS will often list "alternative" (ALT) components for a munition that **should not** be included when calculating the NEW for the item. MIDAS is available at https://midas.dac.army.mil. To use MIDAS, you must first register and obtain a password from the Army's Defense Ammunition Center (DAC).

Occasionally there are some munitions that are not present in the guide due to limited use or munitions that have been misidentified as discontinued or no longer in use. In these cases, it is advised that the base Explosive Ordnance Disposal (EOD) be consulted on which munitions in the guide are most comparable to the munitions in question. This will help determine the most accurate EFs to use.

16.4 Emissions Calculation

Emissions can be calculated by taking the product of the annual quantity or mass of items to be OB/OD and the given EF of that specific munition or energetic material as shown:

$$\boldsymbol{E_{Pol} = Q \times EF_{Pol}}$$

Equation 16-1

Where,

E_{Pol} = Annual emissions of pollutant (lb/yr)
Q = Annual quantity or mass of items to be OB/OD during the year (items/yr or lb NEW/yr)
EF_{Pol} = Emission factor of munition or energetic material (lb/item or lb/lb NEW)

Emissions calculation from OB/OD is graphically represented in Figure 16-2.

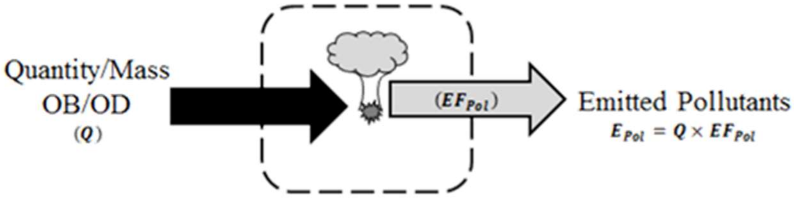

Figure 16-2. OB/OD Control Volume – Without Donor Charge

For open detonation, a donor charge may be used. In this case, emissions from the donor charge must be calculated in addition to emissions from the munitions detonated. Calculation is performed as follows:

$$\boldsymbol{E_{Pol} = \left(Q_{EM} \times EF_{Pol_{EM}}\right) + \left(Q_{DC} \times EF_{Pol_{DC}}\right)}$$

Equation 16-2

Where,

$\mathbf{Q_{EM}}$ = Annual quantity or mass of items to be OD during the year (items/yr or lb NEW/yr)

$\boldsymbol{EF_{pol_{EM}}}$ = Emission factor of munition or energetic material (lb/item or lb/lb NEW)

$\mathbf{Q_{DC}}$ = Annual quantity of donor charge to be OD during the year (lb/yr)

$\boldsymbol{EF_{pol_{DC}}}$ = Emission factor for donor charge (lb/item or lb/lb NEW)

Emissions calculation from OB/OD using a donor charge is graphically represented in Figure 16-3.

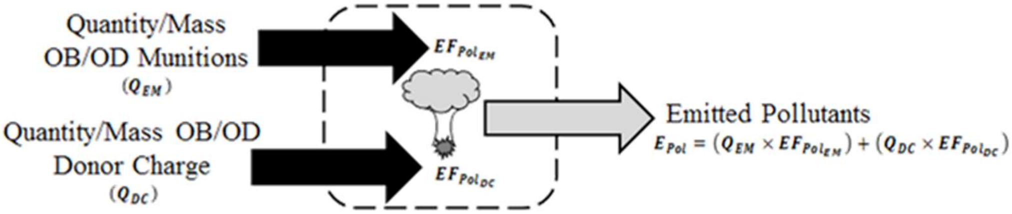

Figure 16-3. OB/OD Control Volume – With Donor Charge

16.5 Information Resources

Information required for calculating emissions from OB/OD operations can be obtained from the base EOD shop. The EOD shop will know the type and quantity of items disposed of, the method of disposal, and the type and quantity of donor charge used to facilitate detonation of the items, if used. Information about specific items may be available from the base EOD shop or online from MIDAS at https://midas.dac.army.mil.

16.6 Example Problem

A USAF base is looking to calculate emissions from the open burn/open detonation of several munitions from the previous year. The EOD shop stated that, during the previous year, 20 of the ¼ lb demolition block charges (M030) and 12 of the M4 incendiary bursters (K010) were openly detonated. A donor charge of 10g of trinitrotoluene (TNT) (ACC2) was used per M4 burster. Determine the total NO_X and benzene emissions from the open detonation of these munitions.

<u>Step 1</u> – **Select and record the appropriate EFs.** The EFs for NO_X are provided in Table 16-1. For the demolition block charges, M4 bursters, and TNT, the NO_X EFs are **3.00E-03 lb/item, 4.20E-03 lb/item, and 9.27E-03 lb/lb NEW,** respectively. Similarly, Table 16-3 provides the benzene EFs for each munition. For the demolition block charges, M4 bursters and TNT, the benzene EFs are **2.90E-07 lb/item, 5.80E-06 lb/item, and 4.10E-06 lb/lb NEW,** respectively.

<u>Step 2</u> – **Calculate the total TNT used.** Since 10 g of TNT were used for each M4 burster, the total TNT used (in pounds) is calculated as follows:

$$\boldsymbol{Q_{DC}} = 10\frac{\cancel{g}}{\cancel{item}} \times 12\frac{\cancel{items}}{yr} \times \frac{0.00220462\ lb}{\cancel{g}} = \mathbf{0.265}\frac{\boldsymbol{lb\ NEW}}{\boldsymbol{yr}}$$

<u>Step 3</u> – **Calculate emissions from the demolition block charges.** Using the EFs provided in Step 1 and the quantities provided in the problem statement, the emissions from the demolition block charges are calculated using Equation 16-1 as follows:

$$E_{Pol} = Q \times EF_{Pol}$$

<u>For NO_X:</u>

$$\boldsymbol{E_{NO_X}} = 20\frac{\cancel{items}}{yr} \times 0.003\frac{lb}{\cancel{item}} = \mathbf{0.06}\frac{\boldsymbol{lb}}{\boldsymbol{yr}}$$

<u>For Benzene:</u>

$$\boldsymbol{E_{Benzene}} = 20\frac{\cancel{items}}{yr} \times 0.00000029\frac{lb}{\cancel{item}} = \mathbf{0.0000058}\frac{\boldsymbol{lb}}{\boldsymbol{yr}}$$

<u>Step 4</u> – Calculate emissions from the M4 bursters and donor charges. This is accomplished by taking the EFs from Step 1, the total mass of TNT used calculated in Step 2, and Equation 16-2 as shown:

$$E_{Pol} = \left(Q_{EM} \times EF_{Pol_{EM}}\right) + \left(Q_{DC} \times EF_{Pol_{DC}}\right)$$

<u>For NO_X:</u>

$$E_{NO_X} = \left(12\,\frac{\cancel{items}}{yr} \times 0.0042\,\frac{lb}{\cancel{item}}\right) + \left(0.265\,\frac{\cancel{lb\ NEW}}{yr} \times 0.00927\,\frac{lb}{\cancel{lb\ NEW}}\right)$$

$$\boldsymbol{E_{NO_X}} = \left(0.0504\,\frac{lb}{yr}\right) + \left(0.0025\,\frac{lb}{yr}\right) = \mathbf{0.0529}$$

<u>For Benzene:</u>

$$E_{benzene} = \left(12\,\frac{\cancel{items}}{yr} \times 0.0000058\,\frac{lb}{\cancel{item}}\right) + \left(0.265\,\frac{\cancel{lb\ NEW}}{yr} \times 0.0000041\,\frac{lb}{\cancel{lb\ NEW}}\right)$$

$$\boldsymbol{E_{benzene}} = \left(0.0000696\,\frac{lb}{yr}\right) + \left(0.0000010865\,\frac{lb}{yr}\right) = \mathbf{0.0000706865}$$

<u>Step 5</u> – Calculate total emissions. Sum the NO_X and benzene emissions from each munition as follows:

$$E_{Pol_{Total}} = \sum_{i=1}^{n}\left(E_{Pol_i} + \cdots + E_{Pol_n}\right)$$

<u>For NO_X:</u>

$$E_{NO_{X_{Total}}} = (0.06 + 0.0529)\,\frac{lb}{yr}$$

$$\boxed{\boldsymbol{E_{NO_{X_{Total}}} = 1.13\mathrm{E}-01\,\frac{lb}{yr}}}$$

<u>For Benzene:</u>

$$E_{\mathrm{Benzene}_{Total}} = (0.0000058 + 0.0000706865)\,\frac{lb}{yr}$$

$$\boxed{\boldsymbol{E_{\mathrm{Benzene}_{Total}} = 7.65\mathrm{E}-05\,\frac{lb}{yr}}}$$

Table 16-1. Criteria Pollutant Emission Factors for Open Burn/Open Detonation

Munition Type	DODIC	Item	Units:	Net Explosive Material (NEW)	NO$_x$	CO (630-08-0)	SO$_2$ (7446-09-5)	Pb (7439-92-1)	VOC[a]	PM$_{10}$	PM$_{2.5}$
Projectiles, Canisters, and Charges	D505	155-mm Illumination Round (M485A2)	lb/item	6.12E+00	9.40E-02	2.60E-02	2.70E-03	5.80E-05	1.50E-03	3.00E+00	---
	D533	155-mm Propelling Charge, Zone 7 (M119A2)	lb/item	2.25E+01	2.80E-02	8.60E+00	---	2.90E-02	---	4.40E-01	1.30E-01
	D540	**155-mm Propelling Charges (M3/M3A1)**	**lb/lb NEW**	[b]	**3.90E-02**	**5.90E-01**	**---**	**9.90E-05**	**---**	**1.70E-02**	**8.10E-03**
	D541	155-mm Propelling Charge, Zone 7 (M4A2)	lb/item	1.33E+01	7.90E-02	6.00E+00	---	3.60E-03	---	3.20E-01	1.40E-01
Grenades	G815	Red Phosphorus Screening Smoke Launcher Grenade (UK) (L8A3)	lb/item	8.32E-01	1.60E-03	2.00E-02	1.20E-03	3.00E-06	3.90E-03	8.00E-01	7.90E-01
	G878	Practice Hand Grenade Fuse (M228)	lb/item	4.50E-03	4.00E-05	1.10E-05	1.10E-05	---	3.20E-07	1.10E-04	9.40E-05
	G881	Fragmentation Hand Grenade (M67)	lb/item	4.10E-01	1.10E-03	1.70E-02	---	5.00E-04	---	3.10E-02	1.70E-02
	G900	Thermite (TH3) Incendiary Hand Grenade (AN-M14)	lb/item	1.55E+00	6.70E-04	8.00E-04	2.60E-02	1.10E-02	---	7.00E-02	4.90E-02
	G911	Offensive Hand Grenade (MK3A2)	lb/item	4.94E-01	7.40E-03	1.40E-02	4.90E-05	3.30E-04	---	3.50E-02	2.00E-02
	G930	Hexachloroethane (HC) Smoke Hand Grenade (AN-M8)	lb/item	1.10E+00	1.00E-03	4.60E-02	1.20E-04	4.70E-04	6.30E-04	6.80E-01	1.10E-01
	G940	Green Smoke Hand Grenade (M18)	lb/item	7.20E-01	1.20E-04	1.20E-02	1.60E-04	3.40E-05	2.10E-03	1.30E-01	1.00E-01
	G945	Yellow Smoke Hand Grenade (M18)	lb/item	7.20E-01	7.80E-05	4.00E-03	9.90E-04	1.50E-05	2.00E-04	---	---
	G950	Red Smoke Hand Grenade (M18)	lb/item	7.20E-01	4.20E-04	5.80E-03	4.30E-04	1.90E-05	5.10E-04	1.40E-01	1.20E-01
	G955	Violet Smoke Hand Grenade (M18)	lb/item	7.20E-01	4.90E-04	1.40E-02	1.60E-04	1.60E-05	1.10E-03	1.20E-01	1.00E-01
	G963	CS Riot Control Agent Hand Grenade (M7A3)	lb/item	7.50E-01	1.40E-03	3.40E-02	5.10E-05	---	5.60E-03	4.20E-02	3.70E-02
	G978	Simulant Screening Smoke Launcher Grenade (M82)	lb/item	1.68E+00	4.40E-04	1.20E-02	---	3.60E-05	2.00E-03	5.30E-02	2.90E-02
	G982	Terephthalic Acid (TA) Smoke Practice Hand Grenade (M83)	lb/item	7.02E-01	3.50E-04	1.80E-02	9.50E-06	5.80E-05	9.50E-03	3.60E-02	2.80E-02
	GG09	Non-Lethal Stun Hand Grenade (M84)	lb/item	7.65E-03	4.10E-04	1.50E-05	---	9.00E-07	---	4.60E-03	3.30E-03
Rockets, Rocket Motors, and Igniters	H163	2.75-inch Rocket with M151 High Explosive Warhead	lb/item	2.32E+00	5.60E-03	4.00E-01	---	6.00E-04	---	2.40E-01	1.20E-01
	H459	2.75-inch Fletchette, MK40 Mod 3 Motor	lb/item	6.02E+00	2.60E-02	1.50E+00	---	5.10E-02	---	1.10E-01	1.00E-01
	H557	66-mm High Explosive Antitank Rocket (M72A3) (Propelling Rocket)	lb/item	1.34E-01	2.10E-03	5.80E-03	2.10E-05	1.80E-05	---	8.10E-03	7.70E-03
		66-mm High Explosive Antitank Rocket (M72A3) (Warhead)	lb/item	6.84E-01	5.00E-03	5.00E-02	---	1.20E-03	---	5.20E-02	3.00E-02
		66-mm High Explosive Antitank Rocket (M72A3) (Total)	lb/item	8.18E-01	7.10E-03	5.50E-02	2.10E-05	1.20E-03	---	6.10E-02	3.80E-02
	H708	35-mm Subcaliber Practice Rocket (M73) (Propelling Rocket)	lb/item	2.64E-02	---	2.50E-03	---	6.20E-06	---	1.20E-03	1.20E-03
		35-mm Subcaliber Practice Rocket (M73) (Warhead)	lb/item	3.20E-03	4.00E-06	---	2.50E-04	---	2.10E-06	5.50E-04	5.30E-04
		35-mm Subcaliber Practice Rocket (M73) (Total)	lb/item	2.96E-02	4.00E-06	2.50E-03	2.50E-04	6.20E-06	2.10E-06	1.80E-03	1.70E-03
	H974	2.75-inch Practice Warhead, MK66 Mod 3 Motor (M267)	lb/item	7.17E+00	---	5.30E-01	---	7.00E-02	---	1.60E-01	1.70E-01

Table 16-1. Criteria Pollutant Emission Factors for Open Burn/Open Detonation (cont.)

Munition Type	DODIC	Item	Units:	Net Explosive Material (NEW)	NO_X	CO (630-08-0)	SO_2 (7446-09-5)	Pb (7439-92-1)	VOC(a)	PM_{10}	$PM_{2.5}$
Mines and Smoke Pots	K010	Field Incendiary Burster (M4)	lb/item	2.04E-02	4.20E-03	4.20E-03	---	---	---	5.10E-02	1.70E-02
	K042	Practice Canister Mine (Volcano) (M88)	lb/item	1.39E-02	9.40E-05	6.80E-05	1.60E-05	7.60E-06	4.90E-06	2.50E-04	2.20E-04
	K051	Anti-Tank Practice Mine Fuze (M604)	lb/item	3.81E-02	---	2.20E-04	---	1.50E-05	---	2.00E-02	1.50E-02
	K145	Antipersonnel Mine (M18A1)	lb/item	1.50E+00	1.80E-02	2.00E-02	9.10E-05	5.70E-05	---	4.90E-02	2.60E-02
	K765	CS Riot Control Agent Capsule	lb/item	---	1.80E-06	1.00E-05	6.30E-08	---	1.00E-05	3.20E-05	2.90E-05
	K866	30-Pound HC Smoke Pot (ABC-M5)	lb/item	3.10E+01	2.60E-03	7.90E-01	4.40E-03	2.40E-02	1.70E-02	3.20E+01	1.70E+01
	K867	Floating Type HC Smoke Pot (M4A2)	lb/item	2.75E+01	2.80E-03	8.90E-01	3.20E-03	1.60E-02	2.20E-02	3.00E+01	2.30E+01
Signals and Simulators	L305	Green Star Parachute Signal Flare (M195)	lb/item	3.16E-01	2.40E-03	9.40E-03	7.80E-05	4.70E-07	1.70E-04	1.20E-01	---
	L306	Red Star Cluster Signal Flare (M158)	lb/item	2.80E-01	3.30E-03	8.80E-03	1.50E-04	1.70E-06	2.80E-04	8.90E-02	---
	L307	White Star Cluster Signal Flare (M159)	lb/item	3.20E-01	2.50E-03	7.50E-03	7.10E-05	3.80E-06	2.40E-04	5.00E-02	---
	L311	Red Star Parachute Signal Flare (126A1)	lb/item	2.96E-01	3.10E-03	1.10E-02	7.30E-05	2.30E-06	3.30E-04	1.20E-01	---
	L312	White Star Parachute Signal Flare (M127A1)	lb/item	2.83E-01	5.70E-03	4.40E-03	1.30E-04	5.50E-06	8.50E-05	1.70E-01	---
	L314	Green Star Cluster Signal Flare (M125A1)	lb/item	1.67E+00	1.70E-03	1.00E-02	2.90E-07	2.00E-06	2.50E-04	6.60E-02	---
	L366	Air Burst Projectile Simulator (M74A1)	lb/item	8.99E-02	8.60E-04	5.20E-03	4.30E-05	1.40E-03	4.90E-04	5.80E-03	4.00E-03
	L367	Anti-Tank Guided Missle and Rocket Launching Simulator (M22)	lb/item	3.12E-02	2.50E-03	4.30E-05	7.60E-05	---	7.30E-06	1.40E-02	1.30E-02
	L410	Aircraft Countermeasure Flare (M206)	lb/item	2.84E-01	1.30E-04	1.30E-03	7.90E-06	---	4.00E-04	6.20E-03	6.20E-03
	L495	Surface Trip Flare (M49A1)	lb/item	1.08E+00	2.90E-03	5.30E-04	1.20E-04	9.90E-06	1.00E-05	1.30E-01	---
	L508	Red Railroad Warning Fusee (M72)	lb/item	---	9.70E-03	2.10E-03	5.60E-03	---	2.60E-04	4.60E-03	4.40E-03
	L592	TOW Blast Simulator	lb/item	5.65E-03	4.90E-05	2.50E-05	3.10E-04	1.60E-05	3.70E-06	1.50E-03	1.30E-03
	L594	Ground Burst Simulator (M115A2)	lb/item	1.41E-01	5.50E-03	2.10E-03	1.50E-04	4.10E-06	1.30E-04	1.90E-01	---
	L595	Liquid Projectile Air Burst Simulator (M9)	lb/item	1.38E-01	6.10E-04	1.30E-03	---	4.20E-06	---	5.50E-03	4.90E-03
	L596	Flash Artillery Simulator (M110)	lb/item	1.88E-01	2.00E-03	6.80E-03	1.80E-04	1.10E-05	4.90E-03	4.50E-02	---
	L598	Flash Booby Trap Simulator (M117)	lb/item	7.70E-03	5.00E-05	5.30E-05	4.40E-04	2.30E-06	3.80E-06	2.50E-03	---
	L599	Illuminating Booby Trap Simulator (M118)	lb/item	1.34E-02	1.90E-06	2.70E-04	2.10E-06	5.50E-08	2.00E-05	3.90E-03	---
	L600	Whistling Booby Trap Simulator (119)	lb/item	1.06E-01	6.60E-05	1.40E-03	8.10E-06	---	6.20E-05	2.40E-03	---
	L601	Hand Grenade Simulator (M116A1)	lb/item	8.13E-02	5.60E-03	3.70E-04	4.70E-04	1.40E-06	4.20E-05	1.20E-01	---
	L602	Artillery Flash Simulator (M21)	lb/item	9.38E-02	2.80E-03	1.30E-05	2.60E-02	2.00E-03	3.60E-04	3.20E-02	1.70E-02
	L709	Target-Hit Simulator (M25)	lb/item	6.00E-02	1.20E-03	9.80E-04	4.20E-06	2.10E-05	1.90E-04	2.50E-02	1.70E-02
	L720	Target Kill Simulator (M26)	lb/item	1.35E+00	4.40E-04	2.10E-01	3.20E-05	---	---	5.20E-02	2.70E-02

Table 16-1. Criteria Pollutant Emission Factors for Open Burn/Open Detonation(cont.)

Munition Type	DODIC	Item	Units:	Net Explosive Material (NEW)	NO_x	CO (630-08-0)	SO_2 (7446-09-5)	Pb (7439-92-1)	VOC[(a)]	PM_{10}	$PM_{2.5}$
Blasting Caps, Demolition Charges, and Detonators	M023	Demolition Block Charge (M112)	lb/item	1.25E+00	7.90E-03	2.60E-02	1.50E-04	1.70E-04	---	2.60E-02	1.90E-02
	M030	1/4-Pound Demolition Block Charge	lb/item	2.50E-01	3.00E-03	5.00E-03	8.10E-05	1.40E-04	---	1.20E-02	4.60E-03
	M031	1/2-Pound Demolition Block Charge	lb/item	5.00E-01	7.40E-03	1.10E-02	7.50E-07	1.10E-04	2.30E-03	6.70E-02	6.40E-03
	M032	1-Pound Demolition Block Charge	lb/item	1.00E+00	1.30E-02	4.80E-03	4.00E-05	2.00E-04	---	2.50E-02	1.40E-02
	M130	Electric Blasting Cap (M6)	lb/item	2.92E-03	7.70E-05	3.20E-04	---	1.50E-04	---	4.00E-04	2.40E-04
	M131	Non-Electric Blasting Cap (M7)	lb/item	2.76E-03	7.10E-05	2.90E-04	---	2.60E-04	---	4.90E-04	3.40E-04
	M174	.50 Calibur Blank Cartridge (Electrically Initiated)	lb/item	2.33E-02	1.30E-04	7.90E-03	---	1.90E-06	---	1.50E-03	1.30E-03
	M241	High Explosive Universal Destructor (M10)	lb/item	2.86E-01	5.50E-03	1.30E-02	1.40E-03	3.30E-02	2.50E-03	1.10E-01	5.40E-02
	M327	Firing Device Coupling Base	lb/item	5.71E-05	7.00E-07	5.50E-06	4.20E-07	6.70E-06	---	1.70E-05	1.50E-05
	M420	15-Pound Demolition Shaped Charge (M2A4)	lb/item	1.01E+01	7.00E-02	6.40E-02	---	3.80E-02	---	3.50E-01	1.50E-01
	M448	8-Second Delay Percussion Detonator (M2A1)	lb/item	6.20E-03	1.60E-04	3.50E-04	---	2.40E-04	---	7.70E-04	4.80E-04
	M456	PETN Type 1 Detonating Cord	lb/item	7.00E-03	7.00E-03	4.70E-02	---	7.30E-05	1.50E-02	1.60E-01	1.10E-02
	M500	Cartridge Actuated Cutter (M21)	lb/item	4.00E-03	1.40E-06	2.10E-04	---	---	---	9.60E-07	7.40E-07
	M591	Military Dynamite Demolition Block Charge (M1)	lb/item	3.70E-01	2.40E-03	5.40E-03	---	1.50E-04	---	8.90E-03	3.50E-03
	M626	Pressure Type Demolition Firing Device (M1)	lb/item	5.71E-05	4.00E-07	4.50E-06	6.20E-07	4.30E-06	---	2.40E-05	2.20E-05
	M630	Pull Type Demolition Firing Device (M1)	lb/item	5.71E-05	7.60E-07	6.30E-06	1.30E-07	6.90E-06	5.80E-08	1.60E-05	5.90E-06
	M670	Time Blasting Fuse (M700)	lb/item	2.70E-03	7.70E-02	9.50E-02	7.20E-04	---	---	3.40E-02	3.50E-02
	M766	Time Blasting Fuse Igniter (M60)	lb/item	5.71E-05	1.80E-06	2.40E-06	---	2.60E-06	---	3.60E-06	2.90E-06
	M913	Linear Demolition Charge (M58A3)	lb/item	5.02E+00	1.80E-02	1.10E-02	---	3.40E-05	---	4.60E-02	2.10E-02
	MD73	Impulse Cartridge (M796)	lb/item	7.83E-04	4.20E-05	1.70E-05	1.40E-07	3.60E-09	---	8.00E-05	7.20E-05
	ML03	Multipurpose Demolition Firing Device (M142)	lb/item	4.71E-05	1.20E-06	3.80E-06	---	5.00E-06	---	8.80E-06	7.70E-06
	ML05	Powder Actuated Cutter (MK24)	lb/item	1.26E+00	1.90E-02	2.30E-02	1.20E-04	1.10E-03	---	6.60E-02	2.90E-02
	ML09	**Linear Shaped Demolition Charge, 20 gr/ft**	**lb/lb NEW**	**2.86E-03**	**4.20E-02**	**1.70E-01**	**---**	**3.40E-01**	**2.10E-02**	**4.30E-01**	**1.30E-02**
	ML15	**Linear Shaped Demolition Charge, 225 gr/ft**	**lb/lb NEW**	**3.21E-02**	**4.60E-02**	**1.80E-01**	**7.40E-07**	**8.50E-01**	**2.00E-02**	**2.30E+00**	**8.10E-02**
	ML47	Non-Electric Blasting Cap with 30-foot Shock Tube (M11)	lb/item	2.73E-03	4.50E-05	3.10E-04	---	1.30E-04	---	4.60E-04	2.90E-04
	MM50	Clipped Shaped Demolition Charge (M221)	lb/item	6.62E-02	3.60E-04	9.70E-03	---	1.90E-04	---	5.20E-03	1.30E-03
	MN02	Non-Electric Blasting Cap with 500-foot Shock Tube (M12)	lb/item	6.18E-03	1.20E-04	2.90E-03	---	5.30E-05	---	2.20E-04	1.20E-04
	MN03	Non-Electric Blasting Cap with 1000-foot Shock Tube (M13)	lb/item	1.10E-02	2.70E-04	6.50E-03	---	5.50E-05	---	2.50E-04	1.60E-04
	MN06	Non-Electric Time Delay Blasting Cap (M14)	lb/item	2.59E-02	5.70E-04	1.80E-03	---	3.80E-05	---	2.30E-03	2.30E-03
	MN07	Non-Electric Time Delay Blasting Cap (M15)	lb/item	4.06E-03	4.20E-05	5.70E-04	---	1.80E-04	---	3.70E-04	2.70E-04
	MN08	Time Blasting Fuse Igniter (M81)	lb/item	4.86E-05	1.90E-06	2.80E-06		4.40E-06		5.40E-06	4.70E-06
	MN60	Electric Match Igniter (M79)	lb/item	1.26E-02	1.20E-04	1.70E-04	8.40E-07	1.40E-05		1.30E-03	9.10E-04
	MN68	Booster Demolition Charge (M151)	lb/item	9.70E-03	9.20E-05	1.20E-03	3.60E-05	1.10E-04	3.60E-05	7.30E-04	6.10E-04

Table 16-1. Criteria Pollutant Emission Factors for Open Burn/Open Detonation (cont.)

Munition Type	DODIC	Item	Units:	Net Explosive Material (NEW)	NOx	CO (630-08-0)	SO_2 (7446-09-5)	Pb (7439-92-1)	VOC[a]	PM_{10}	$PM_{2.5}$
Fuses and Primers	N278	Mechanical Time and Super Quick (MTSQ) Fuse (M564)	lb/item	6.32E-02	8.30E-04	8.70E-04	---	5.10E-04	---	7.90E-03	4.30E-03
	N285	Mechanical Time and Super Quick (MTSQ) Fuse (M577A1)	lb/item	9.39E-04	9.40E-06	2.00E-04	---	4.00E-06	---	1.70E-04	8.90E-05
	N286	Mechanical Time and Super Quick (MTSQ) Fuse (M582)	lb/item	5.27E-02	1.10E-03	2.40E-03	---	5.00E-04	---	1.50E-02	1.00E-02
	N335	Point Detonating Fuse (M557)	lb/item	5.22E-02	7.70E-04	4.50E-03	---	3.00E-04	---	1.40E-02	8.40E-03
	N340	Point Detonating Fuse (M739A1)	lb/item	4.59E-02	5.30E-04	3.50E-04	---	1.00E-04	---	1.60E-02	1.00E-02
	N464	Proximity Fuse (M732)	lb/item	1.37E-02	2.60E-04	1.10E-03	---	1.50E-05	---	2.80E-03	2.00E-03
Energetic Materials[c]	---	**Amatol**	**lb/lb NEW**	**5.00E-01**[d]	1.81E-02	9.70E-03	2.60E-04	3.30E-05	4.50E-04	1.90E-02	---
	J473	**Cartridge, Impulse, ARD446-1**	**lb/lb NEW**	---	8.10E-03	1.30E-02	2.40E-04	3.10E-04	9.80E-04	8.30E-02	---
	MG11	**Cartridge, Impulse, BBU-36/B**	**lb/lb NEW**	---	5.50E-03	8.40E-03	4.00E-04	6.80E-05	7.70E-04	1.80E-01	---
	M943	**Cartridge, Impulse, MK 107**	**lb/lb NEW**	---	1.56E-02	1.40E-02	2.60E-04	---	6.40E-04	2.50E-01	---
	---	**Composition B surrogate**	**lb/lb NEW**	**5.00E-01**[d]	9.49E-03	4.20E-03	1.30E-04	---	1.10E-04	1.20E-02	---
	---	**Detonating Train**	**lb/lb NEW**	---	9.30E-03	9.40E-03	4.60E-04	1.80E-04	8.50E-04	3.60E-02	---
	F841	**Fuse, Tail Bomb FMU-54 A/B**	**lb/lb NEW**	---	9.50E-03	1.80E-02	4.10E-04	---	9.90E-04	3.30E-01	---
	F762	**Fuse, Tail Bomb FMU-139 A/B**	**lb/lb NEW**	---	2.69E-02	2.30E-02	1.40E-03	2.60E-03	1.40E-03	6.00E-01	---
	L231	**Signal, Illumination, Red Star AN-M43A2**	**lb/lb NEW**	---	1.41E-02	2.20E-02	1.30E-02	7.00E-05	7.40E-04	4.50E-01	---
	---	**Tritonal surrogate**	**lb/lb NEW**	---	8.35E-03	4.70E-03	1.60E-04	1.10E-03	2.80E-04	3.70E-01	---
	---	**Tritonal surrogate with calcium stearate**	**lb/lb NEW**	---	6.65E-03	2.70E-03	1.20E-04	9.20E-04	4.00E-05	2.60E-01	---
	---	**TNT (Sandia)**	**lb/lb NEW**	---	1.05E-02	---	1.40E-04	0.00E+00	---	---	---
	---	**TNT (ACC1)**	**lb/lb NEW**	---	---	1.00E-02	---	0.00E+00	2.80E-05	7.30E-02	---
	---	**TNT (ACC2)**	**lb/lb NEW**	---	9.27E-03	6.70E-03	1.40E-04	9.00E-06	4.00E-05	9.30E-02	---

SOURCE (unless otherwise stated): United States EPA. Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources. Fifth edition. Chapter 15.

a) Source document provided an emission factor for total non-methane organic compounds (TNMOC). This value used as a surrogate emission factor for total VOCs.

b) There are variations in the NEW depending on the charge configuration. Refer to Table 15.4.1-1 of AP-42 for specific data.

c) SOURCE: Mitchell, William J. and Jack C. Suggs, “Emission Factors for the Disposal of Energetic Materials by Open Burning and Open Detonation (OB/OD),” U.S. Environmental Protection Agency, August 1998.

d) SOURCE: Wilcox, J. L., et al., "Characterization of Emissions Produced by the Open Burning/Open Detonation of Complex Munitions," Physical Test Division, West Desert Test Center, September 1996.

“---” – No data is available.

“00.00E+00” - Compound was not detected or detected at only the background level.

Table 16-2. GHG Emission Factors for Open Burn/Open Detonation

Munition Type	DODIC	Item	Units:	Net Explosive Material (NEW)	CO_2	CH_4	N_2O	CO_2e[a]
Projectiles, Canisters, and Charges	D505	155-mm Illumination Round (M485A2)	lb/item	6.12E+00	1.80E+00	---	---	1.80E+00
	D533	155-mm Propelling Charge, Zone 7 (M119A2)	lb/item	2.25E+01	4.20E+00	4.60E-02	---	5.35E+00
	D540	**155-mm Propelling Charges (M3/M3A1)**	**lb/lb NEW**	[b]	**2.10E-01**	**3.30E-03**	**---**	2.93E-01
	D541	155-mm Propelling Charge, Zone 7 (M4A2)	lb/item	1.33E+01	4.70E+00	3.60E-02	---	5.60E+00
Grenades	G815	Red Phosphorus Screening Smoke Launcher Grenade (UK) (L8A3)	lb/item	8.32E-01	1.70E-01	---	---	1.70E-01
	G878	Practice Hand Grenade Fuse (M228)	lb/item	4.50E-03	1.70E-04	---	---	1.70E-04
	G881	Fragmentation Hand Grenade (M67)	lb/item	4.10E-01	2.40E-01	2.80E-04	---	2.47E-01
	G900	Thermite (TH3) Incendiary Hand Grenade (AN-M14)	lb/item	1.55E+00	2.10E-02	1.20E-05	---	2.13E-02
	G911	Offensive Hand Grenade (MK3A2)	lb/item	4.94E-01	6.20E-01	2.90E-04	---	6.27E-01
	G930	Hexachloroethane (HC) Smoke Hand Grenade (AN-M8)	lb/item	1.10E+00	3.30E-02	---	---	3.30E-02
	G940	Green Smoke Hand Grenade (M18)	lb/item	7.20E-01	8.40E-02	---	---	8.40E-02
	G945	Yellow Smoke Hand Grenade (M18)	lb/item	7.20E-01	7.70E-02	---	---	7.70E-02
	G950	Red Smoke Hand Grenade (M18)	lb/item	7.20E-01	7.70E-02	---	---	7.70E-02
	G955	Violet Smoke Hand Grenade (M18)	lb/item	7.20E-01	4.30E-02	---	---	4.30E-02
	G963	CS Riot Control Agent Hand Grenade (M7A3)	lb/item	7.50E-01	9.10E-02	---	---	9.10E-02
	G978	Simulant Screening Smoke Launcher Grenade (M82)	lb/item	1.68E+00	1.50E-02	---	---	1.50E-02
	G982	Terephthalic Acid (TA) Smoke Practice Hand Grenade (M83)	lb/item	7.02E-01	1.30E-01	---	---	1.30E-01
	GG09	Non-Lethal Stun Hand Grenade (M84)	lb/item	7.65E-03	1.70E-03	---	---	1.70E-03
Rockets, Rocket Motors, and Igniters	H163	2.75-inch Rocket with M151 High Explosive Warhead	lb/item	2.32E+00	7.00E-01	1.20E-02	---	1.00E+00
	H459	2.75-inch Fletchette, MK40 Mod 3 Motor	lb/item	6.02E+00	2.40E+00	2.20E-02	---	2.95E+00
	H557	66-mm High Explosive Antitank Rocket (M72A3) (Propelling Rocket)	lb/item	1.34E-01	8.50E-02	1.40E-04	---	8.85E-02
		66-mm High Explosive Antitank Rocket (M72A3) (Warhead)	lb/item	6.84E-01	3.60E-01	6.00E-04	---	3.75E-01
		66-mm High Explosive Antitank Rocket (M72A3) (Total)	lb/item	8.18E-01	4.50E-01	7.40E-04	---	4.69E-01
	H708	35-mm Subcaliber Practice Rocket (M73) (Propelling Rocket)	lb/item	2.64E-02	1.40E-02	7.10E-06	---	1.42E-02
		35-mm Subcaliber Practice Rocket (M73) (Warhead)	lb/item	3.20E-03	7.30E-06	---	---	7.30E-06
		35-mm Subcaliber Practice Rocket (M73) (Total)	lb/item	2.96E-02	1.40E-02	7.10E-06	---	1.42E-02
	H974	2.75-inch Practice Warhead, MK66 Mod 3 Motor (M267)	lb/item	7.17E+00	4.80E+00	6.20E-03	---	4.96E+00

Table 16-2. GHG Emission Factors for Open Burn/Open Detonation (cont.)

Munition Type	DODIC	Item	Units:	Net Explosive Material (NEW)	CO_2	CH_4	N_2O	CO_2e(a)
Mines and Smoke Pots	K010	Field Incendiary Burster (M4)	lb/item	2.04E-02	3.40E-01	1.30E-05	---	3.40E-01
	K042	Practice Canister Mine (Volcano) (M88)	lb/item	1.39E-02	1.50E-04	---	---	1.50E-04
	K051	Anti-Tank Practice Mine Fuze (M604)	lb/item	3.81E-02	3.60E-03	---	---	3.60E-03
	K145	Antipersonnel Mine (M18A1)	lb/item	1.50E+00	1.60E+00	3.80E-04	---	1.61E+00
	K765	CS Riot Control Agent Capsule	lb/item	---	9.00E-05	---	---	9.00E-05
	K866	30-Pound HC Smoke Pot (ABC-M5)	lb/item	3.10E+01	4.60E-01	---	---	4.60E-01
	K867	Floating Type HC Smoke Pot (M4A2)	lb/item	2.75E+01	5.30E-01	---	---	5.30E-01
Signals and Simulators	L305	Green Star Parachute Signal Flare (M195)	lb/item	3.16E-01	8.80E-02	---	---	8.80E-02
	L306	Red Star Cluster Signal Flare (M158)	lb/item	2.80E-01	1.80E-01	---	---	1.80E-01
	L307	White Star Cluster Signal Flare (M159)	lb/item	3.20E-01	1.80E-01	---	---	1.80E-01
	L311	Red Star Parachute Signal Flare (126A1)	lb/item	2.96E-01	1.40E-01	---	---	1.40E-01
	L312	White Star Parachute Signal Flare (M127A1)	lb/item	2.83E-01	3.80E-03	---	---	3.80E-03
	L314	Green Star Cluster Signal Flare (M125A1)	lb/item	1.67E+00	1.40E-01	---	---	1.40E-01
	L366	Air Burst Projectile Simulator (M74A1)	lb/item	8.99E-02	1.70E-02	---	---	1.70E-02
	L367	Anti-Tank Guided Missle and Rocket Launching Simulator (M22)	lb/item	3.12E-02	1.10E-02	---	---	1.10E-02
	L410	Aircraft Countermeasure Flare (M206)	lb/item	2.84E-01	1.10E-02	---	---	1.10E-02
	L495	Surface Trip Flare (M49A1)	lb/item	1.08E+00	5.20E-02	---	---	5.20E-02
	L508	Red Railroad Warning Fusee (M72)	lb/item	---	8.50E-02	---	---	8.50E-02
	L592	TOW Blast Simulator	lb/item	5.65E-03	3.60E-04	---	---	3.60E-04
	L594	Ground Burst Simulator (M115A2)	lb/item	1.41E-01	3.40E-03	---	---	3.40E-03
	L595	Liquid Projectile Air Burst Simulator (M9)	lb/item	1.38E-01	8.90E-03	8.10E-05	---	1.09E-02
	L596	Flash Artillery Simulator (M110)	lb/item	1.88E-01	2.50E-01	---	---	2.50E-01
	L598	Flash Booby Trap Simulator (M117)	lb/item	7.70E-03	---	---	---	---
	L599	Illuminating Booby Trap Simulator (M118)	lb/item	1.34E-02	1.70E-02	---	---	1.70E-02
	L600	Whistling Booby Trap Simulator (119)	lb/item	1.06E-01	4.10E-03	---	---	4.10E-03
	L601	Hand Grenade Simulator (M116A1)	lb/item	8.13E-02	4.10E-03	---	---	4.10E-03
	L602	Artillery Flash Simulator (M21)	lb/item	9.38E-02	---	---	---	---
	L709	Target-Hit Simulator (M25)	lb/item	6.00E-02	2.90E-02	5.80E-06	---	2.91E-02
	L720	Target Kill Simulator (M26)	lb/item	1.35E+00	3.90E-01	1.20E-04	---	3.93E-01

Table 16-2. GHG Emission Factors for Open Burn/Open Detonation (cont.)

Munition Type	DODIC	Item	Units:	Net Explosive Material (NEW)	CO_2	CH_4	N_2O	$CO_2e^{(a)}$
Blasting Caps, Demolition Charges, and Detonators	M023	Demolition Block Charge (M112)	lb/item	1.25E+00	7.90E-01	1.60E-03	---	8.30E-01
	M030	1/4-Pound Demolition Block Charge	lb/item	2.50E-01	3.40E-01	2.00E-05	---	3.41E-01
	M031	1/2-Pound Demolition Block Charge	lb/item	5.00E-01	7.20E-01	---	---	7.20E-01
	M032	1-Pound Demolition Block Charge	lb/item	1.00E+00	1.20E+00	---	---	1.20E+00
	M130	Electric Blasting Cap (M6)	lb/item	2.92E-03	7.20E-04	4.50E-06	---	8.33E-04
	M131	Non-Electric Blasting Cap (M7)	lb/item	2.76E-03	8.20E-04	5.20E-06	---	9.50E-04
	M174	.50 Calibur Blank Cartridge (Electrically Initiated)	lb/item	2.33E-02	6.30E-03	4.10E-05	---	7.33E-03
	M241	High Explosive Universal Destructor (M10)	lb/item	2.86E-01	4.40E-01	---	---	4.40E-01
	M327	Firing Device Coupling Base	lb/item	5.71E-05	1.10E-05	---	---	1.10E-05
	M420	15-Pound Demolition Shaped Charge (M2A4)	lb/item	1.01E+01	1.30E+01	---	---	1.30E+01
	M448	8-Second Delay Percussion Detonator (M2A1)	lb/item	6.20E-03	1.40E-03	3.50E-06	---	1.49E-03
	M456	PETN Type 1 Detonating Cord	lb/item	7.00E-03	5.00E+00	---	---	5.00E+00
	M500	Cartridge Actuated Cutter (M21)	lb/item	4.00E-03	1.60E-04	7.50E-06	---	3.48E-04
	M591	Military Dynamite Demolition Block Charge (M1)	lb/item	3.70E-01	3.30E-01	6.50E-05	---	3.32E-01
	M626	Pressure Type Demolition Firing Device (M1)	lb/item	5.71E-05	1.60E-05	---	---	1.60E-05
	M630	Pull Type Demolition Firing Device (M1)	lb/item	5.71E-05	5.40E-06	---	---	5.40E-06
	M670	Time Blasting Fuse (M700)	lb/item	2.70E-03	2.90E-01	5.00E-03	---	4.15E-01
	M766	Time Blasting Fuse Igniter (M60)	lb/item	5.71E-05	1.00E-05	2.70E-08	---	1.07E-05
	M913	Linear Demolition Charge (M58A3)	lb/item	5.02E+00	1.20E+00	2.60E-04	---	1.21E+00
	MD73	Impulse Cartridge (M796)	lb/item	7.83E-04	3.00E-05	2.30E-07	---	3.58E-05
	ML03	Multipurpose Demolition Firing Device (M142)	lb/item	4.71E-05	---	---	---	---
	ML05	Powder Actuated Cutter (MK24)	lb/item	1.26E+00	1.50E+00	2.50E-04	---	1.51E+00
	ML09	**Linear Shaped Demolition Charge, 20 gr/ft**	**lb/lb NEW**	**2.86E-03**	**2.40E-01**	**---**	**---**	**2.40E-01**
	ML15	**Linear Shaped Demolition Charge, 225 gr/ft**	**lb/lb NEW**	**3.21E-02**	**4.40E-01**	**---**	**---**	**4.40E-01**
	ML47	Non-Electric Blasting Cap with 30-foot Shock Tube (M11)	lb/item	2.73E-03	1.80E-03	2.80E-05	---	2.50E-03
	MM50	Clipped Shaped Demolition Charge (M221)	lb/item	6.62E-02	2.10E-02	3.50E-04	---	2.98E-02
	MN02	Non-Electric Blasting Cap with 500-foot Shock Tube (M12)	lb/item	6.18E-03	1.10E-03	4.10E-04	---	1.14E-02
	MN03	Non-Electric Blasting Cap with 1000-foot Shock Tube (M13)	lb/item	1.10E-02	1.30E-03	9.10E-04	---	2.41E-02
	MN06	Non-Electric Time Delay Blasting Cap (M14)	lb/item	2.59E-02	6.80E-03	1.70E-04	---	1.11E-02
	MN07	Non-Electric Time Delay Blasting Cap (M15)	lb/item	4.06E-03	1.10E-03	3.90E-05	---	2.08E-03
	MN08	Time Blasting Fuse Igniter (M81)	lb/item	4.86E-05	8.40E-06	6.30E-08	---	9.98E-06
	MN60	Electric Match Igniter (M79)	lb/item	1.26E-02	9.90E-03	2.10E-06	---	9.95E-03
	MN68	Booster Demolition Charge (M151)	lb/item	9.70E-03	4.50E-03	---	---	4.50E-03

Table 16-2. GHG Emission Factors for Open Burn/Open Detonation (cont.)

Munition Type	DODIC	Item	Units:	Net Explosive Material (NEW)	CO_2	CH_4	N_2O	GHG[a]
Fuses and Primers	N278	Mechanical Time and Super Quick (MTSQ) Fuse (M564)	lb/item	6.32E-02	5.20E-02	1.10E-05	---	5.23E-02
	N285	Mechanical Time and Super Quick (MTSQ) Fuse (M577A1)	lb/item	9.39E-04	5.90E-04	5.60E-06	---	7.30E-04
	N286	Mechanical Time and Super Quick (MTSQ) Fuse (M582)	lb/item	5.27E-02	3.00E-02	4.40E-05	---	3.11E-02
	N335	Point Detonating Fuse (M557)	lb/item	5.22E-02	2.80E-02	1.00E-05	---	2.83E-02
	N340	Point Detonating Fuse (M739A1)	lb/item	4.59E-02	2.50E-02	---	---	2.50E-02
	N464	Proximity Fuse (M732)	lb/item	1.37E-02	5.70E-03	1.80E-05	---	6.15E-03
Energetic Materials[c]	---	**Amatol**	**lb/lb NEW**	**5.00E-01[d]**	7.00E-01	---	---	7.00E-01
	J473	**Cartridge, Impulse, ARD446-1**	**lb/lb NEW**	---	4.80E-01	---	---	4.80E-01
	MG11	**Cartridge, Impulse, BBU-36/B**	**lb/lb NEW**	---	5.00E-01	---	---	5.00E-01
	M943	**Cartridge, Impulse, MK 107**	**lb/lb NEW**	---	8.50E-01	---	---	8.50E-01
	---	**Composition B surrogate**	**lb/lb NEW**	**5.00E-01[d]**	1.10E+00	---	---	1.10E+00
	---	**Detonating Train**	**lb/lb NEW**	---	9.10E-01	---	---	9.10E-01
	F841	**Fuse, Tail Bomb FMU-54 A/B**	**lb/lb NEW**	---	9.40E-01	---	---	9.40E-01
	F762	**Fuse, Tail Bomb FMU-139 A/B**	**lb/lb NEW**	---	1.40E+00	---	---	1.40E+00
	L231	**Signal, Illumination, Red Star AN-M43A2**	**lb/lb NEW**	---	1.10E+00	---	---	1.10E+00
	---	**Tritonal surrogate**	**lb/lb NEW**	---	6.40E-01	---	---	6.40E-01
	---	**Tritonal surrogate with calcium stearate**	**lb/lb NEW**	---	1.30E+00	---	---	1.30E+00
	---	**TNT (Sandia)**	**lb/lb NEW**	---	1.30E+00	---	---	1.30E+00
	---	**TNT (ACC1)**	**lb/lb NEW**	---	1.50E+00	---	---	1.50E+00
	---	**TNT (ACC2)**	**lb/lb NEW**	---	1.40E+00	---	---	1.40E+00

SOURCE (unless otherwise stated): United States EPA. Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources. Fifth edition. Chapter 15.

a) CO_2e calculated by summing the product of the default emission factors for CO_2, N_2O, and CH_4 and their respective Global Warming Potentials (GWP). The GWP for CO_2, N_2O, and CH_4 are 1, 298, and 25 respectively.

b) There are variations in the NEW depending on the charge configuration. Refer to Table 15.4.1-1 of AP-42 for specific data.

c) SOURCE: Mitchell, William J. and Jack C. Suggs, “Emission Factors for the Disposal of Energetic Materials by Open Burning and Open Detonation (OB/OD),” U.S. Environmental Protection Agency, August 1998.

d) SOURCE: Wilcox, J. L., et al., "Characterization of Emissions Produced by the Open Burning/Open Detonation of Complex Munitions," Physical Test Division, West Desert Test Center, September 1996.

“---” – No data is available.

“00.00E+00” - Compound was not detected or detected at only the background level.

Table 16-3. HAP Emission Factors for Open Burn/Open Detonation

Munition Type	DODIC	Item	Units:	Net Explosive Material - NEW (lb/item)	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)	Allyl Chloride (107-05-1)	Aniline (62-53-3)	Anthracene (120-12-7)	Antimony (7440-36-0)	Arsenic (7440-38-2)	Benzene (71-43-2)	Benzo[a]anthracene (56-55-3)	Benzo[b]fluoranthene (205-99-2)	Benzo[k]fluoranthene (207-08-9)
Projectiles, Canisters, and Charges	D505	155-mm Illumination Round (M485A2)	lb/item	6.12E+00	---	---	---	2.60E-05	7.70E-06	2.90E-05	2.10E-05	---	---	---	2.10E-05	---	1.10E-04	---	---	---
	D533	155-mm Propelling Charge, Zone 7 (M119A2)	lb/item	2.25E+01	5.20E-08	1.30E-06	4.30E-05	1.30E-04	---	---	---	---	---	3.00E-07	---	---	7.40E-04	6.70E-08	1.50E-07	5.20E-08
	D540	**155-mm Propelling Charges (M3/M3A1)**	**lb/lb NEW**	(a)	**1.90E-04**	**2.00E-06**	**4.60E-03**	**1.10E-04**	**---**	**---**	**1.30E-04**	**---**	**---**	**2.00E-07**	**4.70E-05**	**1.20E-06**	**2.20E-04**	**1.30E-07**	**2.90E-07**	**2.50E-07**
	D541	155-mm Propelling Charge, Zone 7 (M4A2)	lb/item	1.33E+01	3.40E-07	7.80E-07	1.30E-05	1.70E-04	---	---	---	---	---	1.70E-07	---	---	1.90E-04	1.50E-07	1.60E-07	---
Grenades	G815	Red Phosphorus Screening Smoke Launcher Grenade (UK) (L8A3)	lb/item	8.32E-01	1.30E-06	2.40E-05	---	3.50E-04	4.80E-06	3.00E-05	5.40E-06	---	---	1.70E-06	9.40E-06	7.60E-06	8.70E-04	5.40E-06	6.80E-06	2.50E-06
	G878	Practice Hand Grenade Fuse (M228)	lb/item	4.50E-03	---	---	---	---	---	3.00E-08	---	---	---	---	---	---	4.60E-08	---	---	---
	G881	Fragmentation Hand Grenade (M67)	lb/item	4.10E-01	1.20E-08	7.90E-08	---	3.40E-05	---	---	1.30E-06	---	---	1.50E-08	---	5.80E-06	4.10E-06	3.20E-09	---	---
	G900	Thermite (TH3) Incendiary Hand Grenade (AN-M14)	lb/item	1.55E+00	4.20E-09	3.20E-08	2.10E-06	1.60E-07	2.50E-06	8.30E-07	---	---	---	2.40E-09	---	---	2.00E-06	2.40E-09	6.20E-09	3.90E-09
	G911	Offensive Hand Grenade (MK3A2)	lb/item	4.94E-01	8.70E-08	1.10E-06	5.80E-05	2.10E-05	---	4.70E-06	3.90E-06	---	---	1.50E-07	---	---	3.70E-05	1.10E-07	8.00E-08	6.60E-08
	G930	Hexachloroethane (HC) Smoke Hand Grenade (AN-M8)	lb/item	1.10E+00	---	---	---	1.20E-05	1.00E-06	6.80E-06	3.20E-06	2.70E-06	2.90E-06	---	5.40E-07	---	1.30E-05	---	---	---
	G940	Green Smoke Hand Grenade (M18)	lb/item	7.20E-01	---	---	3.40E-04	6.90E-06	1.10E-05	8.40E-05	5.10E-07	---	---	---	---	---	3.30E-04	---	---	---
	G945	Yellow Smoke Hand Grenade (M18)	lb/item	7.20E-01	---	---	9.20E-06	2.30E-07	---	2.60E-06	1.10E-07	---	---	---	---	---	7.10E-06	---	---	---
	G950	Red Smoke Hand Grenade (M18)	lb/item	7.20E-01	---	---	4.60E-05	2.90E-06	---	2.60E-05	9.70E-07	---	---	---	---	---	1.70E-05	---	---	---
	G955	Violet Smoke Hand Grenade (M18)	lb/item	7.20E-01	---	---	8.00E-05	2.80E-05	---	3.10E-06	3.60E-05	---	---	---	---	---	8.10E-05	---	---	---
	G963	CS Riot Control Agent Hand Grenade (M7A3)	lb/item	7.50E-01	---	---	---	3.30E-04	3.30E-06	1.00E-03	1.10E-04	---	---	---	---	---	2.30E-04	---	---	---
	G978	Simulant Screening Smoke Launcher Grenade (M82)	lb/item	1.68E+00	---	---	8.50E-05	2.20E-03	---	3.90E-05	---	---	---	---	1.80E-07	---	4.70E-05	---	---	---
	G982	Terephthalic Acid (TA) Smoke Practice Hand Grenade (M83)	lb/item	7.02E-01	2.00E-07	4.40E-07	2.00E-05	4.60E-06	1.80E-05	4.20E-04	---	---	---	8.10E-08	2.90E-05	1.20E-08	5.50E-03	---	1.80E-07	---
	GG09	Non-Lethal Stun Hand Grenade (M84)	lb/item	7.65E-03	---	---	---	---	---	---	---	---	---	---	---	---	1.20E-07	---	---	---
Rockets, Rocket Motors, and Igniters	H163	2.75-inch Rocket with M151 High Explosive Warhead	lb/item	2.32E+00	9.80E-07	7.10E-06	6.00E-04	3.50E-04	---	1.10E-04	2.70E-05	---	---	1.20E-06	1.00E-05	4.40E-06	2.50E-04	5.10E-07	---	5.20E-08
	H459	2.75-inch Fletchette, MK40 Mod 3 Motor	lb/item	6.02E+00	4.80E-07	3.00E-05	4.80E-04	2.20E-04	---	---	4.80E-05	---	---	1.20E-06	---	---	1.70E-03	1.70E-06	2.00E-06	1.50E-06
	H557	66-mm High Explosive Antitank Rocket (M72A3) (Propelling Rocket)	lb/item	1.34E-01	1.60E-10	2.00E-09	2.60E-06	1.50E-06	---	---	6.80E-07	---	---	5.00E-10	6.60E-06	---	2.00E-06	5.00E-10	4.70E-10	2.10E-09
		66-mm High Explosive Antitank Rocket (M72A3) (Warhead)	lb/item	6.84E-01	2.80E-08	7.70E-07	---	7.70E-05	---	---	5.40E-06	---	---	4.70E-08	---	---	1.50E-05	1.70E-08	---	6.00E-09
		66-mm High Explosive Antitank Rocket (M72A3) (Total)	lb/item	8.18E-01	2.80E-08	7.70E-07	2.60E-06	7.80E-05	---	---	6.10E-06	---	---	4.80E-08	6.60E-06	---	1.70E-05	1.80E-08	4.70E-10	8.20E-09
	H708	35-mm Subcaliber Practice Rocket (M73) (Propelling Rocket)	lb/item	2.64E-02	---	---	6.00E-07	---	---	---	1.60E-06	---	---	---	2.10E-06	---	6.80E-07	6.00E-10	---	---
		35-mm Subcaliber Practice Rocket (M73) (Warhead)	lb/item	3.20E-03	---	---	---	---	---	---	---	---	---	---	2.70E-05	---	4.50E-08	---	---	---
		35-mm Subcaliber Practice Rocket (M73) (Total)	lb/item	2.96E-02	---	---	6.00E-07	---	---	---	1.60E-06	---	---	---	3.00E-05	---	7.20E-07	6.00E-10	---	---
	H974	2.75-inch Practice Warhead, MK66 Mod 3 Motor (M267)	lb/item	7.17E+00	3.80E-07	1.30E-05	2.00E-04	8.70E-05	---	---	2.60E-05	---	---	1.00E-06	---	---	3.80E-04	7.60E-07	6.20E-07	5.40E-07

Table 16-3. HAP Emission Factors for Open Burn/Open Detonation (cont.)

Munition Type	DODIC	Item	Units:	Net Explosive Material - NEW (lb/item)	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)	Allyl Chloride (107-05-1)	Aniline (62-53-3)	Anthracene (120-12-7)	Antimony (7440-36-0)	Arsenic (7440-38-2)	Benzene (71-43-2)	Benzo[a]anthracene (56-55-3)	Benzo[b]fluoranthene (205-99-2)	Benzo[k]fluoranthene (207-08-9)
Mines and Smoke Pots	K010	Field Incendiary Burster (M4)	lb/item	2.04E-02	4.30E-09	3.10E-08	1.50E-05	3.70E-06	---	2.00E-05	1.50E-06	---	---	9.40E-09	---	---	5.80E-06	5.20E-09	2.20E-09	---
	K042	Practice Canister Mine (Volcano) (M88)	lb/item	1.39E-02	---	---	1.40E-06	---	---	---	---	---	---	---	3.70E-06	---	2.10E-07	---	---	---
	K051	Anti-Tank Practice Mine Fuze (M604)	lb/item	3.81E-02	---	---	---	6.10E-08	---	---	3.60E-07	---	---	3.20E-09	9.00E-06	---	2.00E-07	5.60E-09	1.40E-08	5.20E-08
	K145	Antipersonnel Mine (M18A1)	lb/item	1.50E+00	6.30E-08	1.60E-06	5.40E-05	4.50E-05	2.60E-06	---	9.70E-06	---	---	2.00E-07	---	---	1.30E-04	5.10E-08	2.60E-08	2.60E-08
	K765	CS Riot Control Agent Capsule	lb/item	---	---	---	---	1.50E-06	---	4.40E-08	---	---	---	---	---	---	8.80E-08	---	---	---
	K866	30-Pound HC Smoke Pot (ABC-M5)	lb/item	3.10E+01	---	---	---	3.10E-04	---	---	---	---	---	---	1.30E-03	1.50E-04	4.90E-04	---	---	---
	K867	Floating Type HC Smoke Pot (M4A2)	lb/item	2.75E+01	---	---	2.30E-04	---	---	---	---	---	---	---	---	7.10E-06	3.90E-04	---	---	---
Signals and Simulators	L305	Green Star Parachute Signal Flare (M195)	lb/item	3.16E-01	---	---	---	1.30E-06	3.90E-07	1.10E-06	1.30E-06	---	---	---	1.20E-06	---	1.30E-05	---	---	---
	L306	Red Star Cluster Signal Flare (M158)	lb/item	2.80E-01	---	---	9.00E-07	1.60E-06	5.50E-07	2.90E-06	2.00E-06	---	---	---	---	---	2.30E-05	---	---	---
	L307	White Star Cluster Signal Flare (M159)	lb/item	3.20E-01	---	---	5.50E-07	9.80E-07	6.80E-07	3.40E-06	9.10E-07	---	---	---	---	---	1.70E-05	---	---	---
	L311	Red Star Parachute Signal Flare (126A1)	lb/item	2.96E-01	---	---	1.40E-06	1.10E-06	2.80E-06	4.20E-07	8.50E-07	---	---	---	4.70E-07	---	1.30E-05	---	---	---
	L312	White Star Parachute Signal Flare (M127A1)	lb/item	2.83E-01	---	---	---	1.70E-06	7.90E-07	1.20E-06	2.00E-06	---	---	---	1.60E-06	---	9.60E-06	---	---	---
	L314	Green Star Cluster Signal Flare (M125A1)	lb/item	1.67E+00	---	---	---	2.10E-06	8.00E-07	1.30E-06	4.30E-06	---	---	---	1.30E-06	---	1.70E-05	---	---	---
	L366	Air Burst Projectile Simulator (M74A1)	lb/item	8.99E-02	---	---	---	5.40E-07	---	---	7.60E-07	---	---	---	8.90E-05	---	3.90E-06	---	---	---
	L367	Anti-Tank Guided Missle and Rocket Launching Simulator (M22)	lb/item	3.12E-02	---	---	---	---	---	---	---	---	---	---	---	---	3.20E-06	---	---	---
	L410	Aircraft Countermeasure Flare (M206)	lb/item	2.84E-01	---	---	---	---	---	---	---	---	---	---	---	---	8.40E-06	---	---	---
	L495	Surface Trip Flare (M49A1)	lb/item	1.08E+00	---	---	5.60E-07	---	1.20E-06	6.50E-07	---	---	---	---	5.00E-07	---	4.00E-06	---	---	---
	L508	Red Railroad Warning Fusee (M72)	lb/item	---	---	5.00E-08	---	3.40E-06	5.70E-07	9.00E-06	9.30E-07	---	---	---	---	---	2.70E-05	---	---	---
	L592	TOW Blast Simulator	lb/item	5.65E-03	---	---	4.40E-07	---	---	1.90E-07	---	---	---	---	5.90E-08	---	1.10E-07	---	---	---
	L594	Ground Burst Simulator (M115A2)	lb/item	1.41E-01	---	---	---	2.60E-07	6.10E-07	2.70E-06	---	---	---	---	2.70E-05	2.60E-07	8.80E-06	---	---	---
	L595	Liquid Projectile Air Burst Simulator (M9)	lb/item	1.38E-01	---	---	1.80E-04	---	---	---	---	---	---	6.30E-08	---	---	2.70E-06	---	---	---
	L596	Flash Artillery Simulator (M110)	lb/item	1.88E-01	---	1.00E-06	---	---	---	1.80E-05	---	---	---	---	4.50E-05	---	2.10E-03	---	---	---
	L598	Flash Booby Trap Simulator (M117)	lb/item	7.70E-03	---	---	---	2.90E-08	3.90E-09	1.60E-07	2.50E-08	---	---	---	8.90E-04	1.80E-06	3.50E-07	---	---	---
	L599	Illuminating Booby Trap Simulator (M118)	lb/item	1.34E-02	---	---	1.80E-07	3.00E-08	1.90E-08	1.50E-07	1.10E-08	---	---	---	8.40E-06	1.20E-08	1.10E-06	---	---	---
	L600	Whistling Booby Trap Simulator (119)	lb/item	1.06E-01	---	---	2.70E-07	---	3.40E-08	2.70E-07	---	---	---	---	---	---	7.10E-06	---	---	---
	L601	Hand Grenade Simulator (M116A1)	lb/item	8.13E-02	---	---	---	---	3.80E-07	1.70E-06	3.40E-07	---	---	---	2.00E-05	2.70E-07	1.50E-06	---	---	---
	L602	Artillery Flash Simulator (M21)	lb/item	9.38E-02	---	---	---	3.60E-07	---	---	---	---	---	---	1.20E-04	---	1.30E-06	---	---	---
	L709	Target-Hit Simulator (M25)	lb/item	6.00E-02	---	---	6.50E-07	3.70E-04	4.60E-07	---	---	---	---	---	2.80E-07	---	2.40E-06	---	---	---
	L720	Target Kill Simulator (M26)	lb/item	1.35E+00	1.90E-06	3.20E-04	1.10E-05	1.50E-06	---	1.80E-05	3.20E-07	---	---	7.60E-06	---	---	3.80E-03	6.60E-06	2.70E-05	3.50E-05
Fuses and Primers	N278	Mechanical Time and Super Quick (MTSQ) Fuse (M564)	lb/item	6.32E-02	---	2.80E-08	1.30E-06	2.80E-06	---	---	4.00E-06	---	---	3.90E-09	5.00E-05	1.30E-07	9.70E-07	1.80E-09	1.10E-09	1.90E-09
	N285	Mechanical Time and Super Quick (MTSQ) Fuse (M577A1)	lb/item	9.39E-04	---	8.40E-09	3.00E-07	6.10E-08	---	---	5.60E-07	---	---	---	---	---	3.80E-07	---	---	---
	N286	Mechanical Time and Super Quick (MTSQ) Fuse (M582)	lb/item	5.27E-02	---	4.80E-08	3.70E-06	7.60E-06	---	---	5.20E-07	---	---	---	4.00E-06	---	1.00E-06	---	---	1.10E-08
	N335	Point Detonating Fuse (M557)	lb/item	5.22E-02	5.30E-10	2.70E-09	6.20E-07	1.60E-06	2.70E-08	---	1.30E-06	---	---	7.40E-10	7.10E-06	---	2.10E-07	---	7.40E-10	---
	N340	Point Detonating Fuse (M739A1)	lb/item	4.59E-02	---	1.60E-09	6.50E-07	4.10E-07	---	---	4.90E-07	---	---	---	2.20E-06	---	3.70E-07	---	---	---
	N464	Proximity Fuse (M732)	lb/item	1.37E-02	7.80E-09	6.60E-08	5.30E-07	---	---	---	1.10E-07	---	---	5.80E-09	1.30E-06	3.40E-08	2.40E-07	---	---	1.20E-08

Table 16-3. HAP Emission Factors for Open Burn/Open Detonation (cont.)

Munition Type	DODIC	Item	Units:	Net Explosive Material - NEW (lb/item)	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)	Allyl Chloride (107-05-1)	Aniline (62-53-3)	Anthracene (120-12-7)	Antimony (7440-36-0)	Arsenic (7440-38-2)	Benzene (71-43-2)	Benzo[a]anthracene (56-55-3)	Benzo[b]fluoranthene (205-99-2)	Benzo[k]fluoranthene (207-08-9)
Blasting Caps, Demolition Charges, and Detonators	M023	Demolition Block Charge (M112)	lb/item	1.25E+00	3.20E-08	3.50E-07	---	1.20E-04	---	---	9.40E-06	---	---	5.00E-08	2.90E-06	---	1.40E-05	---	---	---
	M030	1/4-Pound Demolition Block Charge	lb/item	2.50E-01	4.90E-09	3.80E-08	---	---	---	---	5.80E-07	---	---	7.00E-09	---	---	2.90E-07	2.70E-09	---	---
	M031	1/2-Pound Demolition Block Charge	lb/item	5.00E-01	---	---	---	---	---	---	---	---	---	---	3.20E-05	4.70E-06	3.70E-05	---	---	---
	M032	1-Pound Demolition Block Charge	lb/item	1.00E+00	9.20E-09	1.00E-07	---	---	---	---	3.10E-07	---	---	1.20E-08	---	---	1.70E-07	---	---	---
	M130	Electric Blasting Cap (M6)	lb/item	2.92E-03	---	---	1.50E-07	2.30E-06	---	---	2.70E-08	---	---	---	---	---	6.90E-08	---	---	---
	M131	Non-Electric Blasting Cap (M7)	lb/item	2.76E-03	---	9.30E-10	---	2.70E-06	---	---	4.90E-07	---	---	---	1.40E-08	---	7.30E-08	---	---	---
	M174	.50 Calibur Blank Cartridge (Electrically Initiated)	lb/item	2.33E-02	1.40E-09	1.40E-08	4.10E-06	2.70E-06	---	9.30E-06	2.70E-07	---	---	6.50E-10	4.70E-07	---	1.00E-05	2.30E-10	2.60E-09	1.10E-09
	M241	High Explosive Universal Destructor (M10)	lb/item	2.86E-01	---	---	---	2.50E-06	---	---	5.00E-07	---	---	---	2.60E-03	---	2.70E-05	---	---	---
	M327	Firing Device Coupling Base	lb/item	5.71E-05	---	---	2.70E-09	---	---	---	---	---	---	---	3.10E-06	7.80E-10	---	---	---	---
	M420	15-Pound Demolition Shaped Charge (M2A4)	lb/item	1.01E+01	---	9.20E-07	3.90E-04	1.40E-05	---	7.70E-05	1.90E-05	---	---	6.00E-07	1.30E-04	7.60E-04	7.90E-05	2.10E-07	---	---
	M448	8-Second Delay Percussion Detonator (M2A1)	lb/item	6.20E-03	---	1.30E-09	2.60E-07	3.20E-06	---	3.10E-08	7.80E-08	---	---	1.70E-10	5.70E-07	3.40E-09	3.70E-07	---	8.50E-11	---
	M456	PETN Type 1 Detonating Cord	lb/item	7.00E-03	---	3.30E-06	---	6.80E-07	---	---	---	---	---	4.10E-07	7.60E-05	1.10E-05	3.30E-04	---	4.70E-07	1.10E-06
	M500	Cartridge Actuated Cutter (M21)	lb/item	4.00E-03	---	4.10E-10	1.00E-08	1.40E-07	---	---	2.00E-08	---	---	---	---	---	1.80E-06	---	---	---
	M591	Military Dynamite Demolition Block Charge (M1)	lb/item	3.70E-01	6.30E-09	2.90E-08	6.90E-06	1.30E-05	---	---	---	---	---	7.30E-09	---	---	6.10E-07	2.20E-09	---	---
	M626	Pressure Type Demolition Firing Device (M1)	lb/item	5.71E-05	---	---	---	3.40E-08	---	---	4.80E-09	---	---	---	3.30E-06	3.10E-09	3.60E-09	---	---	---
	M630	Pull Type Demolition Firing Device (M1)	lb/item	5.71E-05	---	---	1.50E-08	---	---	---	---	---	---	---	3.30E-06	4.40E-10	4.70E-10	---	---	---
	M670	Time Blasting Fuse (M700)	lb/item	2.70E-03	---	4.10E-07	2.30E-03	1.90E-04	---	---	6.70E-05	---	---	5.80E-08	---	---	3.80E-04	1.20E-07	9.40E-08	3.60E-08
	M766	Time Blasting Fuse Igniter (M60)	lb/item	5.71E-05	---	---	6.00E-11	---	---	---	1.30E-08	---	---	---	6.10E-07	---	1.80E-08	---	---	---
	M913	Linear Demolition Charge (M58A3)	lb/item	5.02E+00	3.80E-08	2.60E-07	4.50E-05	4.30E-05	---	7.40E-06	6.60E-05	---	---	5.80E-08	---	---	1.40E-05	8.70E-09	3.90E-09	---
	MD73	Impulse Cartridge (M796)	lb/item	7.83E-04	---	3.40E-11	5.40E-08	6.20E-08	---	---	9.30E-09	---	---	---	---	---	3.00E-08	6.70E-12	8.60E-12	6.70E-12
	ML03	Multipurpose Demolition Firing Device (M142)	lb/item	4.71E-05	---	1.00E-10	6.30E-09	8.20E-08	---	---	8.40E-09	---	---	---	5.60E-07	5.20E-10	8.20E-09	---	---	---
	ML05	Powder Actuated Cutter (MK24)	lb/item	1.26E+00	4.30E-08	1.10E-06	3.20E-05	1.20E-04	8.70E-06	---	2.40E-04	---	---	1.30E-07	7.10E-06	1.60E-06	1.10E-04	5.60E-08	2.60E-08	2.90E-08
	ML09	**Linear Shaped Demolition Charge, 20 gr/ft**	**lb/lb NEW**	**2.86E-03**	**6.90E-07**	**2.70E-06**	**---**	**1.70E-04**	**---**	**---**	**1.80E-05**	**---**	**---**	**2.70E-07**	**9.20E-02**	**3.60E-04**	**4.40E-04**	**---**	**---**	**---**
	ML15	**Linear Shaped Demolition Charge, 225 gr/ft**	**lb/lb NEW**	**3.21E-02**	**4.30E-07**	**2.90E-06**	**---**	**7.40E-05**	**---**	**---**	**3.30E-06**	**---**	**---**	**4.00E-07**	**3.00E-01**	**8.30E-04**	**5.90E-04**	**---**	**---**	**---**
	ML47	Non-Electric Blasting Cap with 30-foot Shock Tube (M11)	lb/item	2.73E-03	---	4.30E-09	1.60E-07	1.30E-06	---	---	3.20E-07	---	---	---	---	---	2.10E-06	---	---	1.80E-09
	MM50	Clipped Shaped Demolition Charge (M221)	lb/item	6.62E-02	---	6.20E-08	2.20E-06	5.80E-05	---	---	9.00E-07	---	---	1.10E-08	---	---	5.20E-06	5.80E-09	3.30E-09	3.80E-09
	MN02	Non-Electric Blasting Cap with 500-foot Shock Tube (M12)	lb/item	6.18E-03	2.50E-09	2.80E-08	---	6.20E-06	---	7.60E-08	1.20E-06	---	---	---	3.70E-08	---	1.10E-05	4.90E-09	4.80E-09	3.40E-09
	MN03	Non-Electric Blasting Cap with 1000-foot Shock Tube (M13)	lb/item	1.10E-02	2.70E-09	3.30E-08	---	1.30E-05	---	---	2.50E-06	---	---	---	2.10E-07	---	2.50E-05	4.70E-09	4.70E-09	3.30E-09
	MN06	Non-Electric Time Delay Blasting Cap (M14)	lb/item	2.59E-02	1.10E-08	1.60E-07	7.30E-05	8.50E-05	---	---	1.40E-06	---	---	---	---	---	7.90E-05	1.70E-08	3.20E-08	0.00E+00
	MN07	Non-Electric Time Delay Blasting Cap (M15)	lb/item	4.06E-03	---	1.00E-09	1.00E-07	1.30E-06	---	---	2.20E-07	---	---	2.80E-10	---	---	1.50E-06	3.80E-10	3.50E-10	2.80E-10
	MN08	Time Blasting Fuse Igniter (M81)	lb/item	4.86E-05	---	---	8.60E-09	4.20E-08	---	---	1.40E-08	---	---	---	6.50E-07	1.10E-09	8.80E-09	---	---	---
	MN60	Electric Match Igniter (M79)	lb/item	1.26E-02	---	1.60E-08	5.40E-07	1.40E-07	---	---	5.40E-08	---	---	1.80E-09	---	2.60E-09	1.20E-06	1.30E-09	1.50E-09	2.00E-09
	MN68	Booster Demolition Charge (M151)	lb/item	9.70E-03	---	---	1.90E-06	3.10E-06	1.80E-07	2.30E-07	8.40E-07	---	---	---	---	---	5.90E-06	---	---	---

Table 16-3. HAP Emission Factors for Open Burn/Open Detonation (cont.)

Munition Type	DODIC	Item	Units:	Net Explosive Material - NEW (lb/item)	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)	Allyl Chloride (107-05-1)	Aniline (62-53-3)	Anthracene (120-12-7)	Antimony (7440-36-0)	Arsenic (7440-38-2)	Benzene (71-43-2)	Benzo[a]anthracene (56-55-3)	Benzo[b]fluoranthene (205-99-2)	Benzo[k]fluoranthene (207-08-9)
Energetic Materials (c)	---	Amatol	lb/lb NEW	5.00E-01 (d)	---	---	---	---	---	---	---	0.00E+00	---	---	0.00E+00	---	2.30E-05	---	---	---
	J473	Cartridge, Impulse, ARD446-1	lb/lb NEW	---	---	---	---	---	---	---	---	0.00E+00	---	---	1.80E-04	---	6.70E-05	---	---	---
	MG11	Cartridge, Impulse, BBU-36/B	lb/lb NEW	---	---	---	---	---	---	---	---	9.30E-06	---	---	0.00E+00	---	2.10E-05	---	---	---
	M943	Cartridge, Impulse, MK 107	lb/lb NEW	---	---	---	---	---	---	---	---	5.10E-06	---	---	0.00E+00	---	6.40E-05	---	---	---
	---	Composition B surrogate	lb/lb NEW	5.00E-01 (d)	---	---	---	---	---	---	---	0.00E+00	---	---	0.00E+00	---	2.60E-06	---	---	---
	---	Detonating Train	lb/lb NEW	---	---	---	---	---	---	---	---	0.00E+00	---	---	0.00E+00	---	2.50E-05	---	---	---
	F841	Fuse, Tail Bomb FMU-54 A/B	lb/lb NEW	---	---	---	---	---	---	---	---	1.50E-05	---	---	0.00E+00	---	1.10E-04	---	---	---
	F762	Fuse, Tail Bomb FMU-139 A/B	lb/lb NEW	---	---	---	---	---	---	---	---	3.00E-05	---	---	2.20E-04	---	1.20E-04	---	---	---
	L231	Signal, Illumination, Red Star AN-M43A2	lb/lb NEW	---	---	---	---	---	---	---	---	1.80E-05	---	---	0.00E+00	---	3.40E-05	---	---	---
	---	Tritonal surrogate	lb/lb NEW	---	---	---	---	---	---	---	---	0.00E+00	---	---	0.00E+00	---	5.70E-06	---	---	---
	---	Tritonal surrogate with calcium stearate	lb/lb NEW	---	---	---	---	---	---	---	---	0.00E+00	---	---	0.00E+00	---	3.10E-06	---	---	---
	---	TNT (Sandia)	lb/lb NEW	---	---	---	---	---	---	---	---	---	---	---	6.70E-07	---	3.00E-06	---	---	---
	---	TNT (ACC1)	lb/lb NEW	---	---	---	---	---	---	---	---	0.00E+00	---	---	0.00E+00	---	4.10E-06	---	---	---
	---	TNT (ACC2)	lb/lb NEW	---	---	---	---	---	---	---	---	0.00E+00	---	---	0.00E+00	---	4.10E-06	---	---	---

Table 16-3. HAP Emission Factors for Open Burn/Open Detonation (cont.)

Munition Type	DODIC	Item	Units:	Net Explosive Material - NEW (lb/item)	Benzo[g,h,i]perylene (191-24-2)	Benzo[a]pyrene (50-32-8)	Benzo[e]pyrene (192-97-2)	Benzyl Chloride (100-44-7)	Beryllium (7440-41-7)	Biphenyl (92-52-4)	Bromomethane (74-83-9)	1,3-Butadiene (106-99-0)	Cadmium (7440-43-9)	Carbon Disulfide (75-15-0)	Carbon Tetrachloride (56-23-5)	Carbonyl Sulfide (463-58-1)	Chlorine (7782-50-5)	Chlorobenzene (108-90-7)	Chloroethane (75-00-3)	Chloroform (67-66-3)
Projectiles, Canisters, and Charges	D505	155-mm Illumination Round (M485A2)	lb/item	6.12E+00	---	---	---	---	2.10E-07	---	---	---	7.40E-05	6.40E-05	1.70E-07	3.80E-06	2.00E-06	---	---	---
	D533	155-mm Propelling Charge, Zone 7 (M119A2)	lb/item	2.25E+01	1.10E-06	1.40E-07	1.90E-07	---	---	---	---	---	---	---	---	---	---	---	---	---
	D540	**155-mm Propelling Charges (M3/M3A1)**	**lb/lb NEW**	[(a)]	**1.80E-06**	**4.70E-07**	**4.40E-07**	**---**	**---**	**---**	**---**	**---**	**1.40E-05**	**---**	**---**	**7.50E-05**	**---**	**---**	**---**	**---**
	D541	155-mm Propelling Charge, Zone 7 (M4A2)	lb/item	1.33E+01	1.30E-06	---	2.90E-07	---	---	---	---	---	---	---	---	---	---	---	---	---
Grenades	G815	Red Phosphorus Screening Smoke Launcher Grenade (UK) (L8A3)	lb/item	8.32E-01	3.00E-06	---	---	---	---	8.20E-06	---	1.40E-04	---	2.80E-05	---	---	---	---	3.40E-06	---
	G878	Practice Hand Grenade Fuse (M228)	lb/item	4.50E-03	---	---	---	---	---	---	---	---	---	2.70E-08	---	---	6.10E-07	---	---	---
	G881	Fragmentation Hand Grenade (M67)	lb/item	4.10E-01	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	G900	Thermite (TH3) Incendiary Hand Grenade (AN-M14)	lb/item	1.55E+00	3.60E-09	2.70E-09	---	---	---	---	---	---	---	1.60E-07	---	---	---	---	2.60E-07	---
	G911	Offensive Hand Grenade (MK3A2)	lb/item	4.94E-01	8.80E-08	8.10E-08	1.20E-07	---	---	---	---	---	1.80E-05	1.70E-06	---	---	---	---	---	---
	G930	Hexachloroethane (HC) Smoke Hand Grenade (AN-M8)	lb/item	1.10E+00	---	---	---	3.20E-06	---	---	---	1.60E-06	5.80E-06	---	1.50E-03	---	9.00E-03	2.70E-06	---	3.70E-05
	G940	Green Smoke Hand Grenade (M18)	lb/item	7.20E-01	---	---	---	---	1.10E-08	---	---	1.80E-05	---	4.10E-05	8.60E-08	---	1.60E-06	6.70E-06	1.90E-07	9.70E-06
	G945	Yellow Smoke Hand Grenade (M18)	lb/item	7.20E-01	---	---	---	---	1.70E-08	---	---	1.00E-06	7.30E-09	4.90E-04	2.60E-06	3.70E-06	5.10E-07	4.00E-06	4.60E-07	2.70E-05
	G950	Red Smoke Hand Grenade (M18)	lb/item	7.20E-01	---	---	---	---	4.10E-08	---	---	7.80E-08	---	3.60E-04	5.30E-07	3.40E-06	2.50E-07	1.30E-06	1.50E-07	1.30E-05
	G955	Violet Smoke Hand Grenade (M18)	lb/item	7.20E-01	---	---	---	---	9.80E-10	---	---	1.20E-05	---	1.70E-04	1.10E-06	1.50E-05	1.60E-06	2.40E-06	2.00E-07	4.20E-06
	G963	CS Riot Control Agent Hand Grenade (M7A3)	lb/item	7.50E-01	---	---	---	---	---	---	---	1.10E-05	---	---	---	---	4.70E-05	3.60E-04	---	---
	G978	Simulant Screening Smoke Launcher Grenade (M82)	lb/item	1.68E+00	---	---	---	---	---	---	---	3.80E-05	3.30E-07	---	---	---	---	---	---	---
	G982	Terephthalic Acid (TA) Smoke Practice Hand Grenade (M83)	lb/item	7.02E-01	---	---	---	---	---	8.80E-06	---	8.00E-05	---	---	---	---	---	---	---	---
	GG09	Non-Lethal Stun Hand Grenade (M84)	lb/item	7.65E-03	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Rockets, Rocket Motors, and Igniters	H163	2.75-inch Rocket with M151 High Explosive Warhead	lb/item	2.32E+00	7.90E-08	---	2.10E-07	---	---	---	---	8.50E-05	1.10E-03	2.00E-05	---	---	---	---	---	---
	H459	2.75-inch Fletchette, MK40 Mod 3 Motor	lb/item	6.02E+00	1.30E-05	2.80E-06	3.10E-06	---	---	---	---	---	1.20E-03	---	---	---	---	---	---	---
	H557	66-mm High Explosive Antitank Rocket (M72A3) (Propelling Rocket)	lb/item	1.34E-01	1.40E-09	2.00E-09	---	---	---	---	---	---	1.10E-06	4.10E-08	---	---	---	---	---	---
		66-mm High Explosive Antitank Rocket (M72A3) (Warhead)	lb/item	6.84E-01	---	2.40E-09	2.60E-09	---	---	---	---	---	---	---	---	---	---	---	---	---
		66-mm High Explosive Antitank Rocket (M72A3) (Total)	lb/item	8.18E-01	1.40E-09	4.50E-09	2.60E-09	---	---	---	---	---	1.10E-06	4.10E-08	---	---	---	---	---	---
	H708	35-mm Subcaliber Practice Rocket (M73) (Propelling Rocket)	lb/item	2.64E-02	---	---	---	---	---	---	---	---	7.40E-05	4.30E-08	---	---	---	---	---	---
		35-mm Subcaliber Practice Rocket (M73) (Warhead)	lb/item	3.20E-03	---	---	---	---	---	---	---	---	8.40E-09	---	---	---	---	---	---	---
		35-mm Subcaliber Practice Rocket (M73) (Total)	lb/item	2.96E-02	---	---	---	---	---	---	---	---	7.40E-05	4.30E-08	---	---	---	---	---	---
	H974	2.75-inch Practice Warhead, MK66 Mod 3 Motor (M267)	lb/item	7.17E+00	2.50E-06	1.20E-06	8.00E-07	---	---	---	---	---	6.60E-04	---	---	---	---	---	---	---

Table 16-3. HAP Emission Factors for Open Burn/Open Detonation (cont.)

Munition Type	DODIC	Item	Units:	Net Explosive Material - NEW (lb/item)	Benzo[g,h,i]perylene (191-24-2)	Benzo[a]pyrene (50-32-8)	Benzo[e]pyrene (192-97-2)	Benzyl Chloride (100-44-7)	Beryllium (7440-41-7)	Biphenyl (92-52-4)	Bromomethane (74-83-9)	1,3-Butadiene (106-99-0)	Cadmium (7440-43-9)	Carbon Disulfide (75-15-0)	Carbon Tetrachloride (56-23-5)	Carbonyl Sulfide (463-58-1)	Chlorine (7782-50-5)	Chlorobenzene (108-90-7)	Chloroethane (75-00-3)	Chloroform (67-66-3)
Mines and Smoke Pots	K010	Field Incendiary Burster (M4)	lb/item	2.04E-02	3.50E-09	---	2.40E-09	---	---	---	---	---	---	---	---	---	---	---	---	---
	K042	Practice Canister Mine (Volcano) (M88)	lb/item	1.39E-02	---	---	---	---	---	---	---	1.40E-07	1.40E-08	1.50E-07	---	---	---	---	---	---
	K051	Anti-Tank Practice Mine Fuze (M604)	lb/item	3.81E-02	1.10E-08	5.60E-09	6.00E-09	---	---	---	---	---	5.80E-05	---	---	---	---	---	---	---
	K145	Antipersonnel Mine (M18A1)	lb/item	1.50E+00	---	1.60E-08	2.50E-08	3.30E-06	---	---	---	---	1.10E-04	---	---	---	---	3.30E-07	---	---
	K765	CS Riot Control Agent Capsule	lb/item	---	---	---	---	---	---	---	---	---	---	---	---	---	---	9.50E-08	1.40E-08	---
	K866	30-Pound HC Smoke Pot (ABC-M5)	lb/item	3.10E+01	---	---	---	---	---	---	---	---	1.80E-03	4.60E-03	2.70E-02	---	---	---	---	1.40E-03
	K867	Floating Type HC Smoke Pot (M4A2)	lb/item	2.75E+01	---	---	---	---	---	---	---	1.00E-04	5.40E-03	9.70E-04	1.10E-02	---	---	---	---	5.40E-04
Signals and Simulators	L305	Green Star Parachute Signal Flare (M195)	lb/item	3.16E-01	---	---	---	---	1.60E-08	---	---	3.60E-06	1.20E-06	1.00E-05	2.90E-07	2.60E-07	3.10E-06	---	---	---
	L306	Red Star Cluster Signal Flare (M158)	lb/item	2.80E-01	---	---	---	---	---	---	---	2.80E-06	6.20E-07	1.50E-05	2.50E-07	---	1.80E-05	---	---	---
	L307	White Star Cluster Signal Flare (M159)	lb/item	3.20E-01	---	---	---	---	---	---	---	5.00E-06	1.50E-07	1.20E-05	1.10E-07	---	3.50E-05	---	---	---
	L311	Red Star Parachute Signal Flare (126A1)	lb/item	2.96E-01	---	---	---	---	---	---	---	7.20E-06	6.10E-07	1.40E-05	---	---	---	---	---	---
	L312	White Star Parachute Signal Flare (M127A1)	lb/item	2.83E-01	---	---	---	---	2.50E-08	---	---	1.80E-06	1.30E-07	2.00E-05	2.00E-07	6.90E-07	1.00E-04	---	---	---
	L314	Green Star Cluster Signal Flare (M125A1)	lb/item	1.67E+00	---	---	---	---	1.70E-08	---	---	3.70E-06	8.40E-08	1.70E-05	2.50E-07	7.60E-08	1.20E-05	---	---	---
	L366	Air Burst Projectile Simulator (M74A1)	lb/item	8.99E-02	---	---	---	---	---	---	---	4.00E-07	2.60E-07	---	3.30E-10	---	---	---	---	---
	L367	Anti-Tank Guided Missle and Rocket Launching Simulator (M22)	lb/item	3.12E-02	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	L410	Aircraft Countermeasure Flare (M206)	lb/item	2.84E-01	---	---	---	---	---	---	---	4.30E-07	8.20E-08	1.50E-07	---	---	---	---	---	---
	L495	Surface Trip Flare (M49A1)	lb/item	1.08E+00	---	---	---	---	---	---	---	---	2.40E-07	6.80E-07	2.80E-07	---	2.40E-05	---	---	---
	L508	Red Railroad Warning Fusee (M72)	lb/item	---	---	---	---	---	---	---	---	---	---	1.20E-06	---	---	---	---	---	---
	L592	TOW Blast Simulator	lb/item	5.65E-03	---	---	---	---	---	2.30E-07	---	2.60E-08	7.10E-09	2.10E-07	---	---	---	---	---	---
	L594	Ground Burst Simulator (M115A2)	lb/item	1.41E-01	---	---	---	---	4.80E-08	---	---	9.70E-07	3.80E-07	5.10E-05	9.70E-08	3.90E-07	5.50E-05	---	---	---
	L595	Liquid Projectile Air Burst Simulator (M9)	lb/item	1.38E-01	---	---	---	---	---	---	---	---	---	8.80E-06	---	---	---	---	---	---
	L596	Flash Artillery Simulator (M110)	lb/item	1.88E-01	---	---	---	---	---	---	---	4.40E-04	3.00E-07	1.80E-05	---	5.10E-06	4.70E-05	---	---	---
	L598	Flash Booby Trap Simulator (M117)	lb/item	7.70E-03	---	---	---	---	---	---	---	7.80E-08	6.90E-09	2.90E-06	6.60E-08	1.20E-08	4.30E-04	---	---	---
	L599	Illuminating Booby Trap Simulator (M118)	lb/item	1.34E-02	---	---	---	---	---	---	---	2.40E-07	1.50E-08	7.60E-07	9.80E-09	1.40E-08	1.10E-07	---	---	---
	L600	Whistling Booby Trap Simulator (119)	lb/item	1.06E-01	---	---	---	---	---	---	---	1.10E-06	---	1.70E-06	3.60E-08	---	8.80E-06	---	---	---
	L601	Hand Grenade Simulator (M116A1)	lb/item	8.13E-02	---	---	---	---	3.60E-08	---	---	1.30E-07	2.30E-07	5.40E-05	3.10E-08	2.70E-07	3.90E-06	---	---	---
	L602	Artillery Flash Simulator (M21)	lb/item	9.38E-02	---	---	---	---	---	---	---	1.20E-07	1.00E-05	---	---	---	9.40E-04	---	---	---
	L709	Target-Hit Simulator (M25)	lb/item	6.00E-02	---	---	---	---	3.60E-09	---	---	---	7.50E-08	1.70E-06	---	---	---	---	---	---
	L720	Target Kill Simulator (M26)	lb/item	1.35E+00	8.40E-06	8.90E-06	5.60E-06	---	---	---	---	4.90E-05	---	2.40E-06	---	---	---	8.00E-07	---	---
Fuses and Primers	N278	Mechanical Time and Super Quick (MTSQ) Fuse (M564)	lb/item	6.32E-02	---	---	1.40E-09	---	---	---	---	---	8.20E-07	1.10E-07	---	---	---	---	---	---
	N285	Mechanical Time and Super Quick (MTSQ) Fuse (M577A1)	lb/item	9.39E-04	---	---	9.80E-10	---	---	---	---	---	---	---	---	---	---	---	---	---
	N286	Mechanical Time and Super Quick (MTSQ) Fuse (M582)	lb/item	5.27E-02	---	---	---	---	---	---	---	---	1.50E-07	---	---	---	---	---	---	---
	N335	Point Detonating Fuse (M557)	lb/item	5.22E-02	---	---	---	---	---	---	---	---	4.90E-05	4.30E-08	---	---	---	---	---	---
	N340	Point Detonating Fuse (M739A1)	lb/item	4.59E-02	---	---	---	---	---	---	---	---	4.90E-05	---	---	---	---	---	---	---
	N464	Proximity Fuse (M732)	lb/item	1.37E-02	---	---	3.30E-09	---	---	---	---	---	2.00E-04	---	---	---	---	---	---	---

Table 16-3. HAP Emission Factors for Open Burn/Open Detonation (cont.)

Munition Type	DODIC	Item	Units:	Net Explosive Material - NEW (lb/item)	Benzo[g,h,i]perylene (191-24-2)	Benzo[a]pyrene (50-32-8)	Benzo[e]pyrene (192-97-2)	Benzyl Chloride (100-44-7)	Beryllium (7440-41-7)	Biphenyl (92-52-4)	Bromomethane (74-83-9)	1,3-Butadiene (106-99-0)	Cadmium (7440-43-9)	Carbon Disulfide (75-15-0)	Carbon Tetrachloride (56-23-5)	Carbonyl Sulfide (463-58-1)	Chlorine (7782-50-5)	Chlorobenzene (108-90-7)	Chloroethane (75-00-3)	Chloroform (67-66-3)
Blasting Caps, Demolition Charges, and Detonators	M023	Demolition Block Charge (M112)	lb/item	1.25E+00	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	M030	1/4-Pound Demolition Block Charge	lb/item	2.50E-01	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	M031	1/2-Pound Demolition Block Charge	lb/item	5.00E-01	---	---	---	---	3.90E-07	---	---	6.00E-06	6.70E-06	---	7.50E-07	---	---	---	---	---
	M032	1-Pound Demolition Block Charge	lb/item	1.00E+00	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	M130	Electric Blasting Cap (M6)	lb/item	2.92E-03	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	M131	Non-Electric Blasting Cap (M7)	lb/item	2.76E-03	---	---	---	---	---	---	---	3.50E-07	---	---	---	---	---	---	---	---
	M174	.50 Calibur Blank Cartridge (Electrically Initiated)	lb/item	2.33E-02	8.00E-09	---	2.50E-09	---	---	---	---	---	1.10E-07	2.20E-06	---	---	---	---	---	---
	M241	High Explosive Universal Destructor (M10)	lb/item	2.86E-01	---	---	---	---	---	---	---	2.40E-06	1.70E-03	---	1.40E-06	---	2.70E-04	---	---	---
	M327	Firing Device Coupling Base	lb/item	5.71E-05	---	---	---	---	---	---	---	---	---	6.60E-09	---	---	---	---	---	---
	M420	15-Pound Demolition Shaped Charge (M2A4)	lb/item	1.01E+01	---	---	1.90E-07	---	---	---	---	---	3.30E-05	---	---	---	---	---	---	---
	M448	8-Second Delay Percussion Detonator (M2A1)	lb/item	6.20E-03	---	---	5.70E-11	---	---	---	---	---	4.30E-07	---	---	---	---	---	---	---
	M456	PETN Type 1 Detonating Cord	lb/item	7.00E-03	---	7.00E-09	---	---	9.90E-07	---	---	1.30E-04	1.60E-05	---	---	---	---	---	---	---
	M500	Cartridge Actuated Cutter (M21)	lb/item	4.00E-03	---	---	---	---	---	---	---	3.60E-08	5.30E-08	6.20E-08	---	---	---	---	---	---
	M591	Military Dynamite Demolition Block Charge (M1)	lb/item	3.70E-01	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	M626	Pressure Type Demolition Firing Device (M1)	lb/item	5.71E-05	---	---	---	---	---	---	---	---	3.60E-10	9.60E-09	---	---	---	---	---	---
	M630	Pull Type Demolition Firing Device (M1)	lb/item	5.71E-05	---	---	---	---	---	---	---	---	---	4.60E-09	---	---	---	---	---	---
	M670	Time Blasting Fuse (M700)	lb/item	2.70E-03	---	---	9.80E-08	---	---	---	---	---	---	2.10E-02	---	---	---	---	---	---
	M766	Time Blasting Fuse Igniter (M60)	lb/item	5.71E-05	---	---	---	---	---	---	---	---	---	2.50E-08	---	---	---	---	---	---
	M913	Linear Demolition Charge (M58A3)	lb/item	5.02E+00	---	2.40E-09	5.60E-09	---	---	---	6.60E-07	---	1.90E-04	---	---	---	---	---	---	---
	MD73	Impulse Cartridge (M796)	lb/item	7.83E-04	7.60E-12	---	---	---	---	---	---	---	2.30E-10	---	---	---	---	---	---	---
	ML03	Multipurpose Demolition Firing Device (M142)	lb/item	4.71E-05	---	---	---	---	---	---	---	---	1.00E-09	2.30E-08	---	---	---	---	---	---
	ML05	Powder Actuated Cutter (MK24)	lb/item	1.26E+00	9.30E-09	---	2.50E-08	---	---	---	---	---	3.30E-06	---	---	---	---	---	---	---
	ML09	**Linear Shaped Demolition Charge, 20 gr/ft**	**lb/lb NEW**	**2.86E-03**	**---**	**3.70E-07**	**---**	**---**	**6.90E-07**	**---**	**---**	**8.30E-05**	**8.60E-06**	**---**	**1.20E-06**	**---**	**---**	**---**	**---**	**---**
	ML15	**Linear Shaped Demolition Charge, 225 gr/ft**	**lb/lb NEW**	**3.21E-02**	**6.90E-07**	**---**	**---**	**---**	**3.50E-06**	**---**	**---**	**6.90E-05**	**1.90E-05**	**---**	**2.90E-07**	**---**	**---**	**---**	**---**	**---**
	ML47	Non-Electric Blasting Cap with 30-foot Shock Tube (M11)	lb/item	2.73E-03	2.60E-09	1.70E-09	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	MM50	Clipped Shaped Demolition Charge (M221)	lb/item	6.62E-02	1.40E-09	---	3.40E-09	---	---	---	---	---	1.70E-07	---	---	---	---	---	---	---
	MN02	Non-Electric Blasting Cap with 500-foot Shock Tube (M12)	lb/item	6.18E-03	1.40E-08	9.40E-09	6.50E-09	---	---	---	---	1.80E-06	---	---	---	---	---	---	---	---
	MN03	Non-Electric Blasting Cap with 1000-foot Shock Tube (M13)	lb/item	1.10E-02	1.90E-08	1.00E-08	7.20E-09	---	---	---	---	2.00E-06	---	---	---	---	---	---	---	---
	MN06	Non-Electric Time Delay Blasting Cap (M14)	lb/item	2.59E-02	7.50E-09	7.80E-09	1.90E-08	---	---	2.70E-06	---	---	---	1.50E-05	---	---	---	---	---	---
	MN07	Non-Electric Time Delay Blasting Cap (M15)	lb/item	4.06E-03	1.00E-09	0.00E+00	5.00E-10	---	---	---	---	---	1.90E-08	---	---	---	---	---	---	---
	MN08	Time Blasting Fuse Igniter (M81)	lb/item	4.86E-05	---	---	---	---	---	---	---	---	---	1.20E-08	---	---	---	---	---	---
	MN60	Electric Match Igniter (M79)	lb/item	1.26E-02	3.00E-09	2.20E-09	1.30E-09	---	---	---	---	---	---	4.70E-08	---	---	---	---	---	---
	MN68	Booster Demolition Charge (M151)	lb/item	9.70E-03	---	---	---	---	---	1.10E-07	---	1.10E-06	1.40E-07	1.00E-07	---	---	---	---	---	---

Table 16-3. HAP Emission Factors for Open Burn/Open Detonation (cont.)

Munition Type	DODIC	Item	Units:	Net Explosive Material - NEW (lb/item)	Benzo[g,h,i]perylene (191-24-2)	Benzo[a]pyrene (50-32-8)	Benzo[e]pyrene (192-97-2)	Benzyl Chloride (100-44-7)	Beryllium (7440-41-7)	Biphenyl (92-52-4)	Bromomethane (74-83-9)	1,3-Butadiene (106-99-0)	Cadmium (7440-43-9)	Carbon Disulfide (75-15-0)	Carbon Tetrachloride (56-23-5)	Carbonyl Sulfide (463-58-1)	Chlorine (7782-50-5)	Chlorobenzene (108-90-7)	Chloroethane (75-00-3)	Chloroform (67-66-3)
Energetic Materials [c]	---	Amatol	lb/lb NEW	5.00E-01[d]	---	---	---	---	---	---	---	0.00E+00	0.00E+00	---	3.70E-07	---	---	---	0.00E+00	0.00E+00
	J473	Cartridge, Impulse, ARD446-1	lb/lb NEW	---	---	---	---	---	---	---	---	6.70E-06	0.00E+00	---	0.00E+00	---	---	---	0.00E+00	0.00E+00
	MG11	Cartridge, Impulse, BBU-36/B	lb/lb NEW	---	---	---	---	---	---	---	---	2.80E-06	0.00E+00	---	0.00E+00	---	---	---	0.00E+00	0.00E+00
	M943	Cartridge, Impulse, MK 107	lb/lb NEW	---	---	---	---	---	---	---	---	2.00E-06	1.40E-03	---	0.00E+00	---	---	---	0.00E+00	0.00E+00
	---	Composition B surrogate	lb/lb NEW	5.00E-01[d]	---	---	---	---	---	---	---	0.00E+00	0.00E+00	---	3.60E-07	---	---	---	0.00E+00	0.00E+00
	---	Detonating Train	lb/lb NEW	---	---	---	---	---	---	---	---	9.00E-06	1.10E-05	---	0.00E+00	---	---	---	6.90E-07	0.00E+00
	F841	Fuse, Tail Bomb FMU-54 A/B	lb/lb NEW	---	---	---	---	---	---	---	---	4.50E-06	3.10E-04	---	0.00E+00	---	---	---	0.00E+00	0.00E+00
	F762	Fuse, Tail Bomb FMU-139 A/B	lb/lb NEW	---	---	---	---	---	---	---	---	2.10E-05	2.30E-03	---	2.70E-06	---	---	---	0.00E+00	0.00E+00
	L231	Signal, Illumination, Red Star AN-M43A2	lb/lb NEW	---	---	---	---	---	---	---	---	1.90E-06	8.80E-05	---	0.00E+00	---	---	---	0.00E+00	0.00E+00
	---	Tritonal surrogate	lb/lb NEW	---	---	---	---	---	---	---	---	9.10E-07	0.00E+00	---	3.70E-07	---	---	---	0.00E+00	3.60E-07
	---	Tritonal surrogate with calcium stearate	lb/lb NEW	---	---	---	---	---	---	---	---	1.30E-06	0.00E+00	---	0.00E+00	---	---	---	0.00E+00	0.00E+00
	---	TNT (Sandia)	lb/lb NEW	---	---	---	---	---	---	---	---	---	2.70E-06	---	---	---	---	---	---	---
	---	TNT (ACC1)	lb/lb NEW	---	---	---	---	---	---	---	---	1.70E-06	0.00E+00	---	0.00E+00	---	---	---	0.00E+00	0.00E+00
	---	TNT (ACC2)	lb/lb NEW	---	---	---	---	---	---	---	---	3.70E-07	4.00E-05	---	0.00E+00	---	---	---	0.00E+00	0.00E+00

Table 16-3. HAP Emission Factors for Open Burn/Open Detonation (cont.)

Munition Type	DODIC	Item	Units:	Net Explosive Material - NEW (lb/item)	Chloromethane (74-87-3)	Chromium (7440-47-3)	Chromium [Hexavalent] (18540-29-9)	Chrysene (218-01-9)	Cobalt (7440-48-4)	Cresols [Mixed Isomers] (1319-77-3)	Cumene (98-82-8)	Cyanide (57-12-5)	Dibenz[a,h]anthracene (53-70-3)	Dibenzofuran (132-64-9)	Dibutyl Phthalate (84-74-2)	1,4-Dichlorobenzene (106-46-7)	1,1-Dichloroethane (75-34-3)	1,2-Dichloroethane (107-06-2)	1,2-Dichloropropane (78-87-5)	Dimethyl Phthalate (131-11-3)
Projectiles, Canisters, and Charges	D505	155-mm Illumination Round (M485A2)	lb/item	6.12E+00	---	---	---	---	1.80E-06	---	---	---	---	---	9.50E-06	---	---	---	---	---
	D533	155-mm Propelling Charge, Zone 7 (M119A2)	lb/item	2.25E+01	---	---	8.90E-06	1.00E-07	---	---	---	---	---	---	---	---	---	---	---	---
	D540	**155-mm Propelling Charges (M3/M3A1)**	**lb/lb NEW**	[(a)]	**4.10E-04**	**3.40E-06**	**---**	**1.30E-07**	**6.50E-07**	**---**	**---**	**2.00E-02**	**2.60E-08**	**---**	**---**	**---**	**---**	**8.80E-04**	**---**	**---**
	D541	155-mm Propelling Charge, Zone 7 (M4A2)	lb/item	1.33E+01	---	3.40E-05	1.20E-05	1.80E-07	---	---	---	3.90E-03	---	---	---	---	---	---	---	---
Grenades	G815	Red Phosphorus Screening Smoke Launcher Grenade (UK) (L8A3)	lb/item	8.32E-01	---	1.00E-05	---	6.80E-06	---	1.80E-06	---	---	1.10E-06	2.90E-06	---	---	---	---	---	4.70E-07
	G878	Practice Hand Grenade Fuse (M228)	lb/item	4.50E-03	---	2.10E-06	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	G881	Fragmentation Hand Grenade (M67)	lb/item	4.10E-01	---	1.10E-05	---	6.00E-09	---	---	---	2.10E-05	---	---	2.80E-06	---	---	---	---	---
	G900	Thermite (TH3) Incendiary Hand Grenade (AN-M14)	lb/item	1.55E+00	7.50E-08	5.40E-06	---	4.60E-09	---	---	---	---	---	---	---	---	---	---	---	---
	G911	Offensive Hand Grenade (MK3A2)	lb/item	4.94E-01	1.50E-07	2.80E-05	3.10E-06	1.30E-07	---	---	---	---	3.00E-08	---	3.20E-06	---	---	3.70E-07	---	---
	G930	Hexachloroethane (HC) Smoke Hand Grenade (AN-M8)	lb/item	1.10E+00	9.30E-06	3.80E-06	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	G940	Green Smoke Hand Grenade (M18)	lb/item	7.20E-01	---	1.50E-05	---	---	---	---	---	---	---	---	---	4.90E-07	---	---	---	---
	G945	Yellow Smoke Hand Grenade (M18)	lb/item	7.20E-01	---	2.50E-07	---	---	---	---	---	---	---	---	---	6.50E-07	2.30E-07	6.40E-07	---	---
	G950	Red Smoke Hand Grenade (M18)	lb/item	7.20E-01	---	3.90E-07	---	---	---	---	---	---	---	---	---	8.10E-08	---	---	---	---
	G955	Violet Smoke Hand Grenade (M18)	lb/item	7.20E-01	---	3.00E-07	---	---	4.00E-08	---	---	---	---	---	---	---	---	---	---	---
	G963	CS Riot Control Agent Hand Grenade (M7A3)	lb/item	7.50E-01	3.90E-05	1.00E-06	---	---	---	3.50E-06	---	---	---	---	---	---	---	---	---	---
	G978	Simulant Screening Smoke Launcher Grenade (M82)	lb/item	1.68E+00	---	1.20E-06	---	---	4.10E-08	---	---	---	---	---	---	---	---	---	---	2.70E-07
	G982	Terephthalic Acid (TA) Smoke Practice Hand Grenade (M83)	lb/item	7.02E-01	7.50E-05	4.30E-06	---	4.40E-06	---	7.20E-06	---	---	---	9.00E-06	---	---	---	---	---	---
	GG09	Non-Lethal Stun Hand Grenade (M84)	lb/item	7.65E-03	---	3.50E-06	2.00E-06	---	5.10E-07	---	---	---	---	---	---	---	---	---	---	---
Rockets, Rocket Motors, and Igniters	H163	2.75-inch Rocket with M151 High Explosive Warhead	lb/item	2.32E+00	---	6.30E-05	---	7.40E-07	4.70E-06	---	---	5.70E-05	---	---	4.60E-06	---	---	6.90E-06	---	---
	H459	2.75-inch Fletchette, MK40 Mod 3 Motor	lb/item	6.02E+00	1.20E-05	4.10E-06	---	2.10E-06	---	---	---	---	1.00E-07	---	---	---	---	---	---	---
	H557	66-mm High Explosive Antitank Rocket (M72A3) (Propelling Rocket)	lb/item	1.34E-01	2.50E-08	7.30E-07	2.90E-07	1.10E-09	---	---	---	---	---	---	---	---	---	2.30E-08	---	---
		66-mm High Explosive Antitank Rocket (M72A3) (Warhead)	lb/item	6.84E-01	1.10E-06	1.40E-05	---	1.60E-08	---	---	---	1.80E-04	---	---	3.30E-06	---	---	2.90E-07	---	---
		66-mm High Explosive Antitank Rocket (M72A3) (Total)	lb/item	8.18E-01	1.10E-06	1.50E-05	2.90E-07	1.70E-08	---	---	---	1.80E-04	---	---	3.30E-06	---	---	3.10E-07	---	---
	H708	35-mm Subcaliber Practice Rocket (M73) (Propelling Rocket)	lb/item	2.64E-02	---	4.00E-06	1.10E-07	---	---	---	6.60E-08	---	---	---	---	---	---	---	---	---
		35-mm Subcaliber Practice Rocket (M73) (Warhead)	lb/item	3.20E-03	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
		35-mm Subcaliber Practice Rocket (M73) (Total)	lb/item	2.96E-02	---	4.00E-06	1.10E-07	---	---	---	6.60E-08	---	---	---	---	---	---	---	---	---
	H974	2.75-inch Practice Warhead, MK66 Mod 3 Motor (M267)	lb/item	7.17E+00	---	1.40E-05	---	7.40E-07	---	---	---	---	5.40E-08	---	---	---	---	---	---	---

Table 16-3. HAP Emission Factors for Open Burn/Open Detonation (cont.)

Munition Type	DODIC	Item	Units:	Net Explosive Material - NEW (lb/item)	Chloromethane (74-87-3)	Chromium (7440-47-3)	Chromium [Hexavalent] (18540-29-9)	Chrysene (218-01-9)	Cobalt (7440-48-4)	Cresols [Mixed Isomers] (1319-77-3)	Cumene (98-82-8)	Cyanide (57-12-5)	Dibenz[a,h]anthracene (53-70-3)	Dibenzofuran (132-64-9)	Dibutyl Phthalate (84-74-2)	1,4-Dichlorobenzene (106-46-7)	1,1-Dichloroethane (75-34-3)	1,2-Dichloroethane (107-06-2)	1,2-Dichloropropane (78-87-5)	Dimethyl Phthalate (131-11-3)
Mines and Smoke Pots	K010	Field Incendiary Burster (M4)	lb/item	2.04E-02	7.90E-08	1.80E-05	1.10E-07	5.90E-09	---	---	---	---	---	---	1.60E-06	---	---	---	---	---
	K042	Practice Canister Mine (Volcano) (M88)	lb/item	1.39E-02	---	8.10E-07	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	K051	Anti-Tank Practice Mine Fuze (M604)	lb/item	3.81E-02	---	---	---	1.00E-08	---	---	---	---	---	---	---	---	---	---	---	---
	K145	Antipersonnel Mine (M18A1)	lb/item	1.50E+00	1.30E-06	1.00E-04	2.90E-06	6.70E-08	---	1.40E-06	1.80E-06	---	---	---	6.60E-06	---	---	3.40E-05	---	---
	K765	CS Riot Control Agent Capsule	lb/item	---	9.00E-08	2.10E-08	---	---	---	4.20E-08	---	---	---	---	---	---	---	---	---	---
	K866	30-Pound HC Smoke Pot (ABC-M5)	lb/item	3.10E+01	5.40E-04	2.70E-04	---	---	---	---	---	---	---	---	---	---	---	---	1.40E-04	---
	K867	Floating Type HC Smoke Pot (M4A2)	lb/item	2.75E+01	---	1.60E-04	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Signals and Simulators	L305	Green Star Parachute Signal Flare (M195)	lb/item	3.16E-01	---	7.30E-06	---	---	3.70E-06	---	---	---	---	---	---	---	---	---	---	---
	L306	Red Star Cluster Signal Flare (M158)	lb/item	2.80E-01	---	1.00E-06	---	---	1.30E-07	---	---	---	---	---	---	---	---	---	---	---
	L307	White Star Cluster Signal Flare (M159)	lb/item	3.20E-01	---	2.90E-06	---	---	1.10E-06	---	---	---	---	---	2.10E-06	---	---	---	---	---
	L311	Red Star Parachute Signal Flare (126A1)	lb/item	2.96E-01	---	3.20E-06	---	---	4.10E-07	---	---	---	---	---	2.00E-07	---	---	---	---	---
	L312	White Star Parachute Signal Flare (M127A1)	lb/item	2.83E-01	---	7.50E-06	---	---	2.60E-07	---	---	---	---	---	2.70E-06	---	---	---	---	---
	L314	Green Star Cluster Signal Flare (M125A1)	lb/item	1.67E+00	---	6.50E-06	---	---	7.80E-07	---	---	---	---	---	9.90E-07	---	---	---	---	---
	L366	Air Burst Projectile Simulator (M74A1)	lb/item	8.99E-02	---	9.90E-07	---	---	4.10E-08	---	---	---	---	---	---	---	---	---	---	---
	L367	Anti-Tank Guided Missle and Rocket Launching Simulator (M22)	lb/item	3.12E-02	---	3.50E-07	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	L410	Aircraft Countermeasure Flare (M206)	lb/item	2.84E-01	---	6.60E-07	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	L495	Surface Trip Flare (M49A1)	lb/item	1.08E+00	---	1.50E-05	---	---	9.00E-07	---	---	---	---	---	1.90E-06	---	---	---	---	---
	L508	Red Railroad Warning Fusee (M72)	lb/item	---	---	3.70E-07	---	---	---	---	---	---	---	7.20E-08	---	---	---	---	---	---
	L592	TOW Blast Simulator	lb/item	5.65E-03	5.40E-08	5.50E-08	---	---	---	---	---	---	---	6.40E-09	---	---	---	---	---	---
	L594	Ground Burst Simulator (M115A2)	lb/item	1.41E-01	---	1.20E-06	---	---	5.90E-07	---	---	---	---	---	2.20E-06	---	---	---	---	---
	L595	Liquid Projectile Air Burst Simulator (M9)	lb/item	1.38E-01	---	---	---	---	---	---	8.80E-07	---	1.20E-09	---	---	---	---	---	---	---
	L596	Flash Artillery Simulator (M110)	lb/item	1.88E-01	---	8.50E-06	---	---	9.60E-07	1.30E-06	4.70E-06	---	---	---	---	---	---	---	---	---
	L598	Flash Booby Trap Simulator (M117)	lb/item	7.70E-03	---	1.50E-07	---	---	9.10E-09	---	---	---	---	---	6.20E-08	---	---	---	---	---
	L599	Illuminating Booby Trap Simulator (M118)	lb/item	1.34E-02	---	9.30E-09	---	---	6.70E-09	---	---	---	---	---	6.00E-08	---	---	---	---	---
	L600	Whistling Booby Trap Simulator (119)	lb/item	1.06E-01	---	---	---	---	---	---	---	---	---	---	3.80E-07	---	---	---	---	---
	L601	Hand Grenade Simulator (M116A1)	lb/item	8.13E-02	---	6.20E-07	---	---	3.30E-07	---	---	---	---	---	3.00E-06	---	---	---	---	---
	L602	Artillery Flash Simulator (M21)	lb/item	9.38E-02	---	2.00E-05	---	---	1.00E-06	---	---	---	---	---	---	---	---	---	---	---
	L709	Target-Hit Simulator (M25)	lb/item	6.00E-02	1.80E-08	1.10E-07	---	---	---	---	---	---	---	---	---	---	---	---	---	5.00E-08
	L720	Target Kill Simulator (M26)	lb/item	1.35E+00	2.30E-06	---	---	8.90E-06	---	---	---	---	6.60E-07	---	---	---	---	7.80E-06	---	---
Fuses and Primers	N278	Mechanical Time and Super Quick (MTSQ) Fuse (M564)	lb/item	6.32E-02	7.20E-08	1.20E-06	---	3.30E-09	2.50E-07	---	---	---	---	---	---	---	---	---	---	---
	N285	Mechanical Time and Super Quick (MTSQ) Fuse (M577A1)	lb/item	9.39E-04	5.90E-09	---	---	---	---	---	---	---	---	---	---	---	---	1.20E-08	---	---
	N286	Mechanical Time and Super Quick (MTSQ) Fuse (M582)	lb/item	5.27E-02	5.70E-08	8.60E-06	---	---	3.10E-07	---	---	---	---	---	---	---	---	---	---	---
	N335	Point Detonating Fuse (M557)	lb/item	5.22E-02	2.30E-08	3.30E-06	2.80E-07	---	4.70E-07	---	---	---	---	---	---	---	---	---	---	---
	N340	Point Detonating Fuse (M739A1)	lb/item	4.59E-02	2.30E-08	1.10E-06	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	N464	Proximity Fuse (M732)	lb/item	1.37E-02	2.80E-08	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

Table 16-3. HAP Emission Factors for Open Burn/Open Detonation (cont.)

Munition Type	DODIC	Item	Units:	Net Explosive Material - NEW (lb/item)	Chloromethane (74-87-3)	Chromium (7440-47-3)	Chromium [Hexavalent] (18540-29-9)	Chrysene (218-01-9)	Cobalt (7440-48-4)	Cresols [Mixed Isomers] (1319-77-3)	Cumene (98-82-8)	Cyanide (57-12-5)	Dibenz[a,h]anthracene (53-70-3)	Dibenzofuran (132-64-9)	Dibutyl Phthalate (84-74-2)	1,4-Dichlorobenzene (106-46-7)	1,1-Dichloroethane (75-34-3)	1,2-Dichloroethane (107-06-2)	1,2-Dichloropropane (78-87-5)	Dimethyl Phthalate (131-11-3)
Blasting Caps, Demolition Charges, and Detonators	M023	Demolition Block Charge (M112)	lb/item	1.25E+00	---	9.40E-06	---	---	---	---	---	---	---	---	4.30E-06	---	---	2.90E-07	---	---
	M030	1/4-Pound Demolition Block Charge	lb/item	2.50E-01	6.60E-08	5.40E-06	---	2.60E-09	---	---	---	---	---	---	2.20E-06	---	---	---	---	---
	M031	1/2-Pound Demolition Block Charge	lb/item	5.00E-01	---	3.90E-04	---	---	4.40E-06	---	8.70E-07	---	---	---	1.80E-06	---	---	---	---	3.00E-07
	M032	1-Pound Demolition Block Charge	lb/item	1.00E+00	1.10E-07	8.70E-06	2.10E-06	---	---	---	---	---	---	---	2.90E-06	---	---	---	---	---
	M130	Electric Blasting Cap (M6)	lb/item	2.92E-03	---	1.30E-07	---	---	1.10E-08	---	---	---	---	---	---	---	---	---	---	---
	M131	Non-Electric Blasting Cap (M7)	lb/item	2.76E-03	---	1.40E-07	1.40E-05	---	---	---	---	---	---	---	---	---	---	---	---	---
	M174	.50 Calibur Blank Cartridge (Electrically Initiated)	lb/item	2.33E-02	---	3.20E-08	---	---	5.50E-08	---	---	2.90E-07	---	---	---	---	---	---	---	---
	M241	High Explosive Universal Destructor (M10)	lb/item	2.86E-01	---	3.70E-04	---	---	5.50E-06	---	3.40E-07	---	---	---	---	---	---	---	---	---
	M327	Firing Device Coupling Base	lb/item	5.71E-05	---	3.70E-09	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	M420	15-Pound Demolition Shaped Charge (M2A4)	lb/item	1.01E+01	2.00E-05	3.40E-04	3.80E-05	2.50E-07	4.40E-04	---	---	---	1.50E-08	---	3.20E-06	---	---	---	---	---
	M448	8-Second Delay Percussion Detonator (M2A1)	lb/item	6.20E-03	---	1.20E-05	7.70E-04	1.30E-10	3.00E-09	---	---	---	---	---	---	---	---	---	---	---
	M456	PETN Type 1 Detonating Cord	lb/item	7.00E-03	---	7.10E-04	---	---	1.00E-05	---	1.00E-06	---	---	4.20E-07	3.30E-06	---	---	---	---	---
	M500	Cartridge Actuated Cutter (M21)	lb/item	4.00E-03	8.80E-09	9.50E-09	1.70E-06	---	---	---	---	---	---	---	---	---	---	3.40E-08	---	---
	M591	Military Dynamite Demolition Block Charge (M1)	lb/item	3.70E-01	---	2.30E-06	---	6.90E-09	---	---	---	---	---	---	4.30E-06	---	---	---	---	---
	M626	Pressure Type Demolition Firing Device (M1)	lb/item	5.71E-05	6.20E-11	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	M630	Pull Type Demolition Firing Device (M1)	lb/item	5.71E-05	1.00E-10	1.70E-07	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	M670	Time Blasting Fuse (M700)	lb/item	2.70E-03	1.10E-05	---	1.20E-06	1.80E-07	---	---	---	---	---	---	---	9.00E-05	---	---	---	---
	M766	Time Blasting Fuse Igniter (M60)	lb/item	5.71E-05	8.50E-11	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	M913	Linear Demolition Charge (M58A3)	lb/item	5.02E+00	5.20E-07	1.00E-05	1.40E-07	1.50E-08	---	---	---	---	---	---	6.30E-06	---	---	---	---	---
	MD73	Impulse Cartridge (M796)	lb/item	7.83E-04	---	5.50E-07	4.50E-07	7.30E-12	---	---	2.20E-09	8.70E-09	7.30E-12	---	---	---	---	---	---	---
	ML03	Multipurpose Demolition Firing Device (M142)	lb/item	4.71E-05	7.90E-10	1.10E-09	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	ML05	Powder Actuated Cutter (MK24)	lb/item	1.26E+00	1.90E-06	2.70E-05	---	6.90E-08	2.10E-06	---	9.50E-06	---	---	---	---	---	---	2.30E-06	---	---
	ML09	**Linear Shaped Demolition Charge, 20 gr/ft**	**lb/lb NEW**	**2.86E-03**	**---**	**6.00E-04**	**---**	**---**	**5.90E-06**	**---**	**3.50E-06**	**---**	**---**	**3.80E-07**	**1.10E-06**	**---**	**---**	**---**	**---**	**---**
	ML15	**Linear Shaped Demolition Charge, 225 gr/ft**	**lb/lb NEW**	**3.21E-02**	**---**	**3.70E-03**	**---**	**---**	**3.20E-05**	**---**	**3.60E-06**	**---**	**---**	**2.00E-06**	**2.00E-06**	**---**	**---**	**---**	**---**	**6.70E-07**
	ML47	Non-Electric Blasting Cap with 30-foot Shock Tube (M11)	lb/item	2.73E-03	---	2.40E-07	2.20E-05	---	1.80E-08	---	---	---	---	---	---	---	---	---	---	---
	MM50	Clipped Shaped Demolition Charge (M221)	lb/item	6.62E-02	7.80E-10	5.50E-06	2.60E-08	5.30E-09	1.60E-07	---	---	---	---	---	---	---	---	---	---	---
	MN02	Non-Electric Blasting Cap with 500-foot Shock Tube (M12)	lb/item	6.18E-03	---	1.30E-07	1.60E-05	4.60E-09	---	---	---	---	---	---	---	---	---	---	---	---
	MN03	Non-Electric Blasting Cap with 1000-foot Shock Tube (M13)	lb/item	1.10E-02	---	1.10E-07	3.80E-05	4.40E-09	---	---	---	---	3.60E-10	---	---	---	---	---	---	---
	MN06	Non-Electric Time Delay Blasting Cap (M14)	lb/item	2.59E-02	4.90E-05	---	1.00E-05	1.50E-07	---	2.40E-06	---	---	4.70E-09	---	---	---	---	---	---	---
	MN07	Non-Electric Time Delay Blasting Cap (M15)	lb/item	4.06E-03	---	7.10E-08	6.20E-09	3.80E-10	---	---	---	---	---	---	---	---	---	---	---	---
	MN08	Time Blasting Fuse Igniter (M81)	lb/item	4.86E-05	6.70E-11	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	MN60	Electric Match Igniter (M79)	lb/item	1.26E-02	4.00E-10	---	2.60E-09	1.60E-09	---	---	---	---	---	---	---	---	---	---	---	---
	MN68	Booster Demolition Charge (M151)	lb/item	9.70E-03	---	1.60E-06	---	---	1.20E-08	---	---	---	---	---	---	---	---	---	---	---

Table 16-3. HAP Emission Factors for Open Burn/Open Detonation (cont.)

Munition Type	DODIC	Item	Units:	Net Explosive Material - NEW (lb/item)	Chloromethane (74-87-3)	Chromium (7440-47-3)	Chromium [Hexavalent] (18540-29-9)	Chrysene (218-01-9)	Cobalt (7440-48-4)	Cresols [Mixed Isomers] (1319-77-3)	Cumene (98-82-8)	Cyanide (57-12-5)	Dibenz[a,h]anthracene (53-70-3)	Dibenzofuran (132-64-9)	Dibutyl Phthalate (84-74-2)	1,4-Dichlorobenzene (106-46-7)	1,1-Dichloroethane (75-34-3)	1,2-Dichloroethane (107-06-2)	1,2-Dichloropropane (78-87-5)	Dimethyl Phthalate (131-11-3)
Energetic Materials (c)	---	Amatol	lb/lb NEW	5.00E-01(d)	7.50E-07	0.00E+00	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	J473	Cartridge, Impulse, ARD446-1	lb/lb NEW	---	1.20E-06	0.00E+00	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	MG11	Cartridge, Impulse, BBU-36/B	lb/lb NEW	---	1.00E-06	2.20E-05	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	M943	Cartridge, Impulse, MK 107	lb/lb NEW	---	9.60E-07	3.30E-05	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	---	Composition B surrogate	lb/lb NEW	5.00E-01(d)	0.00E+00	0.00E+00	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	---	Detonating Train	lb/lb NEW	---	7.00E-07	0.00E+00	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	F841	Fuse, Tail Bomb FMU-54 A/B	lb/lb NEW	---	3.10E-06	3.90E-05	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	F762	Fuse, Tail Bomb FMU-139 A/B	lb/lb NEW	---	4.70E-06	1.40E-04	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	L231	Signal, Illumination, Red Star AN-M43A2	lb/lb NEW	---	1.70E-06	5.70E-05	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	---	Tritonal surrogate	lb/lb NEW	---	5.60E-07	0.00E+00	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	---	Tritonal surrogate with calcium stearate	lb/lb NEW	---	3.70E-07	0.00E+00	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	---	TNT (Sandia)	lb/lb NEW	---	---	2.40E-06	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	---	TNT (ACC1)	lb/lb NEW	---	0.00E+00	0.00E+00	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	---	TNT (ACC2)	lb/lb NEW	---	0.00E+00	2.30E-05	---	---	---	---	---	---	---	---	---	---	---	---	---	---

Table 16-3. HAP Emission Factors for Open Burn/Open Detonation (cont.)

Munition Type	DODIC	Item	Units:	Net Explosive Material - NEW (lb/item)	2,4-Dinitrotoluene (121-14-2)	Total Dioxin/Furan Compounds (---)	Diphenylamine (122-39-4)	2-(2-Ethoxyethoxy)ethanol (111-90-0)	Ethylbenzene (100-41-4)	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)	Hexachlorobenzene (118-74-1)	Hexachlorobutadiene (87-68-3)	Hexachlorocyclopentadiene (77-47-4)	1,2,3,4,7,8-Hexachlorodibenzo-p-dioxin (39227-28-6)
Projectiles, Canisters, and Charges	D505	155-mm Illumination Round (M485A2)	lb/item	6.12E+00	---	---	---	---	7.30E-06	---	---	---	---	---	---	---	---	---	---	---
	D533	155-mm Propelling Charge, Zone 7 (M119A2)	lb/item	2.25E+01	---	7.50E-10	---	---	2.40E-05	---	4.30E-07	7.50E-07	7.20E-05	5.90E-11	1.30E-11	---	---	---	---	---
	D540	**155-mm Propelling Charges (M3/M3A1)**	**lb/lb NEW**	[(a)]	**---**	**7.00E-10**	**---**	**1.30E-05**	**6.00E-04**	**6.00E-03**	**8.00E-07**	**6.00E-07**	**3.10E-03**	**9.80E-11**	**9.00E-12**	**7.10E-11**	**---**	**---**	**---**	**1.20E-10**
	D541	155-mm Propelling Charge, Zone 7 (M4A2)	lb/item	1.33E+01	---	1.40E-09	---	---	---	8.20E-05	7.60E-07	7.80E-07	6.50E-05	1.10E-10	2.50E-11	---	---	---	---	---
Grenades	G815	Red Phosphorus Screening Smoke Launcher Grenade (UK) (L8A3)	lb/item	8.32E-01	---	3.10E-10	8.80E-07	---	1.80E-05	---	2.00E-05	9.00E-06	---	5.50E-12	---	3.00E-12	1.40E-06	---	---	---
	G878	Practice Hand Grenade Fuse (M228)	lb/item	4.50E-03	---	3.10E-13	---	---	---	1.90E-08	---	---	1.20E-07	5.40E-14	---	---	---	---	---	---
	G881	Fragmentation Hand Grenade (M67)	lb/item	4.10E-01	---	2.70E-10	---	---	---	1.60E-05	4.00E-08	1.40E-08	---	2.30E-11	2.40E-12	2.80E-13	---	---	---	1.30E-13
	G900	Thermite (TH3) Incendiary Hand Grenade (AN-M14)	lb/item	1.55E+00	---	---	---	---	---	3.60E-05	7.80E-09	1.00E-08	---	---	---	---	---	---	---	---
	G911	Offensive Hand Grenade (MK3A2)	lb/item	4.94E-01	1.40E-05	2.90E-10	---	---	8.50E-07	6.50E-06	3.20E-07	2.00E-07	4.30E-05	2.10E-11	2.80E-12	---	---	---	---	---
	G930	Hexachloroethane (HC) Smoke Hand Grenade (AN-M8)	lb/item	1.10E+00	---	1.40E-07	---	---	---	---	---	---	---	1.10E-10	7.10E-09	1.50E-09	2.40E-04	5.90E-05	3.80E-05	---
	G940	Green Smoke Hand Grenade (M18)	lb/item	7.20E-01	---	5.60E-10	---	---	6.30E-06	---	---	---	---	3.80E-11	4.40E-11	9.80E-12	---	---	---	1.60E-12
	G945	Yellow Smoke Hand Grenade (M18)	lb/item	7.20E-01	---	4.60E-09	---	---	3.10E-07	---	---	---	---	9.10E-11	2.40E-10	8.90E-11	---	---	---	1.90E-11
	G950	Red Smoke Hand Grenade (M18)	lb/item	7.20E-01	---	6.60E-10	---	---	9.60E-07	---	---	---	---	3.40E-11	6.30E-11	1.60E-11	---	1.30E-06	---	1.20E-12
	G955	Violet Smoke Hand Grenade (M18)	lb/item	7.20E-01	---	4.60E-10	---	---	1.00E-06	---	---	---	---	8.00E-11	1.80E-11	---	---	---	---	1.70E-12
	G963	CS Riot Control Agent Hand Grenade (M7A3)	lb/item	7.50E-01	---	4.70E-10	---	---	4.40E-06	---	---	6.40E-07	5.30E-04	3.30E-11	---	---	---	---	---	---
	G978	Simulant Screening Smoke Launcher Grenade (M82)	lb/item	1.68E+00	---	1.90E-08	---	---	---	3.80E-06	---	---	4.60E-05	2.40E-09	1.40E-09	---	---	---	---	---
	G982	Terephthalic Acid (TA) Smoke Practice Hand Grenade (M83)	lb/item	7.02E-01	---	2.10E-10	---	---	---	---	2.90E-07	7.90E-06	2.00E-04	2.70E-11	6.30E-13	---	---	---	---	2.60E-11
	GG09	Non-Lethal Stun Hand Grenade (M84)	lb/item	7.65E-03	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Rockets, Rocket Motors, and Igniters	H163	2.75-inch Rocket with M151 High Explosive Warhead	lb/item	2.32E+00	---	2.50E-11	2.20E-06	---	8.40E-06	---	2.90E-06	2.00E-06	3.60E-04	---	---	---	---	---	---	---
	H459	2.75-inch Fletchette, MK40 Mod 3 Motor	lb/item	6.02E+00	---	1.70E-10	---	---	---	---	---	3.70E-06	3.40E-04	1.80E-11	---	---	---	---	---	---
	H557	66-mm High Explosive Antitank Rocket (M72A3) (Propelling Rocket)	lb/item	1.34E-01	---	2.20E-11	---	---	3.80E-08	---	1.70E-09	9.10E-10	1.30E-05	1.40E-12	6.10E-14	---	---	---	---	---
		66-mm High Explosive Antitank Rocket (M72A3) (Warhead)	lb/item	6.84E-01	9.70E-08	5.50E-10	---	---	3.50E-07	1.10E-05	1.20E-07	3.90E-08	---	3.00E-11	3.80E-12	4.90E-13	---	---	---	1.60E-13
		66-mm High Explosive Antitank Rocket (M72A3) (Total)	lb/item	8.18E-01	9.70E-08	5.70E-10	---	---	3.90E-07	1.10E-05	1.30E-07	4.00E-08	1.30E-05	3.10E-11	3.90E-12	4.90E-13	---	---	---	1.60E-13
	H708	35-mm Subcaliber Practice Rocket (M73) (Propelling Rocket)	lb/item	2.64E-02	---	2.30E-14	---	---	---	---	2.50E-09	9.50E-10	1.30E-06	2.30E-14	---	---	---	---	---	---
		35-mm Subcaliber Practice Rocket (M73) (Warhead)	lb/item	3.20E-03	2.20E-08	3.80E-11	---	---	3.70E-08	---	---	---	9.20E-08	1.90E-12	3.90E-13	---	---	---	---	---
		35-mm Subcaliber Practice Rocket (M73) (Total)	lb/item	2.96E-02	2.20E-08	3.80E-11	---	---	3.70E-08	---	2.50E-09	9.50E-10	1.40E-06	1.90E-12	3.90E-13	---	---	---	---	---
	H974	2.75-inch Practice Warhead, MK66 Mod 3 Motor (M267)	lb/item	7.17E+00	---	---	---	---	---	---	6.20E-06	2.00E-06	2.50E-04	---	---	---	---	---	---	---

Table 16-3. HAP Emission Factors for Open Burn/Open Detonation (cont.)

Munition Type	DODIC	Item	Units:	Net Explosive Material - NEW (lb/item)	2,4-Dinitrotoluene (121-14-2)	Total Dioxin/Furan Compounds (---)	Diphenylamine (122-39-4)	2-(2-Ethoxyethoxy)ethanol (111-90-0)	Ethylbenzene (100-41-4)	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)	Hexachlorobenzene (118-74-1)	Hexachlorobutadiene (87-68-3)	Hexachlorocyclopentadiene (77-47-4)	1,2,3,4,7,8-Hexachlorodibenzo-p-dioxin (39227-28-6)
Mines and Smoke Pots	K010	Field Incendiary Burster (M4)	lb/item	2.04E-02	---	3.50E-12	---	---	6.20E-07	8.50E-06	1.60E-08	1.80E-08	4.70E-05	---	---	---	---	---	---	---
	K042	Practice Canister Mine (Volcano) (M88)	lb/item	1.39E-02	---	5.80E-12	---	---	---	---	---	---	1.60E-06	8.20E-13	---	---	---	---	---	---
	K051	Anti-Tank Practice Mine Fuze (M604)	lb/item	3.81E-02	---	1.40E-10	---	---	---	---	4.20E-08	5.70E-10	3.70E-08	1.20E-12	1.90E-11	4.60E-12	8.60E-06	---	---	1.30E-13
	K145	Antipersonnel Mine (M18A1)	lb/item	1.50E+00	7.30E-07	2.50E-10	---	---	1.00E-05	6.30E-06	4.00E-07	5.80E-07	1.70E-04	2.30E-11	2.90E-12	3.90E-13	---	---	---	---
	K765	CS Riot Control Agent Capsule	lb/item	---	---	2.40E-12	---	---	4.10E-08	---	---	---	7.00E-09	3.90E-13	---	---	---	---	---	---
	K866	30-Pound HC Smoke Pot (ABC-M5)	lb/item	3.10E+01	1.60E-03	1.20E-05	---	---	---	---	---	---	---	1.50E-08	1.50E-06	1.70E-07	2.10E-02	1.40E-03	1.30E-02	1.50E-09
	K867	Floating Type HC Smoke Pot (M4A2)	lb/item	2.75E+01	---	4.10E-06	---	---	---	---	---	---	---	1.00E-08	3.30E-07	8.70E-08	7.40E-02	1.50E-03	---	8.40E-10
Signals and Simulators	L305	Green Star Parachute Signal Flare (M195)	lb/item	3.16E-01	---	---	---	---	5.20E-07	---	---	---	---	---	---	---	---	---	---	---
	L306	Red Star Cluster Signal Flare (M158)	lb/item	2.80E-01	---	---	---	---	4.80E-06	2.10E-06	---	---	---	---	---	---	---	---	---	---
	L307	White Star Cluster Signal Flare (M159)	lb/item	3.20E-01	---	---	---	---	4.70E-06	6.80E-06	---	---	---	---	---	---	---	---	---	---
	L311	Red Star Parachute Signal Flare (126A1)	lb/item	2.96E-01	---	---	---	---	3.40E-07	7.20E-07	---	---	---	---	---	---	---	---	---	---
	L312	White Star Parachute Signal Flare (M127A1)	lb/item	2.83E-01	---	---	---	---	8.90E-07	---	---	---	---	---	---	---	---	---	---	---
	L314	Green Star Cluster Signal Flare (M125A1)	lb/item	1.67E+00	---	---	---	---	1.70E-06	1.80E-05	---	---	---	---	---	---	---	---	---	---
	L366	Air Burst Projectile Simulator (M74A1)	lb/item	8.99E-02	---	1.60E-10	---	---	5.10E-07	---	---	---	2.90E-06	1.00E-11	4.50E-12	2.80E-12	---	---	---	2.50E-12
	L367	Anti-Tank Guided Missle and Rocket Launching Simulator (M22)	lb/item	3.12E-02	---	4.50E-11	---	---	2.80E-07	1.60E-06	---	---	7.90E-07	2.80E-12	---	---	---	---	---	---
	L410	Aircraft Countermeasure Flare (M206)	lb/item	2.84E-01	---	2.70E-11	---	---	---	2.40E-06	---	---	2.30E-06	3.20E-12	---	---	---	---	---	---
	L495	Surface Trip Flare (M49A1)	lb/item	1.08E+00	---	---	---	---	---	2.20E-06	---	---	---	---	---	---	---	---	---	---
	L508	Red Railroad Warning Fusee (M72)	lb/item	---	---	1.50E-11	---	---	6.20E-07	4.40E-07	---	3.30E-08	3.80E-07	3.60E-12	---	---	---	---	---	---
	L592	TOW Blast Simulator	lb/item	5.65E-03	---	1.40E-11	---	---	---	---	---	---	7.10E-08	1.00E-12	2.30E-13	---	---	---	---	5.20E-14
	L594	Ground Burst Simulator (M115A2)	lb/item	1.41E-01	---	---	---	---	7.50E-07	---	---	---	---	---	---	---	---	---	---	---
	L595	Liquid Projectile Air Burst Simulator (M9)	lb/item	1.38E-01	---	3.70E-12	---	---	---	---	---	---	9.40E-06	---	---	---	---	---	---	---
	L596	Flash Artillery Simulator (M110)	lb/item	1.88E-01	---	---	---	---	2.00E-03	---	---	2.10E-07	---	---	---	---	---	---	---	---
	L598	Flash Booby Trap Simulator (M117)	lb/item	7.70E-03	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	L599	Illuminating Booby Trap Simulator (M118)	lb/item	1.34E-02	---	---	---	---	2.60E-07	8.90E-08	---	---	---	---	---	---	---	---	---	---
	L600	Whistling Booby Trap Simulator (119)	lb/item	1.06E-01	---	---	---	---	2.90E-06	---	---	---	---	---	---	---	---	---	---	---
	L601	Hand Grenade Simulator (M116A1)	lb/item	8.13E-02	---	---	---	---	3.30E-07	3.40E-07	---	---	---	---	---	---	---	---	---	---
	L602	Artillery Flash Simulator (M21)	lb/item	9.38E-02	---	4.40E-01	---	---	7.30E-07	---	---	---	3.00E-06	1.00E-11	1.20E-12	---	---	---	---	---
	L709	Target-Hit Simulator (M25)	lb/item	6.00E-02	---	9.90E-09	---	---	9.10E-08	5.20E-06	4.00E-09	1.60E-10	1.30E-06	7.20E-10	3.30E-09	7.80E-10	---	---	---	5.10E-10
	L720	Target Kill Simulator (M26)	lb/item	1.35E+00	---	4.10E-12	---	---	3.80E-06	3.40E-06	4.10E-05	4.50E-06	7.40E-07	1.90E-13	6.00E-13	2.40E-13	---	---	---	---
Fuses and Primers	N278	Mechanical Time and Super Quick (MTSQ) Fuse (M564)	lb/item	6.32E-02	---	8.00E-12	---	---	1.50E-07	---	1.30E-08	5.00E-09	1.80E-06	1.10E-12	1.40E-13	9.80E-14	---	---	---	---
	N285	Mechanical Time and Super Quick (MTSQ) Fuse (M577A1)	lb/item	9.39E-04	---	9.70E-14	---	---	1.30E-08	---	6.60E-09	---	1.30E-07	---	---	---	---	---	---	---
	N286	Mechanical Time and Super Quick (MTSQ) Fuse (M582)	lb/item	5.27E-02	---	6.60E-12	---	---	---	---	2.30E-08	1.10E-08	2.00E-06	3.60E-13	3.40E-13	---	---	---	---	---
	N335	Point Detonating Fuse (M557)	lb/item	5.22E-02	---	7.00E-12	---	---	---	8.50E-06	1.20E-09	4.70E-10	---	5.10E-13	6.80E-13	2.60E-13	---	---	---	---
	N340	Point Detonating Fuse (M739A1)	lb/item	4.59E-02	---	1.00E-12	---	---	4.90E-08	5.40E-06	1.70E-09	4.80E-10	9.70E-07	---	2.80E-13	---	---	---	---	---
	N464	Proximity Fuse (M732)	lb/item	1.37E-02	---	2.80E-12	---	---	---	4.10E-07	3.10E-08	1.20E-08	5.80E-07	---	---	---	---	---	---	---

Table 16-3. HAP Emission Factors for Open Burn/Open Detonation (cont.)

Munition Type	DODIC	Item	Units:	Net Explosive Material - NEW (lb/item)	2,4-Dinitrotoluene (121-14-2)	Total Dioxin/Furan Compounds (---)	Diphenylamine (122-39-4)	2-(2-Ethoxyethoxy)ethanol (111-90-0)	Ethylbenzene (100-41-4)	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)	Hexachlorobenzene (118-74-1)	Hexachlorobutadiene (87-68-3)	Hexachlorocyclopentadiene (77-47-4)	1,2,3,4,7,8-Hexachlorodibenzo-p-dioxin (39227-28-6)
Blasting Caps, Demolition Charges, and Detonators	M023	Demolition Block Charge (M112)	lb/item	1.25E+00	---	3.80E-10	---	---	---	1.50E-05	7.10E-08	1.80E-08	1.40E-04	2.90E-11	3.00E-12	2.30E-13	---	---	---	2.30E-13
	M030	1/4-Pound Demolition Block Charge	lb/item	2.50E-01	3.60E-07	8.90E-11	---	---	7.60E-07	3.70E-06	1.20E-08	1.50E-08	---	6.40E-12	9.70E-13	1.30E-13	---	---	---	---
	M031	1/2-Pound Demolition Block Charge	lb/item	5.00E-01	4.60E-07	1.40E-09	---	---	---	2.20E-05	1.40E-07	---	5.40E-05	1.30E-10	6.10E-11	---	---	---	---	3.70E-12
	M032	1-Pound Demolition Block Charge	lb/item	1.00E+00	1.50E-06	2.50E-10	---	---	---	9.90E-06	---	2.10E-08	5.80E-05	1.50E-11	1.80E-12	5.50E-13	---	---	---	---
	M130	Electric Blasting Cap (M6)	lb/item	2.92E-03	---	1.10E-12	---	---	---	---	2.30E-09	---	5.90E-07	8.70E-14	7.80E-14	6.10E-14	---	---	---	1.30E-14
	M131	Non-Electric Blasting Cap (M7)	lb/item	2.76E-03	---	2.50E-14	---	---	---	---	1.70E-09	---	2.40E-07	1.60E-14	---	---	---	---	---	---
	M174	.50 Calibur Blank Cartridge (Electrically Initiated)	lb/item	2.33E-02	---	---	---	---	---	---	6.00E-10	3.30E-09	3.00E-07	---	---	---	---	---	---	---
	M241	High Explosive Universal Destructor (M10)	lb/item	2.86E-01	---	1.00E-09	---	---	3.80E-06	1.00E-05	---	---	2.00E-05	1.90E-10	2.10E-11	4.20E-12	---	---	---	1.20E-11
	M327	Firing Device Coupling Base	lb/item	5.71E-05	---	---	---	---	---	---	1.60E-11	---	4.00E-10	---	---	---	---	---	---	---
	M420	15-Pound Demolition Shaped Charge (M2A4)	lb/item	1.01E+01	---	7.40E-10	---	---	3.90E-06	---	6.60E-07	6.90E-07	6.00E-04	1.10E-10	---	---	---	---	---	---
	M448	8-Second Delay Percussion Detonator (M2A1)	lb/item	6.20E-03	---	3.50E-12	---	---	---	---	5.20E-10	3.60E-10	3.20E-06	3.00E-13	---	---	---	---	---	---
	M456	PETN Type 1 Detonating Cord	lb/item	7.00E-03	---	2.80E-09	---	---	3.70E-05	6.10E-05	1.70E-06	8.20E-07	4.60E-04	2.90E-10	1.30E-10	---	---	---	---	6.10E-12
	M500	Cartridge Actuated Cutter (M21)	lb/item	4.00E-03	---	---	---	---	1.00E-08	---	---	---	1.30E-08	---	---	---	---	---	---	---
	M591	Military Dynamite Demolition Block Charge (M1)	lb/item	3.70E-01	1.10E-07	1.40E-10	---	---	6.40E-07	1.10E-05	3.10E-08	1.10E-08	---	9.90E-12	1.30E-12	1.40E-13	---	---	---	2.40E-13
	M626	Pressure Type Demolition Firing Device (M1)	lb/item	5.71E-05	---	4.10E-13	---	---	1.10E-09	---	---	---	---	3.30E-14	---	---	---	---	---	---
	M630	Pull Type Demolition Firing Device (M1)	lb/item	5.71E-05	6.00E-10	---	---	---	5.40E-10	---	---	---	---	---	---	---	---	---	---	---
	M670	Time Blasting Fuse (M700)	lb/item	2.70E-03	---	3.20E-12	---	---	2.90E-05	---	3.70E-08	---	1.00E-03	---	---	---	---	---	---	3.20E-12
	M766	Time Blasting Fuse Igniter (M60)	lb/item	5.71E-05	---	9.90E-14	---	---	2.50E-09	---	---	---	9.80E-09	---	---	---	---	---	---	---
	M913	Linear Demolition Charge (M58A3)	lb/item	5.02E+00	---	3.10E-10	---	---	6.20E-07	9.40E-06	1.10E-07	9.90E-08	---	3.40E-11	2.70E-12	8.50E-13	---	---	---	4.70E-13
	MD73	Impulse Cartridge (M796)	lb/item	7.83E-04	---	1.20E-15	---	---	1.70E-08	---	1.80E-12	---	5.90E-07	---	---	---	---	---	---	2.40E-16
	ML03	Multipurpose Demolition Firing Device (M142)	lb/item	4.71E-05	---	---	---	---	---	---	9.80E-12	---	2.40E-08	---	---	---	---	---	---	---
	ML05	Powder Actuated Cutter (MK24)	lb/item	1.26E+00	---	1.60E-10	---	---	9.40E-06	---	3.20E-07	1.10E-07	8.40E-05	1.70E-11	8.80E-12	2.30E-12	---	---	---	---
	ML09	**Linear Shaped Demolition Charge, 20 gr/ft**	**lb/lb NEW**	**2.86E-03**	**---**	**4.50E-07**	**---**	**---**	**2.70E-05**	**1.50E-05**	**9.40E-07**	**1.30E-06**	**6.70E-03**	**1.10E-07**	**3.80E-09**	**3.60E-09**	**---**	**---**	**---**	**6.20E-09**
	ML15	**Linear Shaped Demolition Charge, 225 gr/ft**	**lb/lb NEW**	**3.21E-02**	**---**	**2.20E-07**	**---**	**---**	**6.20E-05**	**1.90E-05**	**9.40E-07**	**1.50E-06**	**2.40E-03**	**5.20E-08**	**1.10E-09**	**1.00E-09**	**---**	**---**	**---**	**1.60E-09**
	ML47	Non-Electric Blasting Cap with 30-foot Shock Tube (M11)	lb/item	2.73E-03	---	3.50E-13	---	---	---	---	4.40E-09	---	5.30E-07	8.60E-15	1.00E-13	---	---	---	---	---
	MM50	Clipped Shaped Demolition Charge (M221)	lb/item	6.62E-02	---	2.30E-11	---	---	---	---	1.60E-08	2.30E-08	1.10E-06	2.10E-12	6.10E-13	---	---	---	---	---
	MN02	Non-Electric Blasting Cap with 500-foot Shock Tube (M12)	lb/item	6.18E-03	---	7.00E-14	---	---	1.10E-07	---	5.00E-09	4.50E-09	7.60E-07	8.70E-16	---	---	---	---	---	---
	MN03	Non-Electric Blasting Cap with 1000-foot Shock Tube (M13)	lb/item	1.10E-02	---	---	---	---	7.90E-08	---	5.60E-09	5.10E-09	8.70E-07	---	---	---	---	---	---	---
	MN06	Non-Electric Time Delay Blasting Cap (M14)	lb/item	2.59E-02	---	---	---	---	8.80E-07	---	5.40E-08	1.60E-07	1.10E-05	---	---	---	---	---	---	---
	MN07	Non-Electric Time Delay Blasting Cap (M15)	lb/item	4.06E-03	---	7.20E-13	---	---	---	---	1.40E-09	---	4.80E-07	4.10E-13	---	---	---	---	---	3.10E-15
	MN08	Time Blasting Fuse Igniter (M81)	lb/item	4.86E-05	---	---	---	---	4.10E-10	---	---	---	8.60E-09	---	---	---	---	---	---	---
	MN60	Electric Match Igniter (M79)	lb/item	1.26E-02	---	2.00E-13	---	---	3.30E-08	---	9.10E-09	1.30E-09	2.70E-07	---	---	3.10E-14	---	---	---	---
	MN68	Booster Demolition Charge (M151)	lb/item	9.70E-03	---	2.10E-09	---	---	3.30E-09	---	---	---	4.20E-07	1.00E-10	2.20E-11	2.60E-12	---	---	---	1.20E-12

Table 16-3. HAP Emission Factors for Open Burn/Open Detonation (cont.)

Munition Type	DODIC	Item	Units:	Net Explosive Material - NEW (lb/item)	2,4-Dinitrotoluene (121-14-2)	Total Dioxin/Furan Compounds (---)	Diphenylamine (122-39-4)	2-(2-Ethoxyethoxy)ethanol (111-90-0)	Ethylbenzene (100-41-4)	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)	Hexachlorobenzene (118-74-1)	Hexachlorobutadiene (87-68-3)	Hexachlorocyclopentadiene (77-47-4)	1,2,3,4,7,8-Hexachlorodibenzo-p-dioxin (39227-28-6)
Energetic Materials (c)	---	Amatol	lb/lb NEW	5.00E-01 (d)	---	---	---	---	1.20E-06	---	---	---	---	---	---	---	---	---	---	---
	J473	Cartridge, Impulse, ARD446-1	lb/lb NEW	---	---	---	---	---	1.90E-06	---	---	---	---	---	---	---	---	---	---	---
	MG11	Cartridge, Impulse, BBU-36/B	lb/lb NEW	---	---	---	---	---	2.40E-06	---	---	---	---	---	---	---	---	---	---	---
	M943	Cartridge, Impulse, MK 107	lb/lb NEW	---	---	---	---	---	9.70E-07	---	---	---	---	---	---	---	---	---	---	---
	---	Composition B surrogate	lb/lb NEW	5.00E-01 (d)	---	---	---	---	2.00E-06	---	---	---	---	---	---	---	---	---	---	---
	---	Detonating Train	lb/lb NEW	---	---	---	---	---	6.00E-07	---	---	---	---	---	---	---	---	---	---	---
	F841	Fuse, Tail Bomb FMU-54 A/B	lb/lb NEW	---	---	---	---	---	2.40E-06	---	---	---	---	---	---	---	---	---	---	---
	F762	Fuse, Tail Bomb FMU-139 A/B	lb/lb NEW	---	---	---	---	---	3.20E-06	---	---	---	---	---	---	---	---	---	---	---
	L231	Signal, Illumination, Red Star AN-M43A2	lb/lb NEW	---	---	---	---	---	4.60E-07	---	---	---	---	---	---	---	---	---	---	---
	---	Tritonal surrogate	lb/lb NEW	---	---	---	---	---	2.50E-06	---	---	---	---	---	---	---	---	---	---	---
	---	Tritonal surrogate with calcium stearate	lb/lb NEW	---	---	---	---	---	1.60E-06	---	---	---	---	---	---	---	---	---	---	---
	---	TNT (Sandia)	lb/lb NEW	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	---	TNT (ACC1)	lb/lb NEW	---	---	---	---	---	4.70E-07	---	---	---	---	---	---	---	---	---	---	---
	---	TNT (ACC2)	lb/lb NEW	---	---	---	---	---	0.00E+00	---	---	---	---	---	---	---	---	---	---	---

Table 16-3. HAP Emission Factors for Open Burn/Open Detonation (cont.)

Munition Type	DODIC	Item	Units:	Net Explosive Material - NEW (lb/item)	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)	1,2,3,7,8,9-Hexachlorodibenzofuran (72918-21-9)	2,3,4,6,7,8-Hexachlorodibenzofuran (60851-34-5)	Hexachloroethane (67-72-1)	Hexane (110-54-3)	Hydrochloric Acid (7647-01-0)	Hydrogen Cyanide (74-90-8)	Hydrogen Fluoride (7664-39-3)	Indeno[1,2,3-cd]pyrene (193-39-5)	Isophorone (78-59-1)	Lead (7439-92-1)	Manganese (7439-96-5)	Mercury (7439-97-6)
Projectiles, Canisters, and Charges	D505	155-mm Illumination Round (M485A2)	lb/item	6.12E+00	---	---	---	---	---	---	---	2.60E-06	---	---	---	---	---	5.80E-05	5.40E-05	1.20E-08
	D533	155-mm Propelling Charge, Zone 7 (M119A2)	lb/item	2.25E+01	---	2.80E-12	1.80E-12	---	---	---	---	---	---	2.60E-02	---	---	---	2.90E-02	3.70E-05	---
	D540	**155-mm Propelling Charges (M3/M3A1)**	**lb/lb NEW**	(a)	**6.30E-12**	**5.30E-12**	**---**	**2.70E-11**	**---**	**5.90E-11**	**---**	**---**	**---**	**3.40E-03**	**---**	**7.40E-07**	**---**	**9.90E-05**	**1.00E-05**	**---**
	D541	155-mm Propelling Charge, Zone 7 (M4A2)	lb/item	1.33E+01	4.60E-12	5.80E-12	2.10E-12	---	---	---	---	---	---	5.00E-02	---	---	---	3.60E-03	1.00E-04	---
Grenades	G815	Red Phosphorus Screening Smoke Launcher Grenade (UK) (L8A3)	lb/item	8.32E-01	---	9.30E-13	5.50E-12	2.00E-12	---	1.30E-12	---	---	1.70E-03	5.10E-05	---	2.80E-06	---	3.00E-06	8.50E-07	---
	G878	Practice Hand Grenade Fuse (M228)	lb/item	4.50E-03	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	G881	Fragmentation Hand Grenade (M67)	lb/item	4.10E-01	7.10E-13	5.50E-13	5.60E-13	2.80E-13	---	2.10E-13	---	---	---	4.20E-04	---	---	---	5.00E-04	3.80E-05	---
	G900	Thermite (TH3) Incendiary Hand Grenade (AN-M14)	lb/item	1.55E+00	---	---	---	---	---	---	---	---	---	4.90E-06	---	3.90E-09	---	1.10E-02	1.20E-04	---
	G911	Offensive Hand Grenade (MK3A2)	lb/item	4.94E-01	5.40E-13	8.50E-13	---	---	---	---	---	---	---	2.60E-04	---	4.10E-08	---	3.30E-04	6.20E-05	---
	G930	Hexachloroethane (HC) Smoke Hand Grenade (AN-M8)	lb/item	1.10E+00	---	---	1.50E-09	6.80E-10	1.30E-10	4.50E-10	1.10E-05	---	6.90E-03	---	---	---	---	4.70E-04	5.90E-05	---
	G940	Green Smoke Hand Grenade (M18)	lb/item	7.20E-01	2.20E-12	3.20E-12	1.50E-11	7.00E-12	9.50E-12	9.20E-12	---	---	8.00E-04	---	---	---	---	3.40E-05	5.30E-06	4.40E-09
	G945	Yellow Smoke Hand Grenade (M18)	lb/item	7.20E-01	5.00E-11	4.70E-11	3.50E-10	1.80E-10	3.30E-11	1.80E-10	---	7.90E-08	2.80E-06	---	---	---	---	1.50E-05	1.90E-07	1.30E-09
	G950	Red Smoke Hand Grenade (M18)	lb/item	7.20E-01	1.90E-12	2.10E-12	3.80E-11	1.90E-11	5.40E-12	2.50E-11	---	---	6.80E-05	---	---	---	---	1.90E-05	4.00E-07	1.90E-07
	G955	Violet Smoke Hand Grenade (M18)	lb/item	7.20E-01	1.40E-11	6.30E-12	8.50E-12	6.30E-12	---	5.70E-12	---	---	---	---	---	---	---	1.60E-05	1.10E-06	1.20E-08
	G963	CS Riot Control Agent Hand Grenade (M7A3)	lb/item	7.50E-01	---	---	2.10E-11	6.70E-12	---	1.80E-12	---	---	3.50E-04	1.00E-03	---	---	---	---	---	---
	G978	Simulant Screening Smoke Launcher Grenade (M82)	lb/item	1.68E+00	---	---	1.20E-09	---	---	---	---	---	---	6.20E-04	---	---	---	3.60E-05	1.10E-06	---
	G982	Terephthalic Acid (TA) Smoke Practice Hand Grenade (M83)	lb/item	7.02E-01	1.60E-11	2.70E-11	1.30E-12	6.90E-13	---	1.60E-12	---	---	---	5.00E-05	---	---	---	5.80E-05	6.00E-07	---
	GG09	Non-Lethal Stun Hand Grenade (M84)	lb/item	7.65E-03	---	---	---	---	---	---	---	---	4.00E-05	---	---	---	---	9.00E-07	1.80E-06	---
Rockets, Rocket Motors, and Igniters	H163	2.75-inch Rocket with M151 High Explosive Warhead	lb/item	2.32E+00	---	---	---	---	---	---	---	---	---	4.50E-03	---	4.00E-08	---	6.00E-04	6.70E-04	---
	H459	2.75-inch Fletchette, MK40 Mod 3 Motor	lb/item	6.02E+00	---	---	---	---	---	---	---	---	---	4.20E-03	---	4.20E-06	---	5.10E-02	5.00E-05	---
	H557	66-mm High Explosive Antitank Rocket (M72A3) (Propelling Rocket)	lb/item	1.34E-01	---	---	---	9.00E-14	---	---	---	5.10E-06	6.80E-04	2.10E-05	---	---	---	1.80E-05	8.30E-07	---
		66-mm High Explosive Antitank Rocket (M72A3) (Warhead)	lb/item	6.84E-01	8.60E-13	8.00E-13	7.00E-13	2.80E-13	---	2.20E-13	---	---	---	8.80E-05	---	---	---	1.20E-03	9.50E-05	---
		66-mm High Explosive Antitank Rocket (M72A3) (Total)	lb/item	8.18E-01	8.60E-13	8.00E-13	7.00E-13	3.70E-13	---	2.20E-13	---	5.10E-06	6.80E-04	1.10E-04	---	---	---	1.20E-03	9.60E-05	---
	H708	35-mm Subcaliber Practice Rocket (M73) (Propelling Rocket)	lb/item	2.64E-02	---	---	---	---	---	---	---	---	1.40E-04	1.20E-07	1.40E-06	---	---	6.20E-06	---	---
		35-mm Subcaliber Practice Rocket (M73) (Warhead)	lb/item	3.20E-03	1.40E-13	---	---	2.40E-14	---	---	---	5.60E-08	---	---	---	---	---	---	---	---
		35-mm Subcaliber Practice Rocket (M73) (Total)	lb/item	2.96E-02	1.40E-13	---	---	2.40E-14	---	---	---	5.60E-08	1.40E-04	1.20E-07	1.40E-06	---	---	6.20E-06	---	---
	H974	2.75-inch Practice Warhead, MK66 Mod 3 Motor (M267)	lb/item	7.17E+00	---	---	---	---	---	---	---	---	1.70E-03	7.40E-04	---	1.00E-06	---	7.00E-02	4.70E-05	---

Table 16-3. HAP Emission Factors for Open Burn/Open Detonation (cont.)

Munition Type	DODIC	Item	Units:	Net Explosive Material - NEW (lb/item)	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)	1,2,3,7,8,9-Hexachlorodibenzofuran (72918-21-9)	2,3,4,6,7,8-Hexachlorodibenzofuran (60851-34-5)	Hexachloroethane (67-72-1)	Hexane (110-54-3)	Hydrochloric Acid (7647-01-0)	Hydrogen Cyanide (74-90-8)	Hydrogen Fluoride (7664-39-3)	Indeno[1,2,3-cd]pyrene (193-39-5)	Isophorone (78-59-1)	Lead (7439-92-1)	Manganese (7439-96-5)	Mercury (7439-97-6)
Mines and Smoke Pots	K010	Field Incendiary Burster (M4)	lb/item	2.04E-02	---	---	---	---	---	---	---	---	---	1.60E-04	---	---	---	---	1.50E-04	---
	K042	Practice Canister Mine (Volcano) (M88)	lb/item	1.39E-02	---	---	---	---	---	---	---	---	---	---	---	---	---	7.60E-06	---	---
	K051	Anti-Tank Practice Mine Fuze (M604)	lb/item	3.81E-02	2.30E-13	4.50E-13	5.60E-12	2.10E-12	1.90E-13	1.90E-12	---	---	2.00E-04	---	---	1.90E-08	---	1.50E-05	8.30E-07	---
	K145	Antipersonnel Mine (M18A1)	lb/item	1.50E+00	8.20E-13	8.80E-13	---	3.60E-13	---	---	---	---	---	3.60E-04	---	7.40E-09	---	5.70E-05	7.30E-05	---
	K765	CS Riot Control Agent Capsule	lb/item	---	---	---	3.90E-13	1.60E-13	---	1.30E-13	---	2.40E-08	---	6.50E-06	---	---	---	---	---	---
	K866	30-Pound HC Smoke Pot (ABC-M5)	lb/item	3.10E+01	3.80E-09	4.10E-09	1.80E-07	7.80E-08	1.20E-08	6.80E-08	2.00E-03	---	2.80E-01	---	---	6.90E-04	5.50E-03	2.40E-02	6.60E-03	---
	K867	Floating Type HC Smoke Pot (M4A2)	lb/item	2.75E+01	1.50E-09	1.90E-09	1.00E-07	5.70E-08	1.20E-08	3.60E-08	---	---	4.50E-01	---	---	---	---	1.60E-02	5.30E-03	---
Signals and Simulators	L305	Green Star Parachute Signal Flare (M195)	lb/item	3.16E-01	---	---	---	---	---	---	---	---	---	---	---	---	---	4.70E-07	1.10E-05	1.30E-08
	L306	Red Star Cluster Signal Flare (M158)	lb/item	2.80E-01	---	---	---	---	---	---	---	5.80E-07	1.70E-04	---	---	---	---	1.70E-06	1.30E-06	9.50E-08
	L307	White Star Cluster Signal Flare (M159)	lb/item	3.20E-01	---	---	---	---	---	---	---	2.20E-07	---	---	---	---	---	3.80E-06	3.00E-05	3.60E-08
	L311	Red Star Parachute Signal Flare (126A1)	lb/item	2.96E-01	---	---	---	---	---	---	---	2.20E-07	---	---	---	---	---	2.30E-06	2.20E-05	8.60E-08
	L312	White Star Parachute Signal Flare (M127A1)	lb/item	2.83E-01	---	---	---	---	---	---	---	---	---	---	---	---	---	5.50E-06	3.10E-05	4.10E-08
	L314	Green Star Cluster Signal Flare (M125A1)	lb/item	1.67E+00	---	---	---	---	---	---	---	---	1.30E-04	---	---	---	---	2.00E-06	1.60E-05	8.20E-09
	L366	Air Burst Projectile Simulator (M74A1)	lb/item	8.99E-02	3.40E-12	5.40E-12	1.80E-12	2.30E-12	4.40E-12	1.90E-12	---	4.00E-07	---	---	---	---	---	1.40E-03	1.90E-06	---
	L367	Anti-Tank Guided Missle and Rocket Launching Simulator (M22)	lb/item	3.12E-02	---	---	---	---	---	---	---	---	---	9.00E-07	---	---	---	---	5.80E-06	---
	L410	Aircraft Countermeasure Flare (M206)	lb/item	2.84E-01	---	---	---	---	---	---	---	3.70E-08	---	9.00E-06	---	---	---	---	---	---
	L495	Surface Trip Flare (M49A1)	lb/item	1.08E+00	---	---	---	---	---	---	---	4.40E-07	8.20E-06	---	---	---	---	9.90E-06	2.90E-05	8.60E-08
	L508	Red Railroad Warning Fusee (M72)	lb/item	---	---	---	---	---	---	---	---	---	9.00E-05	---	---	---	---	---	---	---
	L592	TOW Blast Simulator	lb/item	5.65E-03	7.20E-14	7.50E-14	---	9.00E-14	9.50E-14	2.70E-14	---	---	4.30E-05	---	---	---	---	1.60E-05	2.50E-08	---
	L594	Ground Burst Simulator (M115A2)	lb/item	1.41E-01	---	---	---	---	---	---	---	---	6.40E-05	---	---	---	---	4.10E-06	3.70E-05	1.80E-08
	L595	Liquid Projectile Air Burst Simulator (M9)	lb/item	1.38E-01	---	---	---	---	---	---	---	---	6.20E-06	---	---	1.20E-09	---	4.20E-06	---	---
	L596	Flash Artillery Simulator (M110)	lb/item	1.88E-01	---	---	---	---	---	---	---	2.30E-04	1.30E-04	---	---	---	---	1.10E-05	1.30E-05	---
	L598	Flash Booby Trap Simulator (M117)	lb/item	7.70E-03	---	---	---	---	---	---	---	8.50E-08	---	---	---	---	---	2.30E-06	4.20E-07	---
	L599	Illuminating Booby Trap Simulator (M118)	lb/item	1.34E-02	---	---	---	---	---	---	---	2.50E-08	2.50E-07	---	---	---	---	5.50E-08	1.40E-08	3.80E-10
	L600	Whistling Booby Trap Simulator (119)	lb/item	1.06E-01	---	---	---	---	---	---	---	---	2.30E-06	---	---	---	---	---	---	---
	L601	Hand Grenade Simulator (M116A1)	lb/item	8.13E-02	---	---	---	---	---	---	---	6.10E-08	---	---	---	---	---	1.40E-06	1.20E-05	1.60E-09
	L602	Artillery Flash Simulator (M21)	lb/item	9.38E-02	9.40E-13	1.20E-12	---	---	---	---	---	6.60E-07	---	---	---	---	---	2.00E-03	4.10E-06	---
	L709	Target-Hit Simulator (M25)	lb/item	6.00E-02	3.70E-10	7.20E-10	2.40E-09	9.10E-10	2.90E-10	9.00E-10	---	---	5.70E-05	---	---	---	---	2.10E-05	1.90E-06	---
	L720	Target Kill Simulator (M26)	lb/item	1.35E+00	---	---	2.40E-13	2.00E-13	---	1.70E-13	---	---	1.30E-05	---	---	1.70E-05	---	---	---	---
Fuses and Primers	N278	Mechanical Time and Super Quick (MTSQ) Fuse (M564)	lb/item	6.32E-02	1.50E-13	3.10E-14	3.10E-13	1.40E-13	---	1.10E-13	---	---	---	5.60E-06	---	3.60E-10	---	5.10E-04	2.30E-05	---
	N285	Mechanical Time and Super Quick (MTSQ) Fuse (M577A1)	lb/item	9.39E-04	---	---	---	---	---	---	---	---	---	3.70E-06	8.30E-07	---	---	4.00E-06	5.80E-08	---
	N286	Mechanical Time and Super Quick (MTSQ) Fuse (M582)	lb/item	5.27E-02	---	2.60E-14	3.90E-13	1.50E-13	---	1.40E-13	---	---	2.20E-06	7.70E-05	---	---	---	5.00E-04	1.10E-05	---
	N335	Point Detonating Fuse (M557)	lb/item	5.22E-02	---	1.10E-13	5.60E-13	2.50E-13	---	2.00E-13	---	---	---	1.60E-05	---	---	---	3.00E-04	7.00E-06	---
	N340	Point Detonating Fuse (M739A1)	lb/item	4.59E-02	---	---	2.20E-13	1.00E-13	---	1.10E-13	---	---	---	2.00E-06	---	---	---	1.00E-04	1.20E-05	---
	N464	Proximity Fuse (M732)	lb/item	1.37E-02	---	---	---	---	---	---	---	---	---	1.10E-05	---	---	---	1.50E-05	1.80E-06	---

Table 16-3. HAP Emission Factors for Open Burn/Open Detonation (cont.)

Munition Type	DODIC	Item	Units:	Net Explosive Material - NEW (lb/item)	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)	1,2,3,7,8,9-Hexachlorodibenzofuran (72918-21-9)	2,3,4,6,7,8-Hexachlorodibenzofuran (60851-34-5)	Hexachloroethane (67-72-1)	Hexane (110-54-3)	Hydrochloric Acid (7647-01-0)	Hydrogen Cyanide (74-90-8)	Hydrogen Fluoride (7664-39-3)	Indeno[1,2,3-cd]pyrene (193-39-5)	Isophorone (78-59-1)	Lead (7439-92-1)	Manganese (7439-96-5)	Mercury (7439-97-6)
Blasting Caps, Demolition Charges, and Detonators	M023	Demolition Block Charge (M112)	lb/item	1.25E+00	5.20E-13	3.90E-13	8.10E-13	3.00E-13	---	1.70E-13	---	4.60E-05	---	5.30E-04	---	---	---	1.70E-04	2.80E-05	---
	M030	1/4-Pound Demolition Block Charge	lb/item	2.50E-01	3.30E-13	2.40E-13	1.90E-13	1.30E-13	---	6.70E-14	---	---	---	1.30E-04	---	---	---	1.40E-04	1.90E-05	---
	M031	1/2-Pound Demolition Block Charge	lb/item	5.00E-01	5.00E-12	6.30E-12	5.80E-12	3.70E-12	---	4.70E-12	---	1.20E-05	---	1.90E-06	---	---	---	1.10E-04	1.20E-04	3.30E-08
	M032	1-Pound Demolition Block Charge	lb/item	1.00E+00	---	---	---	4.40E-13	---	5.40E-13	---	---	---	4.40E-05	---	---	---	2.00E-04	4.30E-05	---
	M130	Electric Blasting Cap (M6)	lb/item	2.92E-03	1.50E-14	2.10E-14	3.10E-14	2.50E-14	1.90E-14	2.30E-14	---	---	2.60E-06	2.20E-05	---	---	---	1.50E-04	2.50E-07	---
	M131	Non-Electric Blasting Cap (M7)	lb/item	2.76E-03	---	---	8.70E-15	---	---	---	---	---	---	1.50E-05	---	---	---	2.60E-04	2.10E-07	---
	M174	.50 Calibur Blank Cartridge (Electrically Initiated)	lb/item	2.33E-02	---	---	---	---	---	---	---	---	---	2.70E-06	---	3.40E-09	---	---	7.60E-08	---
	M241	High Explosive Universal Destructor (M10)	lb/item	2.86E-01	2.80E-11	3.80E-11	7.30E-12	4.20E-12	1.20E-12	4.70E-12	---	3.80E-06	---	1.60E-04	---	---	---	3.30E-02	8.70E-05	1.90E-08
	M327	Firing Device Coupling Base	lb/item	5.71E-05	---	---	---	---	---	---	---	---	---	3.50E-08	---	---	---	6.70E-06	1.40E-09	---
	M420	15-Pound Demolition Shaped Charge (M2A4)	lb/item	1.01E+01	---	1.20E-11	1.60E-11	1.20E-11	---	---	---	---	---	3.10E-04	---	---	---	3.80E-02	1.10E-03	---
	M448	8-Second Delay Percussion Detonator (M2A1)	lb/item	6.20E-03	---	---	---	---	---	---	---	---	8.00E-07	3.60E-05	---	3.00E-11	---	---	2.50E-07	---
	M456	PETN Type 1 Detonating Cord	lb/item	7.00E-03	1.10E-11	8.40E-12	2.00E-11	8.00E-12	---	9.40E-12	---	8.60E-06	---	2.10E-04	---	---	---	7.30E-05	3.20E-04	6.60E-08
	M500	Cartridge Actuated Cutter (M21)	lb/item	4.00E-03	---	---	---	---	---	---	---	---	---	1.00E-07	---	---	---	---	---	---
	M591	Military Dynamite Demolition Block Charge (M1)	lb/item	3.70E-01	3.20E-13	2.50E-13	1.50E-13	2.20E-13	---	1.50E-13	---	5.50E-05	---	1.40E-04	---	---	---	1.50E-04	2.10E-05	---
	M626	Pressure Type Demolition Firing Device (M1)	lb/item	5.71E-05	---	---	---	---	---	---	---	---	4.20E-07	2.00E-08	---	---	---	4.30E-06	1.40E-09	---
	M630	Pull Type Demolition Firing Device (M1)	lb/item	5.71E-05	---	---	---	---	---	---	---	---	---	---	---	---	---	6.90E-06	2.30E-08	---
	M670	Time Blasting Fuse (M700)	lb/item	2.70E-03	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	M766	Time Blasting Fuse Igniter (M60)	lb/item	5.71E-05	---	---	---	---	---	---	---	---	2.70E-08	2.80E-07	---	---	---	2.60E-06	---	---
	M913	Linear Demolition Charge (M58A3)	lb/item	5.02E+00	1.10E-12	1.00E-12	8.00E-13	4.60E-13	---	3.30E-13	---	---	---	2.70E-04	---	---	---	3.40E-05	9.30E-05	---
	MD73	Impulse Cartridge (M796)	lb/item	7.83E-04	2.00E-16	3.00E-16	---	---	4.90E-16	---	---	---	2.90E-08	6.90E-08	---	7.60E-12	---	3.60E-09	8.40E-09	---
	ML03	Multipurpose Demolition Firing Device (M142)	lb/item	4.71E-05	---	---	---	---	---	---	---	---	---	3.80E-07	---	---	---	---	1.90E-10	---
	ML05	Powder Actuated Cutter (MK24)	lb/item	1.26E+00	3.60E-12	2.80E-12	3.30E-12	1.50E-12	---	1.70E-12	---	---	---	3.30E-04	---	5.90E-09	---	1.10E-03	2.40E-04	---
	ML09	**Linear Shaped Demolition Charge, 20 gr/ft**	**lb/lb NEW**	**2.86E-03**	**1.60E-08**	**2.00E-08**	**1.60E-09**	**1.10E-09**	**4.30E-10**	**1.40E-09**	**---**	**7.70E-06**	**---**	**2.30E-02**	**---**	**---**	**---**	**3.40E-01**	**9.50E-05**	**6.80E-08**
	ML15	**Linear Shaped Demolition Charge, 225 gr/ft**	**lb/lb NEW**	**3.21E-02**	**4.30E-09**	**5.00E-09**	**3.80E-10**	**2.80E-10**	**9.50E-11**	**3.60E-10**	**---**	**2.00E-05**	**---**	**6.30E-03**	**---**	**---**	**---**	**8.50E-01**	**1.70E-04**	**4.20E-07**
	ML47	Non-Electric Blasting Cap with 30-foot Shock Tube (M11)	lb/item	2.73E-03	---	5.60E-14	2.00E-14	---	---	---	---	---	---	6.90E-06	---	---	---	1.30E-04	3.20E-07	---
	MM50	Clipped Shaped Demolition Charge (M221)	lb/item	6.62E-02	5.50E-13	4.90E-13	---	---	---	---	---	---	---	9.20E-05	---	1.10E-09	---	1.90E-04	2.40E-05	---
	MN02	Non-Electric Blasting Cap with 500-foot Shock Tube (M12)	lb/item	6.18E-03	---	---	---	---	---	---	---	---	---	7.20E-05	0.00E+00	6.20E-09	---	5.30E-05	1.20E-07	---
	MN03	Non-Electric Blasting Cap with 1000-foot Shock Tube (M13)	lb/item	1.10E-02	---	---	---	---	---	---	---	---	1.10E-06	1.70E-04	0.00E+00	7.10E-09	---	5.50E-05	9.00E-08	---
	MN06	Non-Electric Time Delay Blasting Cap (M14)	lb/item	2.59E-02	---	---	---	---	---	---	---	1.00E-06	---	9.90E-06	3.50E-06	5.00E-09	---	3.80E-05	1.50E-07	---
	MN07	Non-Electric Time Delay Blasting Cap (M15)	lb/item	4.06E-03	2.00E-14	---	---	---	---	---	---	---	---	4.50E-06	---	4.10E-10	---	1.80E-04	9.40E-08	---
	MN08	Time Blasting Fuse Igniter (M81)	lb/item	4.86E-05	---	---	---	---	---	---	---	---	---	4.20E-07	---	---	---	4.40E-06	---	---
	MN60	Electric Match Igniter (M79)	lb/item	1.26E-02	---	---	---	---	---	---	---	---	2.80E-07	1.70E-07	---	1.90E-09	---	1.40E-05	6.40E-08	---
	MN68	Booster Demolition Charge (M151)	lb/item	9.70E-03	2.60E-12	1.80E-12	1.20E-12	9.30E-13	1.30E-12	1.60E-12	---	---	---	1.50E-05	---	---	---	1.10E-04	---	---

Table 16-3. HAP Emission Factors for Open Burn/Open Detonation (cont.)

Munition Type	DODIC	Item	Units:	Net Explosive Material - NEW (lb/item)	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)	1,2,3,7,8,9-Hexachlorodibenzofuran (72918-21-9)	2,3,4,6,7,8-Hexachlorodibenzofuran (60851-34-5)	Hexachloroethane (67-72-1)	Hexane (110-54-3)	Hydrochloric Acid (7647-01-0)	Hydrogen Cyanide (74-90-8)	Hydrogen Fluoride (7664-39-3)	Indeno[1,2,3-cd]pyrene (193-39-5)	Isophorone (78-59-1)	Lead (7439-92-1)	Manganese (7439-96-5)	Mercury (7439-97-6)
Energetic Materials (c)	---	Amatol	lb/lb NEW	5.00E-01(d)	---	---	---	---	---	---	---	5.60E-07	---	---	---	---	---	3.30E-05	---	---
	J473	Cartridge, Impulse, ARD446-1	lb/lb NEW	---	---	---	---	---	---	---	---	1.50E-06	---	---	---	---	---	3.10E-04	---	---
	MG11	Cartridge, Impulse, BBU-36/B	lb/lb NEW	---	---	---	---	---	---	---	---	1.70E-06	---	---	---	---	---	6.80E-05	---	---
	M943	Cartridge, Impulse, MK 107	lb/lb NEW	---	---	---	---	---	---	---	---	5.30E-07	---	---	---	---	---	0.00E+00	---	---
	---	Composition B surrogate	lb/lb NEW	5.00E-01(d)	---	---	---	---	---	---	---	5.50E-07	---	---	---	---	---	0.00E+00	---	---
	---	Detonating Train	lb/lb NEW	---	---	---	---	---	---	---	---	1.80E-06	---	---	---	---	---	1.80E-04	---	---
	F841	Fuse, Tail Bomb FMU-54 A/B	lb/lb NEW	---	---	---	---	---	---	---	---	4.40E-07	---	---	---	---	---	0.00E+00	---	---
	F762	Fuse, Tail Bomb FMU-139 A/B	lb/lb NEW	---	---	---	---	---	---	---	---	6.50E-07	---	---	---	---	---	2.60E-03	---	---
	L231	Signal, Illumination, Red Star AN-M43A2	lb/lb NEW	---	---	---	---	---	---	---	---	8.10E-07	---	---	---	---	---	7.00E-05	---	---
	---	Tritonal surrogate	lb/lb NEW	---	---	---	---	---	---	---	---	0.00E+00	---	---	---	---	---	1.10E-03	---	---
	---	Tritonal surrogate with calcium stearate	lb/lb NEW	---	---	---	---	---	---	---	---	0.00E+00	---	---	---	---	---	9.20E-04	---	---
	---	TNT (Sandia)	lb/lb NEW	---	---	---	---	---	---	---	---	---	---	---	---	---	---	0.00E+00	---	---
	---	TNT (ACC1)	lb/lb NEW	---	---	---	---	---	---	---	---	9.30E-07	---	---	---	---	---	0.00E+00	---	---
	---	TNT (ACC2)	lb/lb NEW	---	---	---	---	---	---	---	---	0.00E+00	---	---	---	---	---	9.00E-06	---	---

Table 16-3. HAP Emission Factors for Open Burn/Open Detonation (cont.)

Munition Type	DODIC	Item	Units:	Net Explosive Material - NEW (lb/item)	Methyl Iodide (74-88-4)	Methyl Isobutyl Ketone (108-10-1)	Methyl Methacrylate (80-62-6)	Methyl tert-butyl ether (1634-04-4)	Methylene Chloride (75-09-2)	1-Methylnaphthalene (90-12-0)	2-Methylnaphthalene (91-57-6)	Monochloroacetic Acid (79-11-8)	Naphthalene (91-20-3)	Nickel (7440-02-0)	N-Nitrosodiphenylamine (86-30-6)	Nitrobenzene (98-95-3)	4-Nitrophenol (100-02-7)	Octabenzone (1843-05-6)	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)
Projectiles, Canisters, and Charges	D505	155-mm Illumination Round (M485A2)	lb/item	6.12E+00	---	---	---	2.10E-07	1.60E-03	---	---	---	1.60E-05	9.20E-06	---	---	---	---	---	---
	D533	155-mm Propelling Charge, Zone 7 (M119A2)	lb/item	2.25E+01	---	---	---	---	---	---	---	---	1.50E-05	2.40E-05	---	---	---	---	6.50E-10	2.00E-11
	D540	**155-mm Propelling Charges (M3/M3A1)**	**lb/lb NEW**	(a)	**---**	**---**	**---**	**7.40E-06**	**5.90E-04**	**---**	**---**	**---**	**1.20E-05**	**8.30E-06**	**---**	**---**	**---**	**2.70E-05**	**5.60E-10**	**1.40E-11**
	D541	155-mm Propelling Charge, Zone 7 (M4A2)	lb/item	1.33E+01	---	---	---	---	---	---	---	---	6.70E-06	8.40E-05	---	---	---	---	1.20E-09	4.30E-11
Grenades	G815	Red Phosphorus Screening Smoke Launcher Grenade (UK) (L8A3)	lb/item	8.32E-01	---	---	---	---	---	---	2.40E-05	---	1.40E-04	---	1.10E-06	---	---	---	4.60E-11	---
	G878	Practice Hand Grenade Fuse (M228)	lb/item	4.50E-03	---	---	---	---	4.60E-08	---	---	---	---	7.00E-07	---	---	---	---	2.00E-13	6.10E-14
	G881	Fragmentation Hand Grenade (M67)	lb/item	4.10E-01	---	---	---	---	---	---	---	---	7.50E-07	---	---	---	---	---	2.40E-10	---
	G900	Thermite (TH3) Incendiary Hand Grenade (AN-M14)	lb/item	1.55E+00	---	---	---	---	3.10E-07	---	---	---	3.90E-07	---	---	---	---	---	---	---
	G911	Offensive Hand Grenade (MK3A2)	lb/item	4.94E-01	---	---	---	---	9.40E-07	---	---	---	2.20E-06	1.50E-05	---	---	---	---	2.60E-10	8.70E-12
	G930	Hexachloroethane (HC) Smoke Hand Grenade (AN-M8)	lb/item	1.10E+00	---	---	---	---	1.30E-05	---	---	---	---	2.10E-06	---	---	---	---	3.00E-10	1.30E-07
	G940	Green Smoke Hand Grenade (M18)	lb/item	7.20E-01	---	---	---	---	4.10E-05	---	---	---	---	7.30E-06	---	---	---	---	2.30E-10	5.50E-11
	G945	Yellow Smoke Hand Grenade (M18)	lb/item	7.20E-01	---	---	---	---	5.50E-06	---	---	---	---	---	---	---	---	---	1.90E-10	7.00E-10
	G950	Red Smoke Hand Grenade (M18)	lb/item	7.20E-01	---	9.80E-07	---	---	2.40E-06	---	---	---	---	---	---	---	---	---	1.60E-10	2.00E-10
	G955	Violet Smoke Hand Grenade (M18)	lb/item	7.20E-01	---	---	---	---	2.00E-06	---	---	---	---	---	---	---	---	---	2.20E-10	4.60E-11
	G963	CS Riot Control Agent Hand Grenade (M7A3)	lb/item	7.50E-01	---	---	---	---	5.20E-06	---	1.20E-06	---	1.20E-05	---	---	---	---	---	1.50E-10	1.30E-11
	G978	Simulant Screening Smoke Launcher Grenade (M82)	lb/item	1.68E+00	---	---	---	---	7.90E-06	---	3.30E-07	---	1.40E-06	7.60E-07	---	---	---	---	1.10E-08	3.60E-09
	G982	Terephthalic Acid (TA) Smoke Practice Hand Grenade (M83)	lb/item	7.02E-01	---	---	---	---	---	---	8.60E-07	1.60E-06	1.30E-05	3.10E-06	---	3.00E-05	---	---	7.10E-12	---
	GG09	Non-Lethal Stun Hand Grenade (M84)	lb/item	7.65E-03	---	---	---	---	---	---	---	---	---	1.70E-06	---	---	---	---	---	---
Rockets, Rocket Motors, and Igniters	H163	2.75-inch Rocket with M151 High Explosive Warhead	lb/item	2.32E+00	---	---	---	---	3.10E-06	---	---	---	2.50E-05	4.30E-04	---	---	---	---	---	---
	H459	2.75-inch Fletchette, MK40 Mod 3 Motor	lb/item	6.02E+00	---	---	---	---	2.80E-03	---	---	---	1.10E-04	---	---	---	---	---	1.50E-10	---
	H557	66-mm High Explosive Antitank Rocket (M72A3) (Propelling Rocket)	lb/item	1.34E-01	---	---	---	---	1.70E-05	---	---	---	3.00E-08	5.90E-07	---	---	---	---	1.90E-11	2.90E-13
		66-mm High Explosive Antitank Rocket (M72A3) (Warhead)	lb/item	6.84E-01	---	---	---	---	6.50E-07	---	---	---	1.40E-06	---	---	---	---	---	5.00E-10	1.10E-11
		66-mm High Explosive Antitank Rocket (M72A3) (Total)	lb/item	8.18E-01	---	---	---	---	1.70E-05	---	---	---	1.40E-06	5.90E-07	---	---	---	---	5.20E-10	1.10E-11
	H708	35-mm Subcaliber Practice Rocket (M73) (Propelling Rocket)	lb/item	2.64E-02	---	6.20E-06	4.00E-06	---	---	---	---	---	3.20E-08	---	---	---	---	---	---	---
		35-mm Subcaliber Practice Rocket (M73) (Warhead)	lb/item	3.20E-03	---	---	---	---	---	---	---	---	---	---	---	---	---	---	3.40E-11	1.70E-12
		35-mm Subcaliber Practice Rocket (M73) (Total)	lb/item	2.96E-02	---	6.20E-06	4.00E-06	---	---	---	---	---	3.20E-08	---	---	---	---	---	3.40E-11	1.70E-12
	H974	2.75-inch Practice Warhead, MK66 Mod 3 Motor (M267)	lb/item	7.17E+00	---	---	---	---	1.30E-04	---	---	---	8.60E-06	---	---	---	---	---	---	---

Table 16-3. HAP Emission Factors for Open Burn/Open Detonation (cont.)

Munition Type	DODIC	Item	Units:	Net Explosive Material - NEW (lb/item)	Methyl Iodide (74-88-4)	Methyl Isobutyl Ketone (108-10-1)	Methyl Methacrylate (80-62-6)	Methyl tert-butyl ether (1634-04-4)	Methylene Chloride (75-09-2)	1-Methylnaphthalene (90-12-0)	2-Methylnaphthalene (91-57-6)	Monochloroacetic Acid (79-11-8)	Naphthalene (91-20-3)	Nickel (7440-02-0)	N-Nitrosodiphenylamine (86-30-6)	Nitrobenzene (98-95-3)	4-Nitrophenol (100-02-7)	Octabenzone (1843-05-6)	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)
Mines and Smoke Pots	K010	Field Incendiary Burster (M4)	lb/item	2.04E-02	---	4.70E-07	---	---	2.70E-06	---	---	---	1.60E-07	2.90E-05	---	---	---	---	---	2.70E-12
	K042	Practice Canister Mine (Volcano) (M88)	lb/item	1.39E-02	---	---	---	---	---	---	---	---	1.50E-08	1.70E-07	---	---	---	---	4.80E-12	1.90E-13
	K051	Anti-Tank Practice Mine Fuze (M604)	lb/item	3.81E-02	---	---	2.70E-08	---	6.40E-08	---	---	---	3.00E-09	---	---	---	---	---	2.10E-11	6.30E-11
	K145	Antipersonnel Mine (M18A1)	lb/item	1.50E+00	---	---	1.70E-07	---	3.80E-07	---	---	---	5.40E-06	---	---	---	7.30E-06	---	2.20E-10	5.70E-12
	K765	CS Riot Control Agent Capsule	lb/item	---	---	---	---	---	2.00E-07	---	1.90E-09	---	---	---	---	---	---	---	1.10E-12	9.80E-14
	K866	30-Pound HC Smoke Pot (ABC-M5)	lb/item	3.10E+01	---	---	---	---	7.00E-04	---	---	---	---	3.40E-04	---	---	---	---	5.30E-08	1.20E-05
	K867	Floating Type HC Smoke Pot (M4A2)	lb/item	2.75E+01	---	---	---	---	4.20E-04	---	---	---	---	2.80E-04	---	---	---	---	1.80E-08	3.70E-06
Signals and Simulators	L305	Green Star Parachute Signal Flare (M195)	lb/item	3.16E-01	---	---	---	2.10E-07	1.20E-04	---	6.80E-07	---	8.00E-07	5.20E-07	---	---	---	---	---	---
	L306	Red Star Cluster Signal Flare (M158)	lb/item	2.80E-01	---	---	---	---	---	---	---	---	1.10E-06	6.00E-07	---	---	---	---	---	---
	L307	White Star Cluster Signal Flare (M159)	lb/item	3.20E-01	---	---	---	---	1.80E-05	---	---	---	9.80E-06	5.80E-07	---	---	---	---	---	---
	L311	Red Star Parachute Signal Flare (126A1)	lb/item	2.96E-01	---	---	---	8.70E-08	---	---	---	---	---	6.30E-07	---	---	---	---	---	---
	L312	White Star Parachute Signal Flare (M127A1)	lb/item	2.83E-01	---	---	---	1.30E-07	4.70E-06	---	---	---	4.60E-07	9.20E-07	---	---	---	---	---	---
	L314	Green Star Cluster Signal Flare (M125A1)	lb/item	1.67E+00	---	---	---	1.20E-07	9.30E-05	---	6.90E-07	---	1.00E-06	4.90E-07	---	---	---	---	---	---
	L366	Air Burst Projectile Simulator (M74A1)	lb/item	8.99E-02	---	---	---	---	1.90E-03	7.50E-08	1.20E-08	---	3.00E-07	1.80E-07	---	---	---	---	3.10E-11	1.10E-11
	L367	Anti-Tank Guided Missle and Rocket Launching Simulator (M22)	lb/item	3.12E-02	---	---	---	---	5.90E-07	---	3.30E-08	---	---	---	---	---	---	---	3.60E-11	6.60E-12
	L410	Aircraft Countermeasure Flare (M206)	lb/item	2.84E-01	---	---	---	---	7.80E-06	---	---	---	---	---	---	---	---	---	1.80E-11	5.50E-12
	L495	Surface Trip Flare (M49A1)	lb/item	1.08E+00	---	---	---	6.30E-07	2.40E-05	---	---	---	3.70E-07	3.60E-07	---	---	---	---	---	---
	L508	Red Railroad Warning Fusee (M72)	lb/item	---	---	---	---	---	2.00E-06	---	3.80E-07	---	1.60E-06	3.80E-07	---	---	6.10E-07	---	8.00E-12	3.00E-12
	L592	TOW Blast Simulator	lb/item	5.65E-03	---	---	---	---	2.00E-08	---	---	---	---	8.80E-08	---	---	---	---	1.20E-11	6.90E-13
	L594	Ground Burst Simulator (M115A2)	lb/item	1.41E-01	---	---	---	---	9.00E-06	---	3.10E-07	---	1.30E-06	2.10E-06	---	---	---	---	---	---
	L595	Liquid Projectile Air Burst Simulator (M9)	lb/item	1.38E-01	---	---	---	---	3.00E-06	---	---	---	---	4.90E-07	---	---	---	---	---	---
	L596	Flash Artillery Simulator (M110)	lb/item	1.88E-01	---	---	---	2.10E-03	1.80E-05	---	3.10E-05	---	7.10E-05	5.10E-07	---	---	---	---	---	---
	L598	Flash Booby Trap Simulator (M117)	lb/item	7.70E-03	---	---	---	8.80E-08	4.50E-07	---	---	---	3.00E-08	2.60E-08	---	---	---	---	---	---
	L599	Illuminating Booby Trap Simulator (M118)	lb/item	1.34E-02	---	---	---	---	6.70E-07	---	---	---	8.20E-08	2.50E-08	---	---	---	---	---	---
	L600	Whistling Booby Trap Simulator (119)	lb/item	1.06E-01	---	---	---	8.70E-09	1.70E-06	---	---	---	3.40E-07	---	---	---	---	---	---	---
	L601	Hand Grenade Simulator (M116A1)	lb/item	8.13E-02	---	---	---	---	3.80E-06	---	1.40E-07	---	4.50E-07	1.20E-06	---	---	---	---	---	---
	L602	Artillery Flash Simulator (M21)	lb/item	9.38E-02	---	---	---	---	1.40E-03	---	---	---	6.80E-07	7.30E-07	---	---	---	---	2.80E-11	1.70E-12
	L709	Target-Hit Simulator (M25)	lb/item	6.00E-02	---	---	---	---	---	---	5.10E-08	---	2.50E-07	4.70E-08	---	---	---	---	8.90E-10	3.40E-09
	L720	Target Kill Simulator (M26)	lb/item	1.35E+00	---	---	---	---	2.40E-06	---	4.60E-05	---	1.00E-03	6.10E-06	---	---	---	---	---	1.20E-12
Fuses and Primers	N278	Mechanical Time and Super Quick (MTSQ) Fuse (M564)	lb/item	6.32E-02	---	---	6.20E-07	---	1.50E-07	---	---	---	3.30E-08	1.50E-06	---	---	---	---	5.70E-12	---
	N285	Mechanical Time and Super Quick (MTSQ) Fuse (M577A1)	lb/item	9.39E-04	---	---	1.20E-07	---	1.00E-07	---	---	---	---	---	---	---	---	---	---	---
	N286	Mechanical Time and Super Quick (MTSQ) Fuse (M582)	lb/item	5.27E-02	---	---	---	---	---	---	---	---	1.90E-07	2.80E-06	---	---	---	---	---	---
	N335	Point Detonating Fuse (M557)	lb/item	5.22E-02	---	---	7.60E-08	---	---	---	---	---	8.10E-09	---	---	---	---	---	2.60E-12	8.70E-13
	N340	Point Detonating Fuse (M739A1)	lb/item	4.59E-02	---	---	4.60E-08	7.10E-09	---	---	---	---	1.40E-08	---	---	---	---	---	---	---
	N464	Proximity Fuse (M732)	lb/item	1.37E-02	---	---	---	---	2.10E-06	---	---	---	1.40E-07	---	---	---	---	---	1.90E-12	---

Table 16-3. HAP Emission Factors for Open Burn/Open Detonation (cont.)

Munition Type	DODIC	Item	Units:	Net Explosive Material - NEW (lb/item)	Methyl Iodide (74-88-4)	Methyl Isobutyl Ketone (108-10-1)	Methyl Methacrylate (80-62-6)	Methyl tert-butyl ether (1634-04-4)	Methylene Chloride (75-09-2)	1-Methylnaphthalene (90-12-0)	2-Methylnaphthalene (91-57-6)	Monochloroacetic Acid (79-11-8)	Naphthalene (91-20-3)	Nickel (7440-02-0)	N-Nitrosodiphenylamine (86-30-6)	Nitrobenzene (98-95-3)	4-Nitrophenol (100-02-7)	Octabenzone (1843-05-6)	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)
Blasting Caps, Demolition Charges, and Detonators	M023	Demolition Block Charge (M112)	lb/item	1.25E+00	---	---	---	---	1.90E-06	---	---	---	2.20E-06	---	---	---	---	---	3.30E-10	6.30E-12
	M030	1/4-Pound Demolition Block Charge	lb/item	2.50E-01	---	---	---	---	3.30E-07	---	---	---	7.90E-08	---	---	---	---	---	8.00E-11	---
	M031	1/2-Pound Demolition Block Charge	lb/item	5.00E-01	---	---	---	---	3.70E-02	---	---	---	3.70E-06	1.30E-05	---	---	---	---	1.00E-09	8.90E-11
	M032	1-Pound Demolition Block Charge	lb/item	1.00E+00	---	---	---	---	---	---	---	---	2.60E-07	---	---	---	---	---	2.20E-10	3.40E-12
	M130	Electric Blasting Cap (M6)	lb/item	2.92E-03	---	---	---	---	---	---	---	---	6.70E-09	---	---	4.80E-09	---	---	3.90E-13	3.00E-13
	M131	Non-Electric Blasting Cap (M7)	lb/item	2.76E-03	---	---	3.80E-08	---	---	---	---	---	8.20E-09	5.50E-08	---	---	---	---	---	---
	M174	.50 Calibur Blank Cartridge (Electrically Initiated)	lb/item	2.33E-02	---	---	---	---	3.80E-05	---	---	---	1.80E-07	3.70E-08	---	---	---	---	---	---
	M241	High Explosive Universal Destructor (M10)	lb/item	2.86E-01	---	---	---	---	8.50E-03	---	9.70E-07	---	3.50E-06	7.80E-06	---	---	---	---	6.40E-10	4.20E-11
	M327	Firing Device Coupling Base	lb/item	5.71E-05	---	---	---	---	2.20E-08	---	---	---	---	1.20E-09	---	---	---	---	---	---
	M420	15-Pound Demolition Shaped Charge (M2A4)	lb/item	1.01E+01	---	---	---	---	1.00E-05	---	---	---	7.10E-06	8.20E-04	---	---	---	---	5.00E-10	2.80E-11
	M448	8-Second Delay Percussion Detonator (M2A1)	lb/item	6.20E-03	---	---	---	---	---	---	---	---	1.20E-08	4.10E-06	---	---	---	---	3.10E-12	---
	M456	PETN Type 1 Detonating Cord	lb/item	7.00E-03	---	---	---	---	1.70E-01	---	---	---	8.40E-06	3.10E-05	---	---	---	---	2.10E-09	2.40E-10
	M500	Cartridge Actuated Cutter (M21)	lb/item	4.00E-03	---	---	---	---	1.50E-07	---	---	---	2.30E-08	1.50E-08	---	---	---	---	---	---
	M591	Military Dynamite Demolition Block Charge (M1)	lb/item	3.70E-01	---	---	---	---	1.80E-06	---	---	---	8.90E-07	---	---	---	---	---	1.30E-10	---
	M626	Pressure Type Demolition Firing Device (M1)	lb/item	5.71E-05	---	---	---	---	2.10E-08	---	---	---	---	4.10E-10	---	---	---	---	3.40E-13	3.00E-14
	M630	Pull Type Demolition Firing Device (M1)	lb/item	5.71E-05	---	---	4.10E-10	---	3.70E-08	---	---	---	---	1.10E-07	---	---	---	---	---	---
	M670	Time Blasting Fuse (M700)	lb/item	2.70E-03	---	1.90E-05	---	---	5.10E-05	---	---	---	6.90E-06	---	---	---	---	---	---	---
	M766	Time Blasting Fuse Igniter (M60)	lb/item	5.71E-05	---	---	---	---	2.50E-07	---	---	---	6.50E-10	---	---	---	---	---	---	---
	M913	Linear Demolition Charge (M58A3)	lb/item	5.02E+00	2.60E-07	---	5.20E-07	---	---	---	---	---	1.00E-06	---	---	---	---	---	2.70E-10	9.70E-12
	MD73	Impulse Cartridge (M796)	lb/item	7.83E-04	---	1.80E-09	---	---	7.70E-09	---	---	---	---	3.60E-10	---	---	---	---	---	---
	ML03	Multipurpose Demolition Firing Device (M142)	lb/item	4.71E-05	---	---	---	---	8.60E-08	---	---	---	---	5.30E-10	---	---	---	---	---	---
	ML05	Powder Actuated Cutter (MK24)	lb/item	1.26E+00	---	---	---	---	2.40E-07	---	---	---	4.40E-06	2.80E-05	---	---	3.90E-06	---	1.00E-10	9.40E-12
	ML09	**Linear Shaped Demolition Charge, 20 gr/ft**	**lb/lb NEW**	**2.86E-03**	**---**	**---**	**---**	**---**	**1.50E-01**	**---**	**---**	**---**	**2.20E-05**	**2.20E-05**	**---**	**---**	**---**	**---**	**2.70E-07**	**7.40E-09**
	ML15	**Linear Shaped Demolition Charge, 225 gr/ft**	**lb/lb NEW**	**3.21E-02**	**---**	**---**	**---**	**---**	**1.10E-01**	**1.50E-06**	**9.00E-07**	**---**	**1.80E-05**	**4.80E-05**	**---**	**---**	**---**	**---**	**1.50E-07**	**2.40E-09**
	ML47	Non-Electric Blasting Cap with 30-foot Shock Tube (M11)	lb/item	2.73E-03	---	---	---	---	5.20E-07	---	---	---	7.50E-08	6.90E-08	---	---	---	---	1.30E-13	1.80E-14
	MM50	Clipped Shaped Demolition Charge (M221)	lb/item	6.62E-02	---	---	---	---	7.10E-09	---	---	---	1.70E-07	2.50E-06	---	---	---	---	1.90E-11	---
	MN02	Non-Electric Blasting Cap with 500-foot Shock Tube (M12)	lb/item	6.18E-03	---	---	---	---	1.90E-06	---	---	---	2.80E-07	1.80E-08	---	---	---	---	---	---
	MN03	Non-Electric Blasting Cap with 1000-foot Shock Tube (M13)	lb/item	1.10E-02	---	---	---	---	2.50E-06	---	---	---	3.20E-07	---	---	---	---	---	---	---
	MN06	Non-Electric Time Delay Blasting Cap (M14)	lb/item	2.59E-02	---	---	---	---	3.10E-06	---	3.00E-07	---	1.20E-06	---	---	---	---	---	---	---
	MN07	Non-Electric Time Delay Blasting Cap (M15)	lb/item	4.06E-03	---	---	---	---	---	---	---	---	1.80E-08	1.20E-08	---	---	---	---	---	---
	MN08	Time Blasting Fuse Igniter (M81)	lb/item	4.86E-05	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	MN60	Electric Match Igniter (M79)	lb/item	1.26E-02	---	3.90E-08	---	---	2.00E-08	---	---	---	5.90E-08	---	---	---	---	---	---	---
	MN68	Booster Demolition Charge (M151)	lb/item	9.70E-03	---	---	---	---	---	---	1.60E-08	---	1.10E-07	7.30E-07	---	---	---	---	1.90E-09	1.20E-10

Table 16-3. HAP Emission Factors for Open Burn/Open Detonation (cont.)

Munition Type	DODIC	Item	Units:	Net Explosive Material - NEW (lb/item)	Methyl Iodide (74-88-4)	Methyl Isobutyl Ketone (108-10-1)	Methyl Methacrylate (80-62-6)	Methyl tert-butyl ether (1634-04-4)	Methylene Chloride (75-09-2)	1-Methylnaphthalene (90-12-0)	2-Methylnaphthalene (91-57-6)	Monochloroacetic Acid (79-11-8)	Naphthalene (91-20-3)	Nickel (7440-02-0)	N-Nitrosodiphenylamine (86-30-6)	Nitrobenzene (98-95-3)	4-Nitrophenol (100-02-7)	Octabenzone (1843-05-6)	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)
Energetic Materials [c]	---	Amatol	lb/lb NEW	5.00E-01[d]	---	---	---	---	1.50E-04	---	---	---	---	---	---	---	---	---	---	---
	J473	Cartridge, Impulse, ARD446-1	lb/lb NEW	---	---	---	---	---	5.00E-05	---	---	---	---	---	---	---	---	---	---	---
	MG11	Cartridge, Impulse, BBU-36/B	lb/lb NEW	---	---	---	---	---	1.70E-04	---	---	---	---	---	---	---	---	---	---	---
	M943	Cartridge, Impulse, MK 107	lb/lb NEW	---	---	---	---	---	2.30E-04	---	---	---	---	---	---	---	---	---	---	---
	---	Composition B surrogate	lb/lb NEW	5.00E-01[d]	---	---	---	---	1.40E-04	---	---	---	---	---	---	---	---	---	---	---
	---	Detonating Train	lb/lb NEW	---	---	---	---	---	4.20E-05	---	---	---	---	---	---	---	---	---	---	---
	F841	Fuse, Tail Bomb FMU-54 A/B	lb/lb NEW	---	---	---	---	---	7.40E-04	---	---	---	---	---	---	---	---	---	---	---
	F762	Fuse, Tail Bomb FMU-139 A/B	lb/lb NEW	---	---	---	---	---	1.10E-04	---	---	---	---	---	---	---	---	---	---	---
	L231	Signal, Illumination, Red Star AN-M43A2	lb/lb NEW	---	---	---	---	---	8.10E-06	---	---	---	---	---	---	---	---	---	---	---
	---	Tritonal surrogate	lb/lb NEW	---	---	---	---	---	1.80E-05	---	---	---	---	---	---	---	---	---	---	---
	---	Tritonal surrogate with calcium stearate	lb/lb NEW	---	---	---	---	---	1.60E-04	---	---	---	---	---	---	---	---	---	---	---
	---	TNT (Sandia)	lb/lb NEW	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	---	TNT (ACC1)	lb/lb NEW	---	---	---	---	---	1.80E-04	---	---	---	---	---	---	---	---	---	---	---
	---	TNT (ACC2)	lb/lb NEW	---	---	---	---	---	0.00E+00	---	---	---	---	---	---	---	---	---	---	---

Table 16-3. HAP Emission Factors for Open Burn/Open Detonation (cont.)

Munition Type	DODIC	Item	Units:	Net Explosive Material - NEW (lb/item)	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)	Pentachlorophenol (87-86-5)	Perchloroethylene (127-18-4)	Phenanthrene (85-01-8)	Phenol (108-95-2)	Phosphorus (7723-14-0)	Propionaldehyde (123-38-6)	Pyrene (129-00-0)	Selenium (7782-49-2)	Styrene (100-42-5)	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)	Toluene (108-88-3)
Projectiles, Canisters, and Charges	D505	155-mm Illumination Round (M485A2)	lb/item	6.12E+00	---	---	---	---	---	3.50E-06	---	---	---	---	---	---	2.10E-11(b)	---	---	2.40E-05
	D533	155-mm Propelling Charge, Zone 7 (M119A2)	lb/item	2.25E+01	---	---	---	---	---	1.30E-06	7.60E-06	---	---	1.00E-06	---	1.70E-04	---	2.80E-12	---	6.40E-05
	D540	**155-mm Propelling Charges (M3/M3A1)**	**lb/lb NEW**	(a)	**5.00E-11**	**7.50E-11**	**3.00E-11**	**---**	**---**	**1.40E-06**	**1.80E-05**	**---**	**---**	**2.00E-06**	**---**	**6.70E-04**	**6.80E-11**	**4.90E-11**	**---**	**8.70E-06**
	D541	155-mm Propelling Charge, Zone 7 (M4A2)	lb/item	1.33E+01	---	---	---	---	---	1.20E-06	1.60E-05	---	---	1.60E-06	---	4.70E-05	---	---	---	2.70E-05
Grenades	G815	Red Phosphorus Screening Smoke Launcher Grenade (UK) (L8A3)	lb/item	8.32E-01	---	1.20E-12	2.60E-12	---	---	3.50E-05	2.20E-05	2.20E-01	3.30E-06	5.40E-06	---	6.60E-05	---	---	---	2.60E-04
	G878	Practice Hand Grenade Fuse (M228)	lb/item	4.50E-03	---	---	---	---	---	---	4.30E-09	---	---	---	---	---	---	---	---	9.60E-09
	G881	Fragmentation Hand Grenade (M67)	lb/item	4.10E-01	---	2.10E-13	3.50E-13	---	---	9.70E-08	---	---	---	7.40E-08	---	---	---	8.90E-13	---	4.30E-07
	G900	Thermite (TH3) Incendiary Hand Grenade (AN-M14)	lb/item	1.55E+00	---	---	---	---	---	1.50E-08	2.50E-06	---	1.10E-06	7.00E-09	---	1.90E-07	---	---	---	2.10E-07
	G911	Offensive Hand Grenade (MK3A2)	lb/item	4.94E-01	---	---	---	---	---	7.10E-07	1.70E-06	---	8.00E-06	4.80E-07	---	---	---	1.30E-12	---	8.40E-06
	G930	Hexachloroethane (HC) Smoke Hand Grenade (AN-M8)	lb/item	1.10E+00	---	2.20E-10	3.70E-10	---	1.40E-03	---	2.10E-07	8.00E-06	1.30E-07	---	---	---	---	8.80E-11	---	3.80E-06
	G940	Green Smoke Hand Grenade (M18)	lb/item	7.20E-01	2.70E-12	3.40E-11	6.10E-12	---	5.10E-07	---	---	---	4.60E-05	---	1.40E-07	---	3.20E-12	8.50E-11	---	2.90E-04
	G945	Yellow Smoke Hand Grenade (M18)	lb/item	7.20E-01	6.50E-11	5.30E-10	3.50E-10	---	5.50E-06	---	---	---	---	---	---	1.70E-07	2.10E-11	1.40E-09	4.40E-07	2.10E-06
	G950	Red Smoke Hand Grenade (M18)	lb/item	7.20E-01	---	3.20E-11	1.70E-11	---	6.40E-07	---	---	4.80E-07	---	---	---	---	---	4.20E-11	---	1.70E-06
	G955	Violet Smoke Hand Grenade (M18)	lb/item	7.20E-01	---	6.80E-12	6.30E-12	---	3.80E-06	---	---	---	7.10E-07	---	8.80E-09	---	---	4.30E-11	---	9.30E-06
	G963	CS Riot Control Agent Hand Grenade (M7A3)	lb/item	7.50E-01	---	4.50E-11	4.80E-11	---	---	1.90E-06	3.80E-05	---	---	---	9.90E-08	1.70E-05	---	1.40E-10	---	6.40E-05
	G978	Simulant Screening Smoke Launcher Grenade (M82)	lb/item	1.68E+00	---	---	---	---	---	---	9.40E-07	---	9.70E-06	---	---	---	---	---	---	2.60E-05
	G982	Terephthalic Acid (TA) Smoke Practice Hand Grenade (M83)	lb/item	7.02E-01	6.00E-11	1.20E-12	3.30E-12	---	---	8.70E-07	2.90E-04	5.10E-07	7.90E-07	5.90E-07	2.90E-08	---	3.60E-11	2.00E-12	---	7.30E-05
	GG09	Non-Lethal Stun Hand Grenade (M84)	lb/item	7.65E-03	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Rockets, Rocket Motors, and Igniters	H163	2.75-inch Rocket with M151 High Explosive Warhead	lb/item	2.32E+00	---	---	---	---	---	6.10E-06	1.40E-05	---	6.10E-05	4.40E-06	---	1.40E-05	---	---	---	5.70E-05
	H459	2.75-inch Fletchette, MK40 Mod 3 Motor	lb/item	6.02E+00	---	---	---	---	---	1.20E-05	2.20E-05	---	---	2.80E-05	---	3.50E-05	---	---	---	1.10E-04
	H557	66-mm High Explosive Antitank Rocket (M72A3) (Propelling Rocket)	lb/item	1.34E-01	---	---	---	---	---	2.40E-09	1.40E-06	---	---	2.10E-09	---	5.70E-07	1.30E-13	2.90E-13	---	4.60E-08
		66-mm High Explosive Antitank Rocket (M72A3) (Warhead)	lb/item	6.84E-01	---	---	2.20E-13	---	3.20E-07	2.70E-07	1.50E-06	---	---	1.70E-07	---	---	---	4.50E-13	---	1.30E-05
		66-mm High Explosive Antitank Rocket (M72A3) (Total)	lb/item	8.18E-01	---	---	5.10E-13	---	3.20E-07	2.70E-07	2.90E-06	---	---	1.70E-07	---	5.70E-07	1.30E-13	7.40E-13	---	1.30E-05
	H708	35-mm Subcaliber Practice Rocket (M73) (Propelling Rocket)	lb/item	2.64E-02	---	---	---	---	1.30E-08	2.40E-09	---	---	3.90E-07	2.90E-09	---	8.70E-08	---	---	---	1.50E-07
		35-mm Subcaliber Practice Rocket (M73) (Warhead)	lb/item	3.20E-03	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	3.00E-07
		35-mm Subcaliber Practice Rocket (M73) (Total)	lb/item	2.96E-02	---	---	---	---	1.30E-08	2.40E-09	---	---	3.90E-07	2.90E-09	---	8.70E-08	---	---	---	4.60E-07
	H974	2.75-inch Practice Warhead, MK66 Mod 3 Motor (M267)	lb/item	7.17E+00	---	---	---	---	---	7.40E-06	---	---	---	1.10E-05	---	1.70E-05	---	---	---	4.70E-05

Table 16-3. HAP Emission Factors for Open Burn/Open Detonation (cont.)

Munition Type	DODIC	Item	Units:	Net Explosive Material - NEW (lb/item)	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)	Pentachlorophenol (87-86-5)	Perchloroethylene (127-18-4)	Phenanthrene (85-01-8)	Phenol (108-95-2)	Phosphorus (7723-14-0)	Propionaldehyde (123-38-6)	Pyrene (129-00-0)	Selenium (7782-49-2)	Styrene (100-42-5)	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)	Toluene (108-88-3)
Mines and Smoke Pots	K010	Field Incendiary Burster (M4)	lb/item	2.04E-02	---	---	---	---	---	6.70E-08	---	---	---	3.00E-08	---	7.30E-07	---	7.60E-13	---	2.40E-06
	K042	Practice Canister Mine (Volcano) (M88)	lb/item	1.39E-02	---	---	---	---	---	---	3.10E-08	---	8.50E-07	---	---	---	---	---	---	3.70E-07
	K051	Anti-Tank Practice Mine Fuze (M604)	lb/item	3.81E-02	1.60E-12	1.20E-12	1.60E-12	---	---	3.30E-08	---	---	---	2.50E-08	---	---	1.10E-11	3.00E-12	---	4.80E-08
	K145	Antipersonnel Mine (M18A1)	lb/item	1.50E+00	---	4.50E-13	8.40E-13	---	---	1.80E-06	3.90E-06	---	---	4.10E-07	---	---	---	1.30E-12	---	2.00E-05
	K765	CS Riot Control Agent Capsule	lb/item	---	---	4.50E-14	1.30E-13	---	---	---	2.10E-07	---	---	---	---	3.00E-08	---	3.20E-14	---	6.50E-07
	K866	30-Pound HC Smoke Pot (ABC-M5)	lb/item	3.10E+01	2.80E-09	3.50E-08	5.90E-08	---	4.30E-02	---	---	---	---	---	---	---	1.50E-09	1.10E-08	---	---
	K867	Floating Type HC Smoke Pot (M4A2)	lb/item	2.75E+01	2.00E-09	4.00E-08	3.50E-08	---	7.90E-02	---	---	1.50E-03	7.00E-05	---	2.90E-05	---	8.30E-10	2.10E-08	---	2.00E-04
Signals and Simulators	L305	Green Star Parachute Signal Flare (M195)	lb/item	3.16E-01	---	---	---	---	---	---	---	---	---	---	---	---	2.00E-12	---	---	1.60E-06
	L306	Red Star Cluster Signal Flare (M158)	lb/item	2.80E-01	---	---	---	---	---	---	---	---	---	---	---	2.40E-06	7.30E-13	---	---	8.10E-06
	L307	White Star Cluster Signal Flare (M159)	lb/item	3.20E-01	---	---	---	---	---	---	---	---	---	---	---	1.60E-06	7.20E-13	---	---	6.30E-06
	L311	Red Star Parachute Signal Flare (126A1)	lb/item	2.96E-01	---	---	---	---	---	---	---	---	---	---	---	8.10E-07	7.00E-13	---	---	2.70E-06
	L312	White Star Parachute Signal Flare (M127A1)	lb/item	2.83E-01	---	---	---	---	---	---	---	---	---	---	---	---	1.40E-12	---	---	1.80E-06
	L314	Green Star Cluster Signal Flare (M125A1)	lb/item	1.67E+00	---	---	---	---	---	---	---	---	---	---	---	6.70E-07	2.50E-13	---	---	4.80E-06
	L366	Air Burst Projectile Simulator (M74A1)	lb/item	8.99E-02	3.40E-12	3.00E-12	2.40E-12	---	---	---	1.70E-07	4.00E-06	---	---	1.20E-08	2.40E-07	1.10E-11	6.10E-11	---	---
	L367	Anti-Tank Guided Missle and Rocket Launching Simulator (M22)	lb/item	3.12E-02	---	---	---	---	---	---	1.30E-07	---	---	---	---	---	---	---	---	2.80E-07
	L410	Aircraft Countermeasure Flare (M206)	lb/item	2.84E-01	---	---	---	---	---	---	---	---	---	---	---	2.90E-07	---	---	---	2.60E-07
	L495	Surface Trip Flare (M49A1)	lb/item	1.08E+00	---	---	---	---	---	---	---	---	---	---	---	9.90E-06	5.30E-13	---	---	2.40E-06
	L508	Red Railroad Warning Fusee (M72)	lb/item	---	---	---	---	---	---	8.00E-08	5.00E-07	---	---	---	---	---	---	1.30E-13	---	6.40E-06
	L592	TOW Blast Simulator	lb/item	5.65E-03	5.30E-14	---	---	---	---	---	8.40E-08	1.10E-07	2.70E-08	---	---	---	---	---	---	---
	L594	Ground Burst Simulator (M115A2)	lb/item	1.41E-01	---	---	---	---	---	---	---	---	---	---	---	---	1.70E-12	---	---	1.80E-06
	L595	Liquid Projectile Air Burst Simulator (M9)	lb/item	1.38E-01	---	---	---	---	---	---	---	---	7.70E-07	---	---	4.60E-06	---	---	---	1.00E-06
	L596	Flash Artillery Simulator (M110)	lb/item	1.88E-01	---	---	---	---	5.70E-04	6.70E-07	---	---	---	1.90E-07	---	1.50E-05	1.40E-12	---	---	5.20E-03
	L598	Flash Booby Trap Simulator (M117)	lb/item	7.70E-03	---	---	---	---	---	---	---	---	---	---	1.90E-08	---	6.50E-14	---	---	1.90E-07
	L599	Illuminating Booby Trap Simulator (M118)	lb/item	1.34E-02	---	---	---	---	---	---	5.60E-08	---	---	1.10E-08	---	1.00E-07	3.20E-14	---	---	3.60E-07
	L600	Whistling Booby Trap Simulator (119)	lb/item	1.06E-01	---	---	---	---	---	---	---	---	---	---	---	5.80E-07	1.00E-13	---	---	1.60E-06
	L601	Hand Grenade Simulator (M116A1)	lb/item	8.13E-02	---	---	---	---	---	---	---	---	---	---	1.30E-07	---	4.70E-13	---	---	6.80E-07
	L602	Artillery Flash Simulator (M21)	lb/item	9.38E-02	---	---	---	---	---	---	2.80E-07	2.00E-05	---	---	5.10E-08	4.40E-07	---	---	---	---
	L709	Target-Hit Simulator (M25)	lb/item	6.00E-02	4.90E-10	4.70E-10	1.30E-09	---	---	4.80E-08	2.20E-07	4.40E-06	---	---	---	4.10E-06	---	6.90E-10	---	4.30E-07
	L720	Target Kill Simulator (M26)	lb/item	1.35E+00	---	1.50E-13	2.20E-13	---	---	4.20E-05	---	---	---	2.50E-05	---	2.40E-04	---	9.10E-13	---	2.10E-04
Fuses and Primers	N278	Mechanical Time and Super Quick (MTSQ) Fuse (M564)	lb/item	6.32E-02	---	1.10E-13	1.50E-13	---	---	3.10E-08	---	---	---	1.40E-08	---	1.50E-07	---	---	---	2.10E-07
	N285	Mechanical Time and Super Quick (MTSQ) Fuse (M577A1)	lb/item	9.39E-04	---	---	---	---	---	1.00E-08	---	---	---	8.60E-09	---	---	---	---	---	1.00E-07
	N286	Mechanical Time and Super Quick (MTSQ) Fuse (M582)	lb/item	5.27E-02	---	1.70E-13	2.50E-13	---	---	4.30E-08	---	---	---	2.10E-08	---	---	---	1.20E-13	---	2.10E-07
	N335	Point Detonating Fuse (M557)	lb/item	5.22E-02	8.50E-14	2.30E-13	4.00E-13	---	---	3.70E-09	---	---	---	2.00E-09	---	---	---	1.90E-13	---	5.60E-08
	N340	Point Detonating Fuse (M739A1)	lb/item	4.59E-02	---	1.50E-13	1.80E-13	---	---	3.30E-09	---	---	---	7.80E-10	---	5.60E-07	---	---	---	5.00E-08
	N464	Proximity Fuse (M732)	lb/item	1.37E-02	---	---	---	---	---	4.60E-08	---	---	---	3.00E-08	---	---	---	1.20E-13	---	7.10E-08

Table 16-3. HAP Emission Factors for Open Burn/Open Detonation (cont.)

Munition Type	DODIC	Item	Units:	Net Explosive Material - NEW (lb/item)	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)	Pentachlorophenol (87-86-5)	Perchloroethylene (127-18-4)	Phenanthrene (85-01-8)	Phenol (108-95-2)	Phosphorus (7723-14-0)	Propionaldehyde (123-38-6)	Pyrene (129-00-0)	Selenium (7782-49-2)	Styrene (100-42-5)	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)	Toluene (108-88-3)
Blasting Caps, Demolition Charges, and Detonators	M023	Demolition Block Charge (M112)	lb/item	1.25E+00	---	2.30E-13	9.50E-13	---	---	2.90E-07	---	---	---	1.70E-07	---	---	---	1.10E-12	---	3.70E-06
	M030	1/4-Pound Demolition Block Charge	lb/item	2.50E-01	---	1.40E-13	1.70E-13	---	---	4.80E-08	---	---	---	2.20E-08	---	---	---	6.70E-13	---	9.30E-09
	M031	1/2-Pound Demolition Block Charge	lb/item	5.00E-01	2.30E-12	---	1.90E-12	---	---	3.50E-07	3.80E-06	1.70E-04	---	1.30E-07	---	---	---	3.70E-12	---	2.30E-05
	M032	1-Pound Demolition Block Charge	lb/item	1.00E+00	---	---	7.00E-13	---	---	1.30E-07	---	---	---	---	3.80E-06	---	---	8.60E-13	---	---
	M130	Electric Blasting Cap (M6)	lb/item	2.92E-03	---	---	---	---	---	3.40E-09	---	---	4.30E-08	1.70E-09	---	---	---	1.60E-14	---	3.40E-08
	M131	Non-Electric Blasting Cap (M7)	lb/item	2.76E-03	---	---	---	---	---	3.10E-09	---	---	---	---	---	---	---	---	---	---
	M174	.50 Calibur Blank Cartridge (Electrically Initiated)	lb/item	2.33E-02	---	---	---	---	---	---	---	---	6.40E-07	---	---	---	---	---	---	2.40E-06
	M241	High Explosive Universal Destructor (M10)	lb/item	2.86E-01	1.20E-11	2.50E-12	2.70E-12	---	---	---	1.60E-06	1.20E-04	---	---	5.40E-07	9.70E-07	---	4.50E-12	---	---
	M327	Firing Device Coupling Base	lb/item	5.71E-05	---	---	---	---	---	---	---	---	---	1.40E-11	---	---	---	---	---	---
	M420	15-Pound Demolition Shaped Charge (M2A4)	lb/item	1.01E+01	---	1.40E-11	1.80E-11	---	3.30E-05	2.50E-06	---	---	---	---	---	---	---	6.40E-11	---	2.50E-05
	M448	8-Second Delay Percussion Detonator (M2A1)	lb/item	6.20E-03	---	1.40E-15	---	---	---	1.50E-09	---	---	1.80E-08	---	3.40E-09	---	---	1.70E-14	---	---
	M456	PETN Type 1 Detonating Cord	lb/item	7.00E-03	---	---	---	---	---	3.90E-06	4.60E-06	1.50E-04	---	2.50E-06	---	8.00E-06	---	2.60E-11	---	1.90E-04
	M500	Cartridge Actuated Cutter (M21)	lb/item	4.00E-03	---	---	---	---	---	---	---	---	1.10E-08	---	---	3.80E-08	---	---	---	1.70E-07
	M591	Military Dynamite Demolition Block Charge (M1)	lb/item	3.70E-01	---	---	---	---	---	6.50E-08	---	---	---	3.70E-08	---	---	---	4.40E-13	---	6.80E-08
	M626	Pressure Type Demolition Firing Device (M1)	lb/item	5.71E-05	---	---	---	---	---	---	---	---	---	---	3.30E-10	5.20E-10	---	---	---	3.10E-09
	M630	Pull Type Demolition Firing Device (M1)	lb/item	5.71E-05	---	---	---	---	---	---	3.70E-10	5.40E-09	2.40E-09	---	---	---	---	---	---	2.80E-09
	M670	Time Blasting Fuse (M700)	lb/item	2.70E-03	---	---	---	---	---	---	---	---	---	8.30E-08	---	---	---	---	2.30E-05	1.70E-04
	M766	Time Blasting Fuse Igniter (M60)	lb/item	5.71E-05	---	---	---	---	---	---	---	---	---	---	---	1.50E-09	---	---	---	1.30E-08
	M913	Linear Demolition Charge (M58A3)	lb/item	5.02E+00	3.40E-13	6.80E-13	1.00E-12	---	---	3.60E-07	---	---	5.90E-06	2.30E-07	---	6.10E-07	---	1.90E-12	---	5.50E-06
	MD73	Impulse Cartridge (M796)	lb/item	7.83E-04	---	---	---	---	---	---	---	---	---	8.60E-13	---	---	---	---	---	1.50E-08
	ML03	Multipurpose Demolition Firing Device (M142)	lb/item	4.71E-05	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	1.90E-08
	ML05	Powder Actuated Cutter (MK24)	lb/item	1.26E+00	---	---	3.40E-12	---	---	8.90E-07	3.50E-06	---	---	3.50E-07	---	3.60E-06	---	1.00E-12	---	2.10E-05
	ML09	**Linear Shaped Demolition Charge, 20 gr/ft**	**lb/lb NEW**	**2.86E-03**	**7.10E-09**	**5.60E-10**	**6.80E-10**	**1.80E-05**	**---**	**2.50E-06**	**2.50E-05**	**2.40E-04**	**---**	**1.60E-06**	**---**	**2.20E-05**	**---**	**7.10E-10**	**---**	**1.70E-04**
	ML15	**Linear Shaped Demolition Charge, 225 gr/ft**	**lb/lb NEW**	**3.21E-02**	**1.80E-09**	**1.30E-10**	**1.50E-10**	**---**	**---**	**2.40E-06**	**2.60E-05**	**4.90E-04**	**---**	**1.50E-06**	**---**	**3.30E-05**	**---**	**2.10E-10**	**---**	**3.00E-04**
	ML47	Non-Electric Blasting Cap with 30-foot Shock Tube (M11)	lb/item	2.73E-03	---	---	---	---	---	4.10E-09	---	---	---	6.30E-09	---	5.80E-08	---	1.70E-14	---	2.40E-07
	MM50	Clipped Shaped Demolition Charge (M221)	lb/item	6.62E-02	---	---	---	---	---	4.80E-08	---	---	---	3.00E-08	---	8.80E-07	---	---	---	1.40E-06
	MN02	Non-Electric Blasting Cap with 500-foot Shock Tube (M12)	lb/item	6.18E-03	---	---	---	---	---	5.50E-09	---	---	---	1.10E-08	---	5.70E-07	---	---	---	1.00E-06
	MN03	Non-Electric Blasting Cap with 1000-foot Shock Tube (M13)	lb/item	1.10E-02	---	---	---	---	---	6.00E-09	---	---	---	1.30E-08	---	5.00E-07	---	---	---	1.40E-06
	MN06	Non-Electric Time Delay Blasting Cap (M14)	lb/item	2.59E-02	---	---	---	---	---	2.10E-07	3.00E-06	---	1.40E-05	4.00E-08	---	4.30E-07	---	---	---	1.00E-05
	MN07	Non-Electric Time Delay Blasting Cap (M15)	lb/item	4.06E-03	---	---	---	---	---	1.40E-09	---	---	---	2.80E-09	---	---	---	1.30E-14	---	9.40E-08
	MN08	Time Blasting Fuse Igniter (M81)	lb/item	4.86E-05	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	2.60E-09
	MN60	Electric Match Igniter (M79)	lb/item	1.26E-02	---	---	---	---	---	1.20E-08	---	---	1.10E-07	1.20E-08	---	3.20E-09	---	7.90E-15	---	2.70E-07
	MN68	Booster Demolition Charge (M151)	lb/item	9.70E-03	1.90E-12	---	9.00E-13	---	---	---	5.50E-08	---	5.90E-07	---	---	---	---	---	---	---

Table 16-3. HAP Emission Factors for Open Burn/Open Detonation (cont.)

Munition Type	DODIC	Item	Units:	Net Explosive Material - NEW (lb/item)	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)	Pentachlorophenol (87-86-5)	Perchloroethylene (127-18-4)	Phenanthrene (85-01-8)	Phenol (108-95-2)	Phosphorus (7723-14-0)	Propionaldehyde (123-38-6)	Pyrene (129-00-0)	Selenium (7782-49-2)	Styrene (100-42-5)	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)	Toluene (108-88-3)
Energetic Materials[c]	---	Amatol	lb/lb NEW	5.00E-01[d]	---	---	---	---	3.70E-07	---	---	---	---	---	---	0.00E+00	---	---	---	6.70E-06
	J473	Cartridge, Impulse, ARD446-1	lb/lb NEW	---	---	---	---	---	3.60E-05	---	---	---	---	---	---	5.40E-06	---	---	---	1.70E-05
	MG11	Cartridge, Impulse, BBU-36/B	lb/lb NEW	---	---	---	---	---	2.40E-06	---	---	---	---	---	---	3.60E-06	---	---	---	9.10E-06
	M943	Cartridge, Impulse, MK 107	lb/lb NEW	---	---	---	---	---	0.00E+00	---	---	---	---	---	---	9.40E-06	---	---	---	9.00E-06
	---	Composition B surrogate	lb/lb NEW	5.00E-01[d]	---	---	---	---	1.80E-05	---	---	---	---	---	---	0.00E+00	---	---	---	6.00E-06
	---	Detonating Train	lb/lb NEW	---	---	---	---	---	1.10E-05	---	---	---	---	---	---	4.10E-06	---	---	---	4.20E-06
	F841	Fuse, Tail Bomb FMU-54 A/B	lb/lb NEW	---	---	---	---	---	0.00E+00	---	---	---	---	---	---	7.80E-06	---	---	---	3.20E-05
	F762	Fuse, Tail Bomb FMU-139 A/B	lb/lb NEW	---	---	---	---	---	0.00E+00	---	---	---	---	---	---	2.90E-05	---	---	---	2.30E-05
	L231	Signal, Illumination, Red Star AN-M43A2	lb/lb NEW	---	---	---	---	---	0.00E+00	---	---	---	---	---	---	4.50E-06	---	---	---	3.00E-05
	---	Tritonal surrogate	lb/lb NEW	---	---	---	---	---	2.70E-06	---	---	---	---	---	---	0.00E+00	---	---	---	1.80E-06
	---	Tritonal surrogate with calcium stearate	lb/lb NEW	---	---	---	---	---	3.70E-07	---	---	---	---	---	---	0.00E+00	---	---	---	0.00E+00
	---	TNT (Sandia)	lb/lb NEW	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	---	TNT (ACC1)	lb/lb NEW	---	---	---	---	---	0.00E+00	---	---	---	---	---	---	0.00E+00	---	---	---	5.10E-06
	---	TNT (ACC2)	lb/lb NEW	---	---	---	---	---	0.00E+00	---	---	---	---	---	---	1.50E-06	---	---	---	1.50E-06

Table 16-3. HAP Emission Factors for Open Burn/Open Detonation (cont.)

Munition Type	DODIC	Item	Units:	Net Explosive Material - NEW (lb/item)	1,2,4-Trichlorobenzene (120-82-1)	1,1,1-Trichloroethane (71-55-6)	1,1,2-Trichloroethane (79-00-5)	Trichloroethylene (79-01-6)	2,4,5-Trichlorophenol (95-95-4)	2,4,6-Trichlorophenol (88-06-2)	2,2,4-Trimethylpentane (540-84-1)	Vinyl Acetate (108-05-4)	Vinyl Chloride (75-01-4)	Vinylidene Chloride (75-35-4)	Xylenes [Mixed Isomers] (1330-20-7)
Projectiles, Canisters, and Charges	D505	155-mm Illumination Round (M485A2)	lb/item	6.12E+00	---	---	---	---	---	---	4.10E-06	---	---	---	8.70E-06
	D533	155-mm Propelling Charge, Zone 7 (M119A2)	lb/item	2.25E+01	---	---	---	---	---	---	1.40E-04	---	---	---	2.70E-05
	D540	**155-mm Propelling Charges (M3/M3A1)**	**lb/lb NEW**	(a)	**---**	**5.70E-05**	**---**	**---**	**---**	**---**	**2.30E-04**	**---**	**---**	**9.40E-06**	**1.20E-03**
	D541	155-mm Propelling Charge, Zone 7 (M4A2)	lb/item	1.33E+01	---	---	---	---	---	---	6.00E-04	---	---	---	---
Grenades	G815	Red Phosphorus Screening Smoke Launcher Grenade (UK) (L8A3)	lb/item	8.32E-01	---	---	---	---	---	---	---	---	---	---	---
	G878	Practice Hand Grenade Fuse (M228)	lb/item	4.50E-03	---	---	---	---	---	---	---	---	---	---	---
	G881	Fragmentation Hand Grenade (M67)	lb/item	4.10E-01	---	---	---	---	---	---	---	---	---	---	---
	G900	Thermite (TH3) Incendiary Hand Grenade (AN-M14)	lb/item	1.55E+00	---	---	---	---	---	---	---	---	---	---	---
	G911	Offensive Hand Grenade (MK3A2)	lb/item	4.94E-01	---	---	---	---	---	---	---	---	---	---	---
	G930	Hexachloroethane (HC) Smoke Hand Grenade (AN-M8)	lb/item	1.10E+00	---	---	---	7.90E-06	---	1.00E-06	---	---	2.70E-06	---	---
	G940	Green Smoke Hand Grenade (M18)	lb/item	7.20E-01	---	---	---	1.00E-05	---	---	---	---	6.70E-07	3.40E-07	---
	G945	Yellow Smoke Hand Grenade (M18)	lb/item	7.20E-01	---	5.90E-08	1.20E-06	8.60E-06	---	---	---	---	5.70E-06	4.20E-06	---
	G950	Red Smoke Hand Grenade (M18)	lb/item	7.20E-01	3.60E-08	---	---	4.40E-07	---	---	---	---	2.10E-06	4.00E-07	---
	G955	Violet Smoke Hand Grenade (M18)	lb/item	7.20E-01	---	---	---	6.00E-08	---	---	---	---	2.70E-06	2.40E-07	---
	G963	CS Riot Control Agent Hand Grenade (M7A3)	lb/item	7.50E-01	---	---	---	---	---	---	---	---	1.20E-05	---	---
	G978	Simulant Screening Smoke Launcher Grenade (M82)	lb/item	1.68E+00	---	---	---	---	---	---	---	---	---	---	---
	G982	Terephthalic Acid (TA) Smoke Practice Hand Grenade (M83)	lb/item	7.02E-01	---	---	---	---	4.10E-07	1.10E-05	---	---	---	---	---
	GG09	Non-Lethal Stun Hand Grenade (M84)	lb/item	7.65E-03	---	---	---	---	---	---	---	---	---	---	---
Rockets, Rocket Motors, and Igniters	H163	2.75-inch Rocket with M151 High Explosive Warhead	lb/item	2.32E+00	---	---	---	---	---	---	---	---	---	---	5.20E-06
	H459	2.75-inch Fletchette, MK40 Mod 3 Motor	lb/item	6.02E+00	---	---	---	---	---	---	---	---	---	---	---
	H557	66-mm High Explosive Antitank Rocket (M72A3) (Propelling Rocket)	lb/item	1.34E-01	---	2.10E-07	---	---	---	---	---	---	---	---	3.00E-07
		66-mm High Explosive Antitank Rocket (M72A3) (Warhead)	lb/item	6.84E-01	---	---	---	---	---	---	---	---	---	---	7.60E-07
		66-mm High Explosive Antitank Rocket (M72A3) (Total)	lb/item	8.18E-01	---	2.10E-07	---	---	---	---	---	---	---	---	1.06E-06
	H708	35-mm Subcaliber Practice Rocket (M73) (Propelling Rocket)	lb/item	2.64E-02	---	---	---	---	---	---	---	---	---	---	1.16E-06
		35-mm Subcaliber Practice Rocket (M73) (Warhead)	lb/item	3.20E-03	---	---	---	---	---	---	---	---	---	---	2.67E-07
		35-mm Subcaliber Practice Rocket (M73) (Total)	lb/item	2.96E-02	---	---	---	---	---	---	---	---	---	---	1.43E-06
	H974	2.75-inch Practice Warhead, MK66 Mod 3 Motor (M267)	lb/item	7.17E+00	---	---	---	---	---	---	---	---	---	---	---

Table 16-3. HAP Emission Factors for Open Burn/Open Detonation (cont.)

Munition Type	DODIC	Item	Units:	Net Explosive Material - NEW (lb/item)	1,2,4-Trichlorobenzene (120-82-1)	1,1,1-Trichloroethane (71-55-6)	1,1,2-Trichloroethane (79-00-5)	Trichloroethylene (79-01-6)	2,4,5-Trichlorophenol (95-95-4)	2,4,6-Trichlorophenol (88-06-2)	2,2,4-Trimethylpentane (540-84-1)	Vinyl Acetate (108-05-4)	Vinyl Chloride (75-01-4)	Vinylidene Chloride (75-35-4)	Xylenes [Mixed Isomers] (1330-20-7)
Mines and Smoke Pots	K010	Field Incendiary Burster (M4)	lb/item	2.04E-02	---	---	---	---	---	---	---	---	---	---	2.90E-06
	K042	Practice Canister Mine (Volcano) (M88)	lb/item	1.39E-02	---	---	---	---	---	---	---	---	---	---	---
	K051	Anti-Tank Practice Mine Fuze (M604)	lb/item	3.81E-02	---	---	---	---	---	---	---	---	---	---	---
	K145	Antipersonnel Mine (M18A1)	lb/item	1.50E+00	---	---	---	---	---	---	---	---	3.00E-06	---	5.90E-06
	K765	CS Riot Control Agent Capsule	lb/item	---	---	---	---	---	---	---	---	---	---	---	9.30E-08
	K866	30-Pound HC Smoke Pot (ABC-M5)	lb/item	3.10E+01	---	---	---	3.20E-04	---	9.50E-04	---	---	1.20E-04	---	---
	K867	Floating Type HC Smoke Pot (M4A2)	lb/item	2.75E+01	---	---	---	3.70E-04	---	---	---	---	2.20E-04	1.30E-04	---
Signals and Simulators	L305	Green Star Parachute Signal Flare (M195)	lb/item	3.16E-01	---	---	---	---	---	---	---	---	---	---	1.45E-06
	L306	Red Star Cluster Signal Flare (M158)	lb/item	2.80E-01	---	---	---	---	---	---	1.30E-06	---	---	---	1.34E-05
	L307	White Star Cluster Signal Flare (M159)	lb/item	3.20E-01	---	---	---	---	---	---	3.40E-07	---	---	---	1.43E-05
	L311	Red Star Parachute Signal Flare (126A1)	lb/item	2.96E-01	---	---	---	---	---	---	1.10E-07	---	---	---	6.80E-07
	L312	White Star Parachute Signal Flare (M127A1)	lb/item	2.83E-01	---	---	---	---	---	---	---	---	---	---	8.40E-07
	L314	Green Star Cluster Signal Flare (M125A1)	lb/item	1.67E+00	---	---	---	---	---	---	---	---	---	---	3.30E-06
	L366	Air Burst Projectile Simulator (M74A1)	lb/item	8.99E-02	---	---	---	---	---	---	2.40E-07	---	---	---	2.43E-06
	L367	Anti-Tank Guided Missle and Rocket Launching Simulator (M22)	lb/item	3.12E-02	---	---	---	---	---	---	---	---	---	---	3.00E-07
	L410	Aircraft Countermeasure Flare (M206)	lb/item	2.84E-01	---	---	---	---	---	---	---	---	---	---	---
	L495	Surface Trip Flare (M49A1)	lb/item	1.08E+00	---	---	---	---	---	---	8.80E-07	---	---	---	---
	L508	Red Railroad Warning Fusee (M72)	lb/item	---	---	---	---	---	---	---	---	---	---	---	1.42E-06
	L592	TOW Blast Simulator	lb/item	5.65E-03	---	---	---	---	---	---	---	---	2.80E-08	---	---
	L594	Ground Burst Simulator (M115A2)	lb/item	1.41E-01	---	---	---	---	---	---	4.20E-07	---	---	---	1.47E-06
	L595	Liquid Projectile Air Burst Simulator (M9)	lb/item	1.38E-01	---	---	---	---	---	---	---	---	---	---	---
	L596	Flash Artillery Simulator (M110)	lb/item	1.88E-01	---	---	---	---	---	---	3.30E-05	---	---	---	6.00E-03
	L598	Flash Booby Trap Simulator (M117)	lb/item	7.70E-03	---	---	---	---	---	---	3.40E-07	---	---	---	7.00E-08
	L599	Illuminating Booby Trap Simulator (M118)	lb/item	1.34E-02	---	---	---	---	---	---	4.50E-08	---	---	---	9.80E-07
	L600	Whistling Booby Trap Simulator (119)	lb/item	1.06E-01	---	---	---	---	---	---	5.70E-08	---	---	---	9.70E-06
	L601	Hand Grenade Simulator (M116A1)	lb/item	8.13E-02	---	---	---	---	---	---	2.40E-07	---	---	---	6.00E-07
	L602	Artillery Flash Simulator (M21)	lb/item	9.38E-02	---	---	---	---	---	---	7.70E-07	---	---	---	4.10E-06
	L709	Target-Hit Simulator (M25)	lb/item	6.00E-02	---	1.20E-07	---	---	---	---	---	---	---	---	3.20E-07
	L720	Target Kill Simulator (M26)	lb/item	1.35E+00	---	---	---	---	---	---	---	---	3.10E-07	---	9.50E-06
Fuses and Primers	N278	Mechanical Time and Super Quick (MTSQ) Fuse (M564)	lb/item	6.32E-02	---	---	---	---	---	---	---	---	---	---	---
	N285	Mechanical Time and Super Quick (MTSQ) Fuse (M577A1)	lb/item	9.39E-04	---	---	---	---	---	---	---	---	---	---	1.70E-08
	N286	Mechanical Time and Super Quick (MTSQ) Fuse (M582)	lb/item	5.27E-02	---	---	---	---	---	---	---	---	---	---	---
	N335	Point Detonating Fuse (M557)	lb/item	5.22E-02	---	---	---	---	---	---	---	---	---	---	2.00E-08
	N340	Point Detonating Fuse (M739A1)	lb/item	4.59E-02	---	---	---	---	---	---	---	---	---	---	5.70E-08
	N464	Proximity Fuse (M732)	lb/item	1.37E-02	---	---	---	---	---	---	---	---	---	---	---

Table 16-3. HAP Emission Factors for Open Burn/Open Detonation (cont.)

Munition Type	DODIC	Item	Units:	Net Explosive Material - NEW (lb/item)	1,2,4-Trichlorobenzene (120-82-1)	1,1,1-Trichloroethane (71-55-6)	1,1,2-Trichloroethane (79-00-5)	Trichloroethylene (79-01-6)	2,4,5-Trichlorophenol (95-95-4)	2,4,6-Trichlorophenol (88-06-2)	2,2,4-Trimethylpentane (540-84-1)	Vinyl Acetate (108-05-4)	Vinyl Chloride (75-01-4)	Vinylidene Chloride (75-35-4)	Xylenes [Mixed Isomers] (1330-20-7)
Blasting Caps, Demolition Charges, and Detonators	M023	Demolition Block Charge (M112)	lb/item	1.25E+00	---	7.60E-09	---	---	---	---	---	---	---	---	---
	M030	1/4-Pound Demolition Block Charge	lb/item	2.50E-01	---	5.70E-06	---	---	---	---	---	3.20E-07	---	---	3.80E-06
	M031	1/2-Pound Demolition Block Charge	lb/item	5.00E-01	---	---	---	---	---	---	7.70E-06	---	---	---	---
	M032	1-Pound Demolition Block Charge	lb/item	1.00E+00	---	---	---	---	---	---	---	---	8.00E-08	---	---
	M130	Electric Blasting Cap (M6)	lb/item	2.92E-03	---	---	---	---	---	---	---	---	---	---	---
	M131	Non-Electric Blasting Cap (M7)	lb/item	2.76E-03	---	---	---	---	---	---	---	---	---	---	---
	M174	.50 Calibur Blank Cartridge (Electrically Initiated)	lb/item	2.33E-02	---	---	---	---	---	---	---	---	---	---	2.50E-07
	M241	High Explosive Universal Destructor (M10)	lb/item	2.86E-01	---	---	---	---	---	---	5.20E-06	---	---	---	1.73E-05
	M327	Firing Device Coupling Base	lb/item	5.71E-05	---	---	---	---	---	---	---	---	---	---	1.80E-09
	M420	15-Pound Demolition Shaped Charge (M2A4)	lb/item	1.01E+01	---	---	---	---	---	---	---	---	4.60E-06	---	5.50E-06
	M448	8-Second Delay Percussion Detonator (M2A1)	lb/item	6.20E-03	---	---	---	---	---	---	---	---	---	---	6.10E-08
	M456	PETN Type 1 Detonating Cord	lb/item	7.00E-03	---	---	---	---	---	---	2.70E-05	---	---	---	2.86E-04
	M500	Cartridge Actuated Cutter (M21)	lb/item	4.00E-03	---	---	---	---	---	---	---	---	---	---	2.02E-08
	M591	Military Dynamite Demolition Block Charge (M1)	lb/item	3.70E-01	---	2.20E-08	---	---	---	---	---	---	---	---	3.10E-06
	M626	Pressure Type Demolition Firing Device (M1)	lb/item	5.71E-05	---	---	---	---	---	---	---	---	---	---	1.96E-09
	M630	Pull Type Demolition Firing Device (M1)	lb/item	5.71E-05	---	---	---	---	---	---	---	---	---	---	1.61E-09
	M670	Time Blasting Fuse (M700)	lb/item	2.70E-03	---	---	---	---	---	---	---	---	---	---	5.60E-06
	M766	Time Blasting Fuse Igniter (M60)	lb/item	5.71E-05	---	1.20E-09	---	---	---	---	---	---	4.90E-10	---	6.20E-09
	M913	Linear Demolition Charge (M58A3)	lb/item	5.02E+00	---	---	---	---	---	---	---	---	9.20E-07	---	9.80E-07
	MD73	Impulse Cartridge (M796)	lb/item	7.83E-04	---	---	---	---	---	---	---	---	---	---	1.15E-07
	ML03	Multipurpose Demolition Firing Device (M142)	lb/item	4.71E-05	---	---	---	---	---	---	---	---	---	---	---
	ML05	Powder Actuated Cutter (MK24)	lb/item	1.26E+00	---	---	---	---	---	---	---	---	1.50E-06	---	7.90E-06
	ML09	**Linear Shaped Demolition Charge, 20 gr/ft**	**lb/lb NEW**	**2.86E-03**	**---**	**4.80E-06**	**---**	**---**	**---**	**---**	**4.90E-05**	**---**	**---**	**---**	**9.80E-05**
	ML15	**Linear Shaped Demolition Charge, 225 gr/ft**	**lb/lb NEW**	**3.21E-02**	**---**	**---**	**---**	**---**	**---**	**---**	**7.50E-05**	**---**	**---**	**---**	**3.23E-04**
	ML47	Non-Electric Blasting Cap with 30-foot Shock Tube (M11)	lb/item	2.73E-03	---	---	---	---	---	---	---	---	---	---	---
	MM50	Clipped Shaped Demolition Charge (M221)	lb/item	6.62E-02	---	---	---	---	---	---	---	---	---	---	---
	MN02	Non-Electric Blasting Cap with 500-foot Shock Tube (M12)	lb/item	6.18E-03	---	---	---	---	---	---	---	---	---	---	1.10E-07
	MN03	Non-Electric Blasting Cap with 1000-foot Shock Tube (M13)	lb/item	1.10E-02	---	---	---	---	---	---	---	---	---	---	7.90E-08
	MN06	Non-Electric Time Delay Blasting Cap (M14)	lb/item	2.59E-02	---	---	---	---	---	---	4.10E-07	---	---	---	3.08E-06
	MN07	Non-Electric Time Delay Blasting Cap (M15)	lb/item	4.06E-03	---	---	---	---	---	---	---	---	---	---	---
	MN08	Time Blasting Fuse Igniter (M81)	lb/item	4.86E-05	---	---	---	---	---	---	---	---	---	---	---
	MN60	Electric Match Igniter (M79)	lb/item	1.26E-02	---	---	---	---	---	---	---	---	---	---	9.40E-08
	MN68	Booster Demolition Charge (M151)	lb/item	9.70E-03	---	---	---	---	---	---	---	---	---	---	---

Table 16-3. HAP Emission Factors for Open Burn/Open Detonation (cont.)

Munition Type	DODIC	Item	Units:	Net Explosive Material - NEW (lb/item)	1,2,4-Trichlorobenzene (120-82-1)	1,1,1-Trichloroethane (71-55-6)	1,1,2-Trichloroethane (79-00-5)	Trichloroethylene (79-01-6)	2,4,5-Trichlorophenol (95-95-4)	2,4,6-Trichlorophenol (88-06-2)	2,2,4-Trimethylpentane (540-84-1)	Vinyl Acetate (108-05-4)	Vinyl Chloride (75-01-4)	Vinylidene Chloride (75-35-4)	Xylenes [Mixed Isomers] (1330-20-7)
Energetic Materials[c]	---	Amatol	lb/lb NEW	5.00E-01[d]	---	3.70E-07	---	---	---	---	---	---	0.00E+00	---	---
	J473	Cartridge, Impulse, ARD446-1	lb/lb NEW	---	---	1.20E-06	---	---	---	---	---	---	0.00E+00	---	---
	MG11	Cartridge, Impulse, BBU-36/B	lb/lb NEW	---	---	0.00E+00	---	---	---	---	---	---	1.70E-06	---	---
	M943	Cartridge, Impulse, MK 107	lb/lb NEW	---	---	0.00E+00	---	---	---	---	---	---	2.40E-06	---	---
	---	Composition B surrogate	lb/lb NEW	5.00E-01[d]	---	0.00E+00	---	---	---	---	---	---	0.00E+00	---	---
	---	Detonating Train	lb/lb NEW	---	---	0.00E+00	---	---	---	---	---	---	1.30E-06	---	---
	F841	Fuse, Tail Bomb FMU-54 A/B	lb/lb NEW	---	---	0.00E+00	---	---	---	---	---	---	6.80E-07	---	---
	F762	Fuse, Tail Bomb FMU-139 A/B	lb/lb NEW	---	---	1.60E-05	---	---	---	---	---	---	1.80E-06	---	---
	L231	Signal, Illumination, Red Star AN-M43A2	lb/lb NEW	---	---	0.00E+00	---	---	---	---	---	---	2.30E-06	---	---
	---	Tritonal surrogate	lb/lb NEW	---	---	0.00E+00	---	---	---	---	---	---	0.00E+00	---	---
	---	Tritonal surrogate with calcium stearate	lb/lb NEW	---	---	0.00E+00	---	---	---	---	---	---	0.00E+00	---	---
	---	TNT (Sandia)	lb/lb NEW	---	---	---	---	---	---	---	---	---	---	---	---
	---	TNT (ACC1)	lb/lb NEW	---	---	0.00E+00	---	---	---	---	---	---	0.00E+00	---	---
	---	TNT (ACC2)	lb/lb NEW	---	---	0.00E+00	---	---	---	---	---	---	0.00E+00	---	---

SOURCE: United States EPA. Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources. Fifth edition. Chapter 15.

a) NEW is dependent on the configuration. Refer to Table 15.4.4-1 in AP-42 for assistance in selecting the appropriate NEW.

b) Source states that this is a “toxic equivalent”.

c) SOURCE: Mitchell, William J. and Jack C. Suggs, “Emission Factors for the Disposal of Energetic Materials by Open Burning and Open Detonation (OB/OD),” U.S. Environmental Protection Agency, August 1998.

d) SOURCE: Wilcox, J. L., et al., "Characterization of Emissions Produced by the Open Burning/Open Detonation of Complex Munitions," Physical Test Division, West Desert Test Center, September 1996.

“---” – No data is available.

“00.00E+00” - Compound was not detected or detected at only the background level.

16.7 References

40 CFR 98 Subpart C, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 98-Mandatory Greenhouse Gas Reporting, Subpart C- General Stationary Fuel Combustion Sources," U.S. Environmental Protection Agency

40 CFR 265 Subpart P, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 265-Interim Status Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities, Subpart P-Thermal Treatment," U.S. Environmental Protection Agency

Mitchell 1998, Mitchell, William J. and Jack C. Suggs, "Emission Factors for the Disposal of Energetic Materials by Open Burning and Open Detonation (OB/OD)," U.S. Environmental Protection Agency, August 1998

USEPA 2007, Section 15.4-"Projectiles, Canisters, and Charges," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, January 2007

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USEPA 2008b, Section 15.10-"Fuses and Primers," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, October 2008

USEPA 2009a, Section 15.5-"Grenades," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, July 2009

USEPA 2009b, Section 15.6-"Rockets, Rocket Motors, and Igniters," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, July 2009

USEPA 2009c, Section 15.8-"Signals and Simulators," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, July 2009

USEPA 2009d, Section 15.9-"Blasting Caps, Demolition Charges, and Detonators," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, July 2009

Wilcox 1996, Wilcox, J. L., et al., "Characterization of Emissions Produced by the Open Burning/Open Detonation of Complex Munitions," Physical Test Division, West Desert Test Center, September 1996

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17 OZONE DEPLETING CHEMICALS (ODC)

- *Fugitive Sources*

17.1 Introduction

ODCs are substances that contribute to the depletion of the stratospheric ozone layer within the atmosphere. The importance of the ozone layer is in its ability to absorb solar UV radiation that is considered harmful to life on Earth. It is essential to keep ODCs to a minimum due to their dangerous health and environmental effects. Estimating emissions of ODCs is not only significant for AEI purposes, but may also be necessary for Toxic Release Inventory (TRI) reporting required under the Emergency Planning and Community Right to Know Act (EPCRA).

ODCs are categorized as being either class I or class II based on their ODP value. Class I is regarded as having a greater ODP than class II substances. The ODP is the ratio of the impact on ozone of a chemical compared to the impact of a similar mass of trichlorofluoromethane (CFC-11). These substances contain compounds such as CFC, HCFCs, halons, methyl bromide, 1,1,1-trichloroethane (TCA) (also referred to as methyl chloroform), and carbon tetrachloride. In the stratosphere, ODCs catalyze ozone-degrading reactions in the presence of UV radiation, thus reducing the concentration of beneficial ozone. These substances are widely used in refrigerators, air conditioners, and fire extinguishers, as well as in solvents for cleaning, and as agricultural fumigants at USAF installations. **Emissions from ODCs are typically fugitive in nature** and a graphic representation of emissions is given in Figure 17-1.

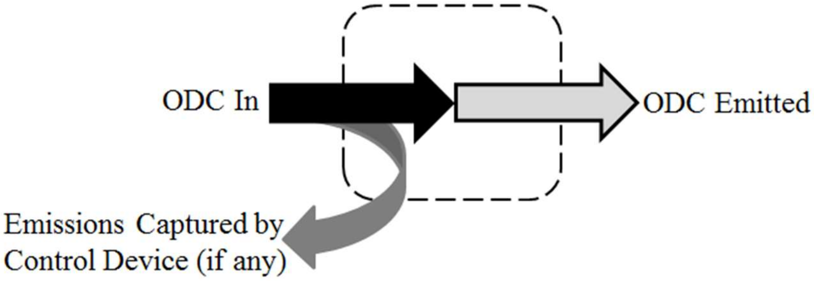

Figure 17-1. Simple Control Volume for Emissions from Ozone Depleting Chemicals

Since 1993, the USAF has reduced the consumption of ODCs by 96 percent. Additionally, the USAF is expected to replace ODCs in the future with non-hazardous substances according to the Department of Defense (DOD). This initiative is the result of the need to protect the integrity of the stratospheric ozone layer and the increased awareness of the GWP of each pollutant as climate change has become an increasingly more prevalent topic. The GWP of a gas is a measure of its ability to trap heat in the atmosphere and uses CO_2 as the baseline reference. For example, CH_4 is stated to have a GWP of 25, which means that it traps 25 times more heat than CO_2 over a 100-year time span. A list of class I and II ODCs is provided in Table 17-1 and Table 17-2.

Table 17-1. List of Class I Ozone Depleting Chemicals

Group	Compound	Chemical Name	ODP(a)	GWP(b)
Group I	CFC-11 ($CFC1_3$)	Trichlorofluoromethane	1.00	4,000
	CFC-12 (CF_2Cl_2)	Dichlorodifluoromethane	1.00	8,500
	CFC-113 ($C_2F_3Cl_3$)	Trichlorotrifluoroethane	0.80	5,000
	CFC-114 ($C_2F_4Cl_2$)	Dichlorotetrafluoroethane	1.00	9,300
	CFC-115 (C_2F_5Cl)	Monochloropentafluoroethane	0.60	9,300
Group II	Halon 1211 (CF_2ClBr)	Bromochlorodifluoromethane	3.00	1,890(c)
	Halon 1301 (CF_3Br)	Bromotrifluoromethane	10.00	7,140(c)
	Halon 2402 ($C_2F_4Br_2$)	Dibromotetrafluoroethane	6.00	1,640(c)
Group III	CFC-13 (CF_3Cl)	Chlorotrifluoromethane	1.00	11,700
	CFC-111 (C_2FCl_5)	Pentachlorofluoroethane	1.00	---
	CFC-112 ($C_2F_2Cl_4$)	Tetrachlorodifluoroethane	1.00	---
	CFC-211 (C_3FCl_7)	Heptachlorofluoropropane	1.00	---
	CFC-212 ($C_3F_2Cl_6$)	Hexachlorodifluoropropane	1.00	---
	CFC-213 ($C_3F_3Cl_5$)	Pentachlorotrifluoropropane	1.00	---
	CFC-214 ($C_3F_4Cl_4$)	Tetrachlorotetrafluoropropane	1.00	---
	CFC-215 ($C_3F_5Cl_3$)	Trichloropentafluoropropane	1.00	---
	CFC-216 ($C_3F_6Cl_2$)	Dichlorohexafluoropropane	1.00	---
	CFC-217 (C_3F_7Cl)	Chloroheptafluoropropane	1.00	---
Group IV	CCl_4	Carbon Tetrachloride	1.10	1,400
Group V	$C_2H_3Cl_3$	1,1,1-Trichloroethane	0.10	110
Group VI	CH_3Br	Bromomethane	0.70	5(c)
Group VII	$CHFBr_2$	Dibromofluoromethane	1.00	---
	CHF_2Br	Bromodifluoromethane	0.74	---
	CH_2FBr	Bromofluoromethane	0.73	---
	C_2HFBr_4	Tetrabromofluoroethane	0.80	---
	$C_2HF_2Br_3$	Tribromodifluoroethane	1.80	---
	$C_2HF_3Br_2$	Dibromotrifluoroethane	1.60	---
	C_2HF_4Br	Bromotetrafluorethane	1.20	---
	$C_2H_2FBr_3$	Tribromofluoroethane	1.10	---
	$C_2H_2F_2Br_2$	Dibromodifluoroethane	1.50	---
	$C_2H_2F_3Br$	Bromotrifluoroethane	1.60	---
	$C_2H_2FBr_2$	Dibromofluoroethane	1.70	---
	$C_2H_3F_2Br$	Bromodifluoroethane	1.10	---
	C_2H_4FBr	Bromofluoroethane	0.10	---
	C_3HFBr_6	Hexabromofluoropropane	1.50	---

Table 17-1. List of Class I Ozone Depleting Chemicals (cont.)

Group	Compound	Chemical Name	ODP[(a)]	GWP[(b)]
Group VII (Continued)	$C_3HF_2Br_5$	Pentabromodifluoropropane	1.90	---
	$C_3HF_3Br_4$	Tetrabromotrifluoropropane	1.80	---
	$C_3HF_4Br_3$	Tribromotetrafluoropropane	2.20	---
	$C_3HF_5Br_2$	Dibromopentafluoropropane	2.00	---
	C_3HF_6Br	Bromohexafluoropropane	3.30	---
	$C_3H_2FBr_5$	Pentabromofluoropropane	1.90	---
	$C_3H_2F_2Br_4$	Tetrabromodifluoropropane	2.10	---
	$C_3H_2F_3Br_3$	Tribromotrifluoropropane	5.60	---
	$C_3H_2F_4Br_2$	Dibromotetrafluoropropane	7.50	---
	$C_3H_2F_5Br$	Bromopentafluoropropane	1.40[(d)]	---
	$C_3H_3FBr_4$	Tetrabromofluoropropane	1.90	---
	$C_3H_3F_2Br_3$	Tribromodifluoropropane	3.10	---
	$C_3H_3F_3Br_2$	Dibromotrifluoropropane	2.50	---
	$C_3H_3F_4Br$	Bromotetrafluoropropane	4.40	---
	$C_3H_4FBr_3$	Tribromofluoropropane	0.30	---
	$C_3H_4F_2Br_2$	Dibromodifluoropropane	1.00	---
	$C_3H_4F_3Br$	Bromotrifluoropropane	0.80	---
	$C_3H_5FBr_2$	Dibromofluoropropane	0.40	---
	$C_3H_5F_2Br$	Bromodifluoropropane	0.80	---
	C_3H_6FBr	Bromofluoropropane	0.70	---
Group VIII	CH_2BrCl	Chlorobromomethane	0.12	---

a) SOURCE: Appendix A to "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 82-Protection of the Stratospheric Ozone, Subpart A-Production and Consumption Controls," U.S. Environmental Protection Agency. Value represents the maximum if a range provided. ODP = Ozone Depletion Potential. GWP = Global Warming Potential.

b) SOURCE (Unless otherwise noted): Appendix I to "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 82-Protection of the Stratospheric Ozone, Subpart A-Production and Consumption Controls," U.S. Environmental Protection Agency.

c) SOURCE: "Scientific Assessment of Ozone Depletion: 2010," World Meteorological Organization (WMO), 2010.

d) SOURCE: "Handbook for the Montreal Protocol on Substances that Deplete the Ozone Layer Ninth edition," Ozone Secretariat, United Nations Environment Programme (UNEP), 2012.

"---" - No data available.

Table 17-2. List of Class II Ozone Depleting Chemicals

Compound	Chemical Name	ODP(a)	GWP(b)
HCFC-21 ($CHFCl_2$)	Dichlorofluoromethane	0.04	---
HCFC-22 (CHF_2Cl)	Monochlorodifluoromethane	0.055	1,700
HCFC-31 (CH_2FCl)	Monochlorofluoromethane	0.02	---
HCFC-121 (C_2HFCl_4)	Tetrachlorofluoroethane	0.04	---
HCFC-122 ($C_2HF_2Cl_3$)	Trichlorodifluoroethane	0.08	---
HCFC-123 ($C_2HF_3Cl_2$)	Dichlorotrifluoroethane	0.02	93
HCFC-124 (C_2HF_4Cl)	Monochlorotetrafluoroethane	0.022	480
HCFC-131 ($C_2H_2FCl_3$)	Trichlorofluoroethane	0.05	---
HCFC-132 ($C_2H_2F_2Cl_2$)	Dichlorodifluoroethane	0.05	---
HCFC-133 ($C_2H_2F_3Cl$)	Monochlorotrifluoroethane	0.06	---
HCFC-141b ($C_2H_3FCl_2$)	Dichlorofluoroethane	0.11	630
HCFC-142b ($C_2H_3F_2Cl$)	Monochlorodifluoroethane	0.065	2,000
HCFC-151 (C_2H_4FCl)	Chlorofluoroethane	0.005	---
HCFC-221 (C_3HFCl_6)	Hexachlorofluoropropane	0.07	---
HCFC-222 ($C_3HF_2Cl_5$)	Pentachlorodifluoropropane	0.09	---
HCFC-223 ($C_3HF_3Cl_4$)	Tetrachlorotrifluoropropane	0.08	---
HCFC-224 ($C_3HF_4Cl_3$)	Trichlorotetrafluoropropane	0.09	---
HCFC-225ca ($C_3HF_5Cl_2$)	Dichloropentafluoropropane	0.025	170
HCFC-225cb ($C_3HF_5Cl_2$)	Dichloropentafluoropropane	0.033	530
HCFC-226 (C_3HF_6Cl)	Monochlorohexafluoropropane	0.1	---
HCFC-231 ($C_3H_2FCl_5$)	Pentachlorofluoropropane	0.09	---
HCFC-232 ($C_3H_2F_2Cl_4$)	Tetrachlorodifluoropropane	0.1	---
HCFC-233 ($C_3H_2F_3Cl_3$)	Trichlorotrifluoropropane	0.23	---
HCFC-234 ($C_3H_2F_4Cl_2$)	Dichlorotetrafluoropropane	0.28	---
HCFC-235 ($C_3H_2F_5Cl$)	Monochloropentafluoropropane	0.52	---
HCFC-241 ($C_3H_3FCl_4$)	Tetrachlorofluoropropane	0.09	---
HCFC-242 ($C_3H_3F_2Cl_3$)	Trichlorodifluoropropane	0.13	---
HCFC-243 ($C_3H_3F_3Cl_2$)	Dichlorotrifluoropropane	0.12	---
HCFC-244 ($C_3H_3F_4Cl$)	Monochlorotetrafluoropropane	0.14	---
HCFC-251 ($C_3H_4FCl_3$)	Trichlorofluoropropane	0.01	---
HCFC-252 ($C_3H_4F_2Cl_2$)	Dichlorodifluoropropane	0.04	---
HCFC-253 ($C_3H_4F_3Cl$)	Monochlorotrifluoropropane	0.03	---
HCFC-261 ($C_3H_5FCl_2$)	Dichlorofluoropropane	0.02	---
HCFC-262 ($C_3H_5F_2Cl$)	Monochlorodifluoropropane	0.02	---
HCFC-271 (C_3H_6FCl)	Monochlorofluoropropane	0.03	---

a) SOURCE: Appendix B to "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 82-Protection of the Stratospheric Ozone, Subpart A-Production and Consumption Controls," U.S. Environmental Protection Agency. Value represents the maximum if a range is provided. ODP = Ozone Depletion Potential. GWP = Global Warming Potential.

b) SOURCE: Appendix I to "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 82-Protection of the Stratospheric Ozone, Subpart A-Production and Consumption Controls," U.S. Environmental Protection Agency.

“---” - No data available.

As the ozone layer absorbs solar UV radiation, it begins to heat the surrounding air. As ODCs damage the ozone layer, the amount of UV radiation absorbed begins to decline, which leads to stratospheric cooling. This cooling subsequently leads to the formation of polar stratospheric clouds that catalyze the reactions resulting in additional ozone layer destruction. Several ODCs may also be classified as GHGs. In addition to the estimation of ODC emissions, it may be beneficial to determine the emissions of GHGs. A list of GHGs and their respective GWPs are provided in Table 17-3.

17.2 Control Techniques

There are several control devices which may be used to control air emissions that are process specific. The most common air emissions control technique is the use of a carbon adsorber. Liquid and gaseous chemicals collect in the porous carbon, reducing the amount of chemical vapor released into the environment.

17.3 Emissions Calculation

ODC emissions may be estimated using a mass balance approach to calculate total emissions produced from each emitting source on a USAF installation. In general, the ODC emissions from an applicable process are considered equal to the amount of ODC used, minus the amount removed for purposes of disposal, recycling, or reclamation. In some cases, emissions of certain ODC-containing products, such as sterilants and coatings, may be controlled using devices such as an incinerator or carbon adsorbers. In these cases, the efficiency of the control device must be considered when making emissions estimates. Calculation of ODC emissions may be made using Equation 17-1 as shown.

Table 17-3. GHG List with Their Respective Global Warming Potentials

Name	Chemical Formula	Global Warming Potential (100 yr.)
Carbon dioxide	CO_2	1
Methane	CH_4	25
Nitrous oxide	N_2O	298
HFC-23	CHF_3	14,800
HFC-32	CH_2F_2	675
HFC-41	CH_3F	92
HFC-125	C_2HF_5	3,500
HFC-134	$C_2H_2F_4$	1,100
HFC-134a	CH_2FCF_3	1,430
HFC-143	$C_2H_3F_3$	353
HFC-143a	$C_2H_3F_3$	4,470
HFC-152	CH_2FCH_2F	53
HFC-152a	CH_3CHF_2	124
HFC-161	CH_3CH_2F	12
HFC-227ea	C_3HF_7	3,220
HFC-236cb	$CH_2FCF_2CF_3$	1,340
HFC-236ea	CHF_2CHFCF_3	1,370
HFC-236fa	$C_3H_2F_6$	9,810
HFC-245ca	$C_3H_3F_5$	693
HFC-245fa	$CHF_2CH_2CF_3$	1,030
HFC-365mfc	$CH_3CF_2CH_2CF_3$	794
HFC-43-10mee	$CF_3CFHCFHCF_2CF_3$	1,640
Sulfur hexafluoride	SF_6	22,800
Trifluoromethyl sulphur pentafluoride	SF_5CF_3	17,700
Nitrogen trifluoride	NF_3	17,200
PFC-14 (Perfluoromethane)	CF_4	7,390
PFC-116 (Perfluoroethane)	C_2F_6	12,200
PFC-218 (Perfluoropropane)	C_3F_8	8,830
Perfluorocyclopropane	$C-C_3F_6$	17,340
PFC-3-1-10 (Perfluorobutane)	C_4F_{10}	8,860
PFC-318 (Perfluorocyclobutane)	$C-C_4F_8$	10,300
PFC-4-1-12 (Perfluoropentane)	C_5F_{12}	9,160
PFC-5-1-14 (Perfluorohexane, FC-72)	C_6F_{14}	9,300
PFC-9-1-18	$C_{10}F_{18}$	7,500
HCFE-235da2 (Isoflurane)	$CHF_2OCHClCF_3$	350
HFE-43-10pccc (H-Galden 1040x, HG-11)	$CHF_2OCF_2OC_2F_4OCHF_2$	1,870
HFE-125	CHF_2OCF_3	14,900
HFE-134 (HG-00)	CHF_2OCHF_2	6,320
HFE-143a	CH_3OCF_3	756
HFE-227ea	$CF_3CHFOCF_3$	1,540
HFE-236ca12 (HG-10)	$CHF_2OCF_2OCHF_2$	2,800
HFE-236ea2 (Desflurane)	$CHF_2OCHFCF_3$	989
HFE-236fa	$CF_3CH_2OCF_3$	487
HFE-245cb2	$CH_3OCF_2CF_3$	708
HFE-245fa1	$CHF_2CH_2OCF_3$	286
HFE-245fa2	$CHF_2OCH_2CF_3$	659
HFE-254cb2	$CH_3OCF_2CHF_2$	359
HFE-263fb2	$CF_3CH_2OCH_3$	11
HFE-329mcc2	$CF_3CF_2OCF_2CHF_2$	919
HFE-338mcf2	$CF_3CF_2OCH_2CF_3$	552
HFE-338pcc13 (HG-01)	$CHF_2OCF_2CF_2OCHF_2$	1,500
HFE-347mcc3 (HFE-7000)	$CH_3OCF_2CF_2CF_3$	575
HFE-347mcf2	$CF_3CF_2OCH_2CHF_2$	374
HFE-347pcf2	$CHF_2CF_2OCH_2CF_3$	580
HFE-356mec3	$CH_3OCF_2CHFCF_3$	101
HFE-356pcc3	$CH_3OCF_2CF_2CHF_2$	110
HFE-356pcf2	$CHF_2CH_2OCF_2CHF_2$	265
HFE-356pcf3	$CHF_2OCH_2CF_2CHF_2$	502
HFE-365mcf3	$CF_3CF_2CH_2OCH_3$	11
HFE-374pc2	$CH_3CH_2OCF_2CHF_2$	557
HFE-449s1 (HFE-7100)	$C_4F_9OCH_3$	297
HFE-569sf2 (HFE-7200)	$C_4F_9OC_2H_5$	59
Sevoflurane (HFE-347mmz1)	$CH_2FOCH(CF_3)_2$	216
HFE-356mmz1	$(CF_3)_2CHOCH_3$	27
HFE-338mmz1	$CHF_2OCH(CF_3)_2$	380
(Octafluorotetramethy-lene) hydroxymethyl group	$X-(CF_2)_4CH(OH)-X$	73
HFE-347mmy1	$CH_3OCF(CF_3)_2$	343
Bis(trifluoromethyl)-methanol	$(CF_3)_2CHOH$	195
2,2,3,3,3-pentafluoropropanol	$CF_3CF_2CH_2OH$	42
PFPMIE (HT-70)	$CF_3OCF(CF_3)CF_2OCF_2OCF_3$	10,300

SOURCE: Table A-1 of "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 98-Mandatory Greenhouse Gas Reporting, Subpart A-General Provision," U.S. Environmental Protection Agency.

$$E_{ODC} = (Q_P - Q_R) \times \left(\frac{WP_{ODC}}{100}\right) \times \left[1 - \left(\frac{CE}{100}\right)\right]$$

Equation 17-1

Where,

E_{ODC} = Annual ODC emissions (lb/yr)
Q_P = Annual quantity of ODC-containing product used in the process (lb/yr)
Q_R = Annual quantity of ODC-containing product removed from the process for purposes of disposal, recycling, or reclamation (lb/yr)
WP_{ODC} = Weight percent of ODC in the product (%)
CE = Efficiency of control device, if applicable (%)
100 = Factor converting from percent to a fraction (%)

A more detailed control volume depicting the emissions from ODCs is provided in Figure 17-2.

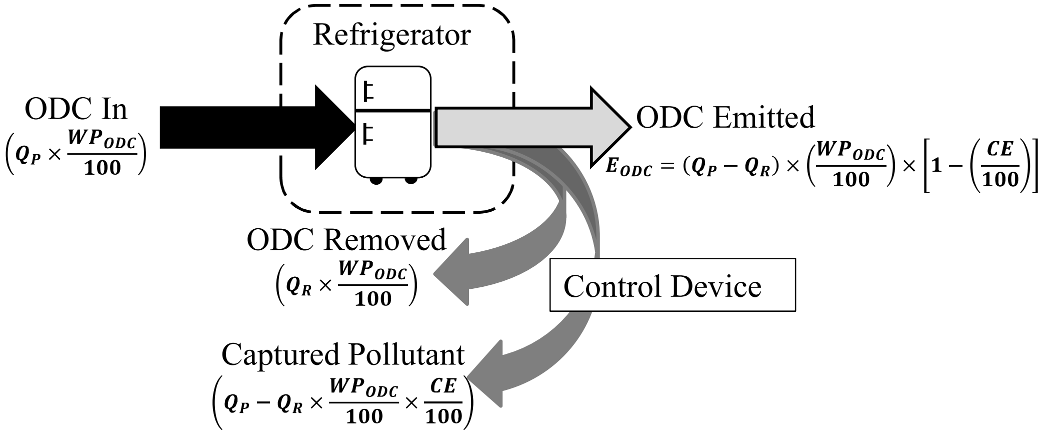

Figure 17-2. Detailed Control Volume of Emissions from Ozone Depleting Chemicals

17.4 Information Resources

Records/data maintained by the HAZMART should be used to identify which products on base contain ODCs and to identify which shops use them. The weight percent of ODC in each applicable product can be determined from SDS or other product literature provided by the manufacturer. Information on the quantity of ODC (or ODC-containing products) used and recovered can be obtained from the applicable shops using those products. If a control device (e.g., incinerator, carbon adsorber, refrigerated condenser) is used to control emissions of ODC-containing products (typically sterilants and coatings), the manufacturer of the control device should be contacted to determine the estimated control efficiency.

17.5 Example Problem

According to base CE, approximately 1,900 lb of pure HCFC-22 was added to base air conditioning systems during the year and 650 lb were removed/recovered. Calculate the annual emissions of HCFC-22. No control device was used in this process.

<u>Step 1</u> – Calculate emissions. The problem statement provided all the information necessary to calculate the emissions from this process. Using the data provided and Equation 17-1, the resulting emissions of HCFC-22 is calculated as follows:

$$E_{ODC} = (Q_P - Q_R) \times \left(\frac{WP_{ODC}}{100}\right) \times \left[1 - \left(\frac{CE}{100}\right)\right]$$

$$E_{HCFC-22} = \left(1900\,\frac{lb}{yr} - 650\,\frac{lb}{yr}\right) \times \left(\frac{100\cancel{\%}}{100\cancel{\%}}\right) \times \left[1 - \left(\frac{0\cancel{\%}}{100\cancel{\%}}\right)\right]$$

$$E_{HCFC-22} = \left(1900\,\frac{lb}{yr} - 650\,\frac{lb}{yr}\right) \times (1) \times [1]$$

$$\boxed{\boldsymbol{E_{HCFC-22} = 1,250\,\frac{lb}{yr}}}$$

17.6 References

40 CFR 82 Subpart A, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 82-Protection of the Stratospheric Ozone, Subpart A-Production and Consumption Controls," U.S. Environmental Protection Agency

40 CFR 98 Subpart A, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 98-Mandatory Greenhouse Gas Reporting, Subpart A-General Provision," U.S. Environmental Protection Agency

UNEP 2012, "Handbook for the Montreal Protocol on Substances that Deplete the Ozone Layer Ninth edition," Ozone Secretariat, United Nations Environment Programme (UNEP), 2012

WMO 2010, "Scientific Assessment of Ozone Depletion: 2010," World Meterological Organization (WMO), 2010

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18 PESTICIDE APPLICATION (PEST)

- *Fugitive Source*

18.1 Introduction

Pesticides are used at most USAF installations as a means of controlling plant and animal life. Pesticides include herbicides, insecticides, fungicides, and rodenticides. They come in a variety of formulations such as a solution/liquid (ready-to-use), emulsifiable concentrate, aqueous suspension, granular/flake, dust/powder, and aerosol sprays, among others. The method of pesticide application varies according to the target pest and the crop or item to be protected. The pesticide may be applied in a variety of ways, including directly on the pest, on the host plant, on the soil surface, beneath the soil surface, or in an enclosed air space. **Pesticide application results in the fugitive release of VOCs and organic HAPs from both the active and inactive ingredients in the pesticide.** Active ingredients in pesticides are defined in 40 CFR Part 152.3 as any substance that will prevent, destroy, repel or mitigate any pest, or that functions as a plant regulator, desiccant, or defoliant. An inert or inactive ingredient is any substance other than an active ingredient, that is intentionally included in a pesticide product. Air pollutants may be emitted during pesticide application or within 30 days after application. Although particulate may be emitted due to the use of granular or dust/powder pesticides, PM emissions are considered negligible and are, therefore, not addressed in this guide. A graphic representation describing emissions from pesticide application is provided in Figure 18-1.

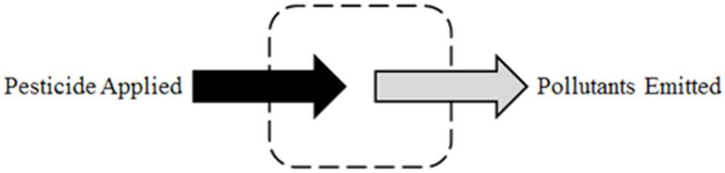

Figure 18-1. Simplified Pesticide Application Control Volume

18.2 Emission Factors

The amount of VOCs and organic HAPs emitted to the atmosphere from pesticide application is a function of the vapor pressure of the active ingredients in the pesticide. Vapor pressure is indicative of the evaporation rate of the pesticide. The volatilization of the pesticide is also greatly influenced by the application method. Surface application of pesticides results in greater emissions than soil incorporation, since soil incorporation limits the amount of pesticide available to evaporate from the soil surface into the atmosphere. EFs have been developed based on both the vapor pressure and application method of pesticides and are given in Section 9.2.2 of AP-42. The EFs are in units of pound pollutant per pound pesticide and are provided in Table 18-1.

Table 18-1. VOC Emission Factors for Pesticide Application

Vapor Pressure Range (mm Hg at 20 - 25°C)	Emission Factor (lb/lb)
Surface Application (SCC 24-61-800-001)	
1×10^{-4} to 1×10^{-6}	3.50E-01
$> 1 \times 10^{-4}$	5.80E-01
Soil Incorporation (SCC 24-61-800-002)	
$< 1 \times 10^{-6}$	2.70E-03
1×10^{-4} to 1×10^{-6}	2.10E-02
$> 1 \times 10^{-4}$	5.20E-02

SOURCE: Section 9.2.2 - "Pesticide Application," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, January 1995. SCC = Source Classification Code.

It is imperative to know the vapor pressure of the active ingredients since the EFs are dependent on these values. Often the SDS provides this data. However, if it is not given, this information may be obtained from the pesticide manufacturer, a chemical reference manual, or a pesticide database such as the one maintained by the California Department of Pesticide Regulation. The Armed Forces Pest Management Board (AFPMB) has produced a list of pesticides approved for use on DOD sites (AFPMB 2014). Table 18-2 provides the vapor pressures of the active ingredients for both AFPMB approved pesticides and several others listed in Section 9.2.2 of AP-42. Note that several pesticides provided in AP-42 are not given in Table 18-2 because their use has since been restricted due to growing concern over the adverse effects they pose to humans and the environment.

Table 18-2. Vapor Pressures for Common Pesticide Active Ingredients

Active Ingredient	Vapor Pressure (mmHg)
Abamectin	4.73E-09
Alachlor	1.40E-05
Aldicarb	3.00E-05
Aldoxycarb	9.00E-05
Allethrin	5.85E-06
Aluminum Phosphide	0.00E+00
Aminopyralid	7.00E-11
Amitraz	2.60E-06
Amitrole	4.40E-07
Ammonium Salt glyphosate	6.75E-08
Atrazine	2.90E-07
Azinphos-methyl	2.00E-07
Azoxystrobin	8.20E-13
Benefin	6.60E-05
Beta-Cyfluthrin	4.20E-10
Bifenthrin	1.34E-07
Boric Acid	1.00E-04
Bromacil	2.48E-07
Bromadiolone	1.60E-10
Bromoxynil butyrate ester	1.00E-04
Captan	8.00E-08
Carbaryl	3.12E-07
Carbofuran	6.00E-07
Chlorfenapyr	7.36E-08
Chloroneb	3.00E-03
Chloropicrin	1.80E+01
Chlorpyrifos	1.70E-05
Clomazone	1.40E-04
Cyfluthrin	2.25E-09
Cypermethrin	1.73E-09
Cyromazine	3.40E-09
2,4-D Acid	8.00E-06
2,4-D Dimethyl Amine Salt	1.00E-07
2,4-D 2-Ethylhexyl ester	3.60E-06
DCNA	1.30E-06
DCPA	2.50E-06
Deltamethrin	9.30E-11
Dichlobenil	1.00E-03
1,3-Dichloropropene	2.90E+01
Dichlorvos	1.58E-02
Dicofol	4.00E-07
Dicrotofos	1.60E-04
Difethialone	9.98E-08
Dimethoate	2.50E-05
Dinocap	4.00E-08
Diquat Dibromide	1.00E-04
Disulfoton	1.50E-04
Diuron	1.00E-07
d-Phenothrin (sumithrin)	1.43E-07
Endosulfan	1.70E-07
EPTC	3.40E-02
Ethalfluralin	8.80E-05
Ethion	2.40E-06
Ethoprop	3.80E-04
Etofenprox	6.10E-09
Fenamiphos	1.00E-06
Fenoxycarb	5.90E-08
Fenthion	2.80E-06
Fipronil	1.50E-08
Fluometuron	9.40E-07
Fluridone	9.75E-08
Geraniol	3.00E-02
Hydramethylnon	2.03E-08
Hydroprene	3.00E-04
Imazapic ammonium salt	1.76E+01
Imazapyr isopropylamine salt	1.75E+01
Imidacloprid	3.00E-12
Isopropylamine salt of glyphosate	1.75E-07
Lambda-Cyhalothrin	1.50E-09
Lindane	3.30E-05
Linuron	1.70E-05
Malathion	2.33E-05
Methamidophos	8.00E-04
Methiocarb	1.20E-04
Methomyl	5.40E-06
Methoprene	2.37E-05
Methyl isothiocyanate	2.10E+01
Methyl parathion	1.50E-05
Methyl sulfometuron	5.50E-16
Metolachlor	3.10E-05
Metribuzin	1.00E-05
Mevinphos	1.30E-04
Molinate	5.60E-03
N,N-Diethyl-M-Toluamide (DEET)	5.60E-03
Naled	2.00E-04
Naled (Dibrom)	1.95E-03
Naphthalene	8.70E-02
Nithiazine	1.30E-07
Norflurazon	2.00E-08
Oxamyl	2.30E-04
Oxyfluorfen	2.00E-07
Parathion	5.00E-06
PCNB	1.10E-04
P-Dichlorobenzene	1.76E+00
Pendimethalin	9.40E-06
Permethrin	5.25E-08
Phorate	6.40E-04
Phosmet	4.90E-07
Picaridin	4.40E-04
Piperonyl Butoxide	1.50E-07
Profenofos	9.00E-07
Prometon	2.33E-06
Prometryn	1.20E-06
Propachlor	2.30E-04
Propanil	4.00E-05
Propargite	3.00E-03
Propoxur	9.70E-06
Pyrethrin I	2.03E-05
Pyrethrin II	3.98E-07
Resmethrin	1.13E-08
Siduron	4.00E-09
Simazine	2.20E-08
Spinosad	1.50E-10
Sulfometuron Methyl	5.50E-16
Tebuthiuron	2.03E-06
Temephos	7.13E-08
Terbacil	3.10E-07
Terbufos	3.20E-04
Tetramethrin	1.58E-05
Thiobencarb	2.20E-05
Thiodicarb	1.00E-07
Triallate	1.10E-04
Tribufos	1.60E-06
Trichlorfon	2.00E-06
Triclopyr	7.50E-07
Trifluralin	1.10E-04
Triforine	2.00E-07
Warfarin	2.25E-05
Zinc Phosphide	4.88E-11

SOURCE: Data taken from either Section 9.2.2-"Pesticide Application," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, January 1995 or "Armed Forces Pest Management Board (AFPMB) Standard Pesticides List Available to DOD Components and Agencies," Armed Forces Pest Management Board (AFPMB), <http://www.afpmb.org/sites/default/files/pubs/standardlists/DOD_PESTICIDES_ LIST.pdf>, October 1, 2014 and respective SDS.

18.3 Emissions Calculation

There are two methods for calculating emissions from pesticide application. The preferred process is a mass balance method, which assumes all VOCs and HAPs in the pesticide are emitted to the atmosphere. The alternative method estimates emissions by utilizing EFs and total mass of pesticide applied. Both approaches are described below.

18.3.1 Calculations Using Mass Balance

To use the mass balance method, the mass of pesticide applied and the weight percent of VOC or HAP must be known. Calculation of emissions from pesticide application is performed as follows:

$$\boldsymbol{E_{Pol} = Q \times \left(\frac{WP_{Pol}}{100}\right)}$$

Equation 18-1

Where,

E_{Pol} = Annual emissions of pollutant (lb/yr)
Q = Annual mass of pesticide applied (lb/yr)
WP_{Pol} = Weight percent of pollutant in the pesticide (%)
100 = Factor for converting a percent to a fraction (%)

A more detailed control volume for emissions from pesticide application describing the mass balance method is provided in Figure 18-2.

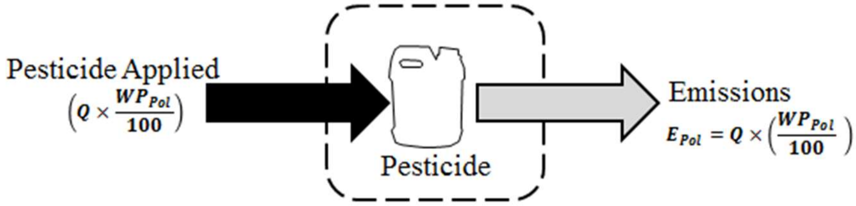

Figure 18-2. Pesticide Application – Mass Balance Method

If the volume, and not the mass, of the pesticide applied during the year is known, then the mass may be calculated using the pesticide density or specific gravity as follows:

$$\boldsymbol{Q = (V \times D) = (V \times SG \times 8.33)}$$

Equation 18-2

Where,

Q = Annual mass of pesticide applied (lb/yr)
V = Annual volume of pesticide applied (gal/yr)
D = Density of the pesticide (lb/gal)
SG = Specific gravity of the pesticide
8.33 = Density of water (lb/gal)

18.3.2 Calculations Using Emission Factors

It is not uncommon for a pesticide SDS to either not include the VOC weight percent, or only provide the volume percent. If the weight percent of the pollutant is unknown and unavailable, the alternative emissions calculation method, the EF method, may be used. This method still requires that the weight percent of the active ingredient(s) in the pesticide be known, but this is more likely to be provided in the SDS, or at least a range provided. Emissions using the EF method are calculated as follows:

$$\boldsymbol{E_{Pol} = Q \times \left[\left(\frac{WP_{Active}}{100}\right) \times EF + \left(\frac{WP_{Inert}}{100}\right) \times \left(\frac{WP_{Pol-Inert}}{100}\right)\right]}$$

Equation 18-3

Where,

E_{Pol} = Annual emissions of pollutant (lb/yr)

Q = Annual mass of pesticide applied (lb/yr)

WP_{Active} = Weight percent of active ingredient in pesticide (%)

100 = Factor for converting a percent to a fraction (%)

EF = Emission factor (lb/lb pesticide applied)

WP_{Inert} = Weight percent of inert ingredient in pesticide (%)

$WP_{Pol-Inert}$ = Weight percent of pollutant in the inert portion of the pesticide (%). **Average VOC contents in the inert portions based on formulations are given in Table 18-3.**

A more detailed control volume for emissions from pesticide application describing the EF method is provided in Figure 18-3.

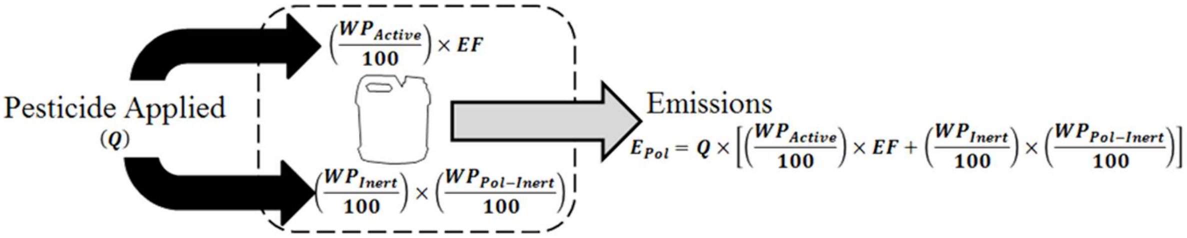

Figure 18-3. Pesticide Application Control Volume – Emission Factor Method

If the average weight percent of VOCs in the inert portion of pesticides is required, but unknown, then an average based on formulation type may be used. The average VOC content for each pesticide formulation is provided in Section 9.2.2 of AP-42 and provided in this guide in Table 18-3.

Table 18-3. Average VOC Content of Pesticide Inert Ingredient Portion, by Formulation Type

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
Wettable powder	25

SOURCE: Section 9.2.2 - “Pesticide Application," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, January 1995. wt. % = weight percent.

18.4 Information Resources

The base entomology shop may be contacted for information pertaining to the names, EPA registration numbers, stock numbers, and quantities of pesticides applied on base. The composition of the pesticides used on base, and its applicable physical and chemical properties may be found in the SDS, the product label, or by contacting the product manufacturer. A list of the most current pesticides available to the DOD community, along with the appropriate SDS and product labels, can be found at the AFPMB website at http://www.afpmb.org/content/DOD-standard-pesticides-and-pest-control-equipment.

18.5 Example Problem

A USAF base incorporated 30 gal of an insecticide into the soil during the 2015 calendar year. According to the SDS, the composition of the insecticide, by weight percent, is as follows: 9.7 percent Lambda-Cyhalothrin (active ingredient), 1 percent Cumene, 1 percent Xylenes, 14.2

percent ethane, and 74.1 percent light aromatic naphtha. The specific gravity is listed as 1.036 and the weight percent total VOC in the pesticide is not provided. Given that the vapor pressure of Lambda-Cyhalothrin is 1.50E-09 mmHg, calculate the VOC, speciated HAP, and total HAP emissions.

<u>Step 1</u> – Determine mass of pesticide used. The problem statement listed the volume of pesticide applied. The mass of the pesticide used is determined using this volume (30 gal/yr), specific gravity (1.036) and Equation 18-2 as shown:

$$\boldsymbol{Q} = (V \times SG \times 8.33)$$

$$\boldsymbol{Q} = \left(30\frac{\cancel{gal}}{yr} \times 1.036 \times 8.33\frac{lb}{\cancel{gal}}\right)$$

$$\boldsymbol{Q} = \left(249.9\frac{lb}{yr} \times 1.036\right) = 258.90\frac{lb}{yr}$$

<u>Step 2</u> – Calculate individual HAP emissions. The ingredients in the pesticide that are designated as HAPs include cumene and xylene. The weight percent of these HAPs in the pesticide is 1 percent each. The mass of the individual HAPs emitted are calculated using Equation 18-1 as shown:

$$E_{Pol} = Q \times \left(\frac{WP_{Pol}}{100}\right)$$

<u>For Cumene:</u>

$$E_{Cumene} = 258.90\frac{lb}{yr} \times \left(\frac{1\cancel{\%}}{100\cancel{\%}}\right)$$

$$E_{Cumene} = 258.90\frac{lb}{yr} \times (0.01)$$

$$\boxed{\boldsymbol{E_{Cumene} = 2.59\frac{lb}{yr}}}$$

<u>For Xylenes:</u>

$$E_{Xylene} = 258.90\frac{lb}{yr} \times \left(\frac{1\cancel{\%}}{100\cancel{\%}}\right)$$

$$E_{Xylene} = 258.90\frac{lb}{yr} \times (0.01)$$

$$\boxed{\boldsymbol{E_{Xylene} = 2.59\frac{lb}{yr}}}$$

Step 3 – **Calculate total HAPs.** The total HAPs emitted is the sum of the individual HAPs calculated in Step 2 as shown:

$$E_{HAP} = 2.59\frac{lb}{yr} + 2.59\frac{lb}{yr}$$

$$\boxed{\boldsymbol{E_{HAP} = 5.18\frac{lb}{yr}}}$$

Step 4 – **Select and record the VOC EF.** Since the weight percent VOC in the pesticide is unknown, the EF method is used. The problem stated the vapor pressure of the active ingredient is 1.50E-09 mmHg. A review of Table 18-1 shows that the EF is **2.70E-03 lb/lb.**

Step 5 – **Determine the weight percent of VOC in the inert portion of the pesticide.** The inert ingredients in the pesticide are composed of cumene, xylene, ethane, and light aromatic naphtha. Ethane, due to its negligible photochemical reactivity, is an exempt VOC and, therefore, the only component not classified as a VOC. The weight percent of the VOCs in the inert portion of the pesticide is calculated by taking the fraction of the VOC in the total inert portion as follows:

$$WP_{VOC-Inert} = \frac{\sum_i^n WP_{VOC_i} + \cdots + WP_{VOC_n}}{WP_{Inert}} \times 100$$

$$\boldsymbol{WP_{VOC-Inert}} = \frac{1\%+1\%+74.1\%}{1\%+1\%+14.2\%+74.1\%} \times 100 = \boldsymbol{84.3}\%$$

Step 6 – **Calculate total VOCs.** The total VOCs emitted from pesticide application is calculated using the mass of pesticide applied as calculated in Step 1, the EF recorded in Step 4, the weight percent of the VOC in the inert portion of the pesticide as calculated in Step 5, and Equation 18-3 as follows:

$$E_{Pol} = Q \times \left[\left(\frac{WP_{Active}}{100}\right) \times EF + \left(\frac{WP_{Inert}}{100}\right) \times \left(\frac{WP_{Pol-Inert}}{100}\right)\right]$$

$$E_{VOC} = 258.90\frac{lb}{yr} \times \left[\left(\frac{9.7\cancel{\%}}{100\cancel{\%}}\right) \times 0.0027\frac{lb}{lb} + \left(\frac{90.3\cancel{\%}}{100\cancel{\%}}\right) \times \left(\frac{84.3\cancel{\%}}{100\cancel{\%}}\right)\right]$$

$$E_{VOC} = 258.90\frac{lb}{yr} \times \left[(0.097) \times 0.0027\frac{lb}{lb} + (0.903) \times (0.843)\right]$$

$$E_{VOC} = 258.90\,\frac{lb}{yr} \times \left[0.0002619\,\frac{lb}{lb} + 0.761229\right]$$

$$E_{VOC} = 258.90\,\frac{\cancel{lb}}{yr} \times \left[0.7614909\,\frac{lb}{\cancel{lb}}\right]$$

$$\boxed{\boldsymbol{E_{VOC} = 197.15\,\frac{lb}{yr}}}$$

18.6 References

40 CFR 152, “Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter E-Pesticide Programs Part 152-Pesticide Registration and Classification Procedures-Definitions,” U.S. Environmental Protection Agency

AFPMB 2013, "Armed Forces Pest Managment Board (AFPMB) Standard Pesticides List Available to DOD Components and Agencies," Armed Forces Pest Management Board (AFPMB),<http://www.afpmb.org/sites/default/files/pubs/standardlists/DOD_PESTICIDES_LIST.pdf>, October 1, 2013

USEPA 1995, Section 9.2.2-“Pesticide Application," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, January 1995

19 SMALL ARMS FIRING RANGE (MUN)

- *Point Source* – Indoor ranges
- *Fugitive Source* – Outdoor ranges

19.1 Introduction

Most USAF installations have one or more firing ranges used for small arms training. These ranges may be either indoor or outdoor. Emissions from indoor ranges are usually exhausted to the atmosphere through a vent or stack. Therefore, **indoor ranges are considered point sources of emissions while outdoor ranges are regarded as fugitive sources.**

Note that small arms firing ranges may be considered either mobile or stationary. Indoor ranges are stationary, but outdoor ranges can be stationary or mobile. This section describes emissions produced from stationary ranges, which are those ranges where the shooter is at a fixed position and the range often has been issued a building number.

Emissions of concern from stationary small arms ranges are criteria pollutants, GHGs, and HAPs. CO is emitted when the energetic material within the ammunition is detonated while lead emissions come from both the primer and the projectile. The primer usually contains lead styphnate ($C_6HN_3O_8Pb$) while some ammunition may also contain lead azide [$Pb(N_3)_2$]. Emissions from small arms stationary ranges are described in a simple control volume in Figure 19-1 below.

To reduce the cost of removing hazardous material from USAF installations, some ranges began to implement lead restrictions. This led to the development of "cleaner" projectiles in the form of "green" bullets. However, "green" bullets are not completely lead-free. For example, the M855A1(A059) is an alternative to the M855. The M855A1 is regarded as a "green" bullet because it replaced the M855's lead slug with a copper slug. However, the M855A1 and M855 use the same no. 41 primer that uses lead styphnate as its primary explosive. Therefore, though the M855A1 slug is copper and not lead, due to the presence of lead in the primer, the M855A1 still emits lead into the atmosphere and should not be considered completely "lead free".

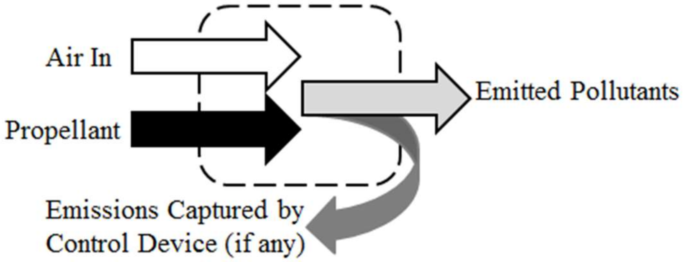

Figure 19-1. Simplified Control Volume for Emissions from Small Arms Stationary Ranges

19.2 Emission Factors

Chapter 15 of the *Compilation of Air Pollutant Emission Factors* (AP-42) provides EFs for several types of ordnances based on Department of Defense Identification Codes (DODIC). These EFs are presented in units of pound per item and pound per pound NEW. For emissions estimation purposes, it may be easier to calculate emissions from small arms firing if an estimate of the total number of rounds is used. Criteria pollutant and GHG EFs for cartridges likely to be used at a small arms stationary range are provided in Table 19-1 and Table 19-2 respectively. Additionally, speciated VOC EFs are provided in Table 19-3. Refer to Chapter 15 of AP-42 for additional information if needed.

Occasionally there are some munitions that are not present in the guide due to limited use or munitions that have been misidentified as discontinued or no longer in use. In these cases, it is advised that the base EOD be consulted on which munitions in the guide are most comparable to the munitions in question to determine the most accurate EFs to use.

Table 19-1. Criteria Pollutant Emission Factors for Cartridges Used at Small Arms Firing Ranges

DODIC Designation	Item Description	Emission Factor (lb/item)				
		NO_X	CO	Pb	PM_{10}	$PM_{2.5}$
A011	12 Gage #00 Shot Cartridge	4.20E-05	1.50E-03	2.00E-05	7.40E-05	6.70E-05
A017	12 Gage #9 Shot Cartridge	2.10E-05	1.00E-03	7.40E-06	2.10E-05	2.00E-05
A059	5.56mm Ball Cartridge	8.50E-05	1.60E-03	5.10E-06	3.90E-05	2.80E-05
A063	5.56mm Tracer Cartridge	6.50E-05	1.40E-03	2.70E-06	4.90E-05	3.30E-05
A065	5.56mm Practice Ball Cartridge	1.90E-05	4.00E-04	3.10E-06	1.10E-05	1.00E-05
A066	5.56mm Ball Cartridge	5.60E-05	1.80E-03	1.30E-05	3.80E-05	3.20E-05
A068	5.56mm Tracer Cartridge	1.70E-05	1.60E-03	2.80E-06	6.70E-05	5.10E-05
A131	7.62mm Tracer Cartridge	4.30E-05	2.80E-03	7.80E-06	9.10E-05	5.80E-05
A136	7.62mm Ball Match Cartridge	4.10E-05	3.00E-03	6.20E-06	6.20E-05	4.70E-05
A143	7.62mm Ball Cartridge	9.70E-05	2.30E-03	4.90E-06	5.10E-05	3.80E-05
A363	9mm Ball Cartridge	1.50E-05	3.10E-04	6.80E-06	2.40E-05	2.00E-05
A518	.50 Caliber SLAP Ball Cartridge	8.50E-05	9.60E-03	2.00E-05	2.10E-04	1.80E-04
A518	.50 Caliber SLAP Tracer Cartridge	1.30E-04	1.10E-02	1.70E-04	8.60E-04	3.40E-04
A525	.50 Caliber Armor Piercing Cartridge	3.30E-05	1.60E-02	2.10E-05	9.70E-04	4.40E-04
A557	.50 Caliber Ball Cartridge and Tracer Cartridge	1.20E-03	1.10E-02	1.30E-05	3.10E-04	1.90E-04

SOURCE: Section 15.1- “Cartridges Smaller than 30mm,” Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, February 2008.

Table 19-2. GHG Emission Factors for Cartridges Used at Small Arms Firing Ranges

DODIC Designation	Item Description	Emission Factor (lb/item)			
		CO_2	CH_4	N_2O	CO_2e[(a)]
A011	12 Gage #00 Shot Cartridge	1.30E-03	1.30E-05	---	1.63E-03
A017	12 Gage #9 Shot Cartridge	8.30E-04	1.10E-05	---	1.11E-03
A059	5.56mm Ball Cartridge	8.70E-04	9.70E-06	---	1.11E-03
A063	5.56mm Tracer Cartridge	7.50E-04	6.70E-06	---	9.18E-04
A065	5.56mm Practice Ball Cartridge	3.20E-04	2.20E-06	---	3.75E-04
A066	5.56mm Ball Cartridge	1.00E-03	1.30E-05	---	1.33E-03
A068	5.56mm Tracer Cartridge	9.80E-04	6.20E-06	---	1.14E-03
A131	7.62mm Tracer Cartridge	1.70E-03	1.60E-05	---	2.10E-03
A136	7.62mm Ball Match Cartridge	1.60E-03	2.30E-05	---	2.18E-03
A143	7.62mm Ball Cartridge	1.20E-03	1.00E-05	---	1.45E-03
A363	9mm Ball Cartridge	2.00E-04	1.40E-06	---	2.35E-04
A518	.50 Caliber SLAP Ball Cartridge	5.30E-03	8.00E-05	---	7.30E-03
A518	.50 Caliber SLAP Tracer Cartridge	5.80E-03	9.20E-05	---	8.10E-03
A525	.50 Caliber Armor Piercing Cartridge	9.20E-03	5.30E-05	---	1.05E-02
A557	.50 Caliber Ball Cartridge and Tracer Cartridge	5.10E-03	1.30E-04	---	8.35E-03

SOURCE: Section 15.1- “Cartridges Smaller than 30mm,” Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, February 2008.

a) CO_2e calculated by summing the product of the default emission factors for CO_2, N_2O, and CH_4 and their respective Global Warming Potentials (GWP). The GWP for CO_2, N_2O, and CH_4 are 1, 298, and 25 respectively.

“---” Indicates No Data Available

Table 19-3. Speciated VOC Emission Factors for Cartridges Used at Small Arms Firing Ranges

Pollutant	HAP[a]	Emission Factors (lb/item)														
		DODIC: A011	A017	A059	A063	A065	A066	A068	A131	A136	A143	A363	A518 (SLAP Ball)	A518 (SLAP Tracer)	A525	A557
Acenaphthene	X	1.50E-10	---	7.20E-11	2.90E-11	2.30E-11	2.10E-10	1.70E-10	5.20E-10	2.70E-10	4.30E-11	3.60E-11	3.70E-09	---	3.30E-09	1.50E-09
Acenaphthylene	X	5.80E-09	5.20E-09	4.20E-10	6.10E-10	4.50E-10	1.60E-09	1.20E-09	3.20E-09	1.60E-09	5.80E-10	2.40E-10	5.60E-08	4.00E-08	9.30E-09	6.90E-09
Acetaldehyde	X	1.90E-07	2.60E-07	2.40E-07	---	---	3.10E-07	1.20E-07	4.00E-07	1.40E-07	---	---	1.70E-07	1.50E-07	5.40E-07	---
Acetonitrile	X	1.00E-07	2.70E-07	3.30E-07	9.70E-08	9.60E-08	7.30E-07	2.30E-07	9.10E-07	9.60E-07	2.40E-07	4.50E-08	1.10E-06	5.50E-06	1.00E-06	1.20E-06
Acetophenone	X	---	---	---	---	---	---	3.30E-08	2.80E-08	---	---	---	---	---	2.00E-07	---
Acrolein	X	---	---	2.60E-08	---	7.60E-08	6.60E-08	---	1.60E-07	4.70E-08	---	8.10E-09	---	---	1.40E-07	---
Acrylonitrile	X	---	5.60E-08	5.20E-08	3.80E-08	1.50E-08	5.80E-08	2.00E-08	7.20E-08	3.60E-08	7.10E-08	2.20E-08	1.10E-07	1.10E-07	1.10E-07	2.70E-07
Anthracene	X	8.10E-11	---	5.20E-11	7.10E-11	1.20E-11	6.60E-11	9.10E-11	1.20E-10	1.80E-10	6.80E-11	3.90E-11	7.50E-09	7.90E-09	7.30E-10	7.20E-10
Antimony	X	9.30E-06	3.20E-09	1.50E-06	1.60E-06	1.70E-06	1.70E-06	1.30E-06	2.40E-06	2.10E-06	2.00E-06	2.00E-06	3.30E-06	5.30E-06	1.10E-05	3.30E-06
Arsenic	X	---	9.40E-10	---	---	5.30E-09	---	---	---	---	---	4.50E-09	---	1.60E-07	---	---
Benzene	X	9.50E-07	2.40E-06	6.30E-07	4.40E-07	2.70E-07	6.20E-07	1.90E-07	7.70E-07	5.50E-07	7.10E-07	1.90E-07	1.30E-05	2.50E-05	9.80E-07	4.00E-06
Benzo[a]anthracene	X	8.40E-11	1.30E-10	1.90E-10	2.20E-10	7.60E-11	---	---	---	3.20E-10	3.40E-10	2.30E-10	1.30E-08	1.00E-08	---	1.70E-09
Benzo[b]fluoranthene	X	3.00E-10	4.70E-10	3.10E-10	4.50E-10	1.40E-10	---	1.20E-10	---	5.30E-10	3.50E-10	2.50E-10	4.70E-08	3.00E-08	---	2.60E-09
Benzo[k]fluoranthene	X	2.10E-10	2.70E-10	1.50E-10	1.90E-10	9.10E-11	---	---	---	1.80E-10	1.70E-10	1.60E-10	9.00E-09	6.70E-09	---	1.20E-09
Benzo[g,h,i]perylene	X	1.90E-09	4.00E-09	1.10E-09	1.10E-09	1.20E-09	---	---	---	4.90E-09	2.40E-09	6.70E-10	4.00E-08	5.50E-08	3.10E-09	1.30E-08
Benzo[a]pyrene	X	6.20E-10	1.00E-09	2.90E-10	2.90E-10	3.00E-10	---	1.20E-10	---	6.40E-10	4.40E-10	2.30E-10	2.10E-08	1.30E-08	---	3.70E-09
Benzo[e]pyrene		6.00E-10	8.80E-10	4.40E-10	5.90E-10	3.40E-10	---	1.20E-10	---	1.00E-09	7.20E-10	2.70E-10	3.60E-08	2.70E-08	1.00E-09	5.40E-09
Beryllium	X	---	---	---	---	---	---	---	---	---	---	---	---	3.80E-08	---	---
Biphenyl	X	---	---	---	---	---	---	---	---	---	---	---	1.00E-07	---	---	---
1,3-Butadiene	X	---	---	1.20E-08	8.50E-09	---	---	---	---	---	1.90E-08	1.20E-09	---	---	---	1.50E-07
t-Butyl alcohol		---	---	2.80E-09	---	---	---	---	---	---	---	---	---	---	---	---
Cadmium	X	---	2.00E-08	---	---	---	---	---	---	---	---	---	---	3.40E-07	---	---
Carbon disulfide	X	1.10E-08	---	---	---	6.10E-09	---	---	---	---	4.50E-09	1.60E-09	---	---	---	---
Chlorobenzene	X	---	---	---	---	---	---	9.70E-10	---	---	---	---	---	---	5.80E-08	---
Chloromethane	X	7.30E-10	---	1.10E-09	1.40E-09	3.30E-10	1.10E-09	2.30E-09	4.60E-09	3.50E-09	3.00E-09	---	---	---	---	2.60E-09
Chromium	X	---	---	---	---	---	---	---	---	---	---	---	---	1.10E-05	---	---
Chromium VI	X	---	1.40E-06	---	---	---	---	---	---	2.40E-09	---	---	---	3.80E-03	---	---
Chrysene	X	1.00E-10	1.10E-10	2.10E-10	2.70E-10	9.30E-11	---	---	---	3.60E-10	3.20E-10	2.40E-10	3.20E-08	2.40E-08	---	2.10E-09
Cobalt	X	---	---	---	---	---	---	---	---	---	---	---	---	8.10E-08	---	---
Cyanide	X	---	---	8.30E-08	7.50E-07	7.20E-09	---	1.20E-06	8.90E-07	2.50E-07	6.60E-07	---	5.30E-07	---	6.80E-06	1.10E-05
Dibenz[a,h]anthracene	X	---	---	4.00E-11	---	---	---	---	---	---	3.80E-11	3.00E-11	3.70E-09	2.10E-09	---	3.00E-10
Dibutyl phthalate	X	---	---	---	---	---	---	---	---	3.10E-08	---	---	4.60E-08	---	---	---
1,2-Dichloroethane	X	---	---	1.20E-08	7.80E-09	4.50E-09	1.50E-08	3.80E-09	1.50E-08	1.10E-08	9.90E-09	2.80E-09	---	1.40E-07	---	7.40E-08
Dioxins/Furans		---	1.00E-13	9.40E-15	---	---	6.70E-15	1.70E-13	5.70E-13	---	1.20E-14	---	5.20E-13	4.40E-12	2.10E-12	6.50E-14

Table 19-3. Speciated VOC Emission Factors for Cartridges Used at Small Arms Firing Ranges (cont.)

Pollutant	HAP(a)	Emission Factors (lb/item)														
		DODIC: A011	A017	A059	A063	A065	A066	A068	A131	A136	A143	A363	A518 (SLAP Ball)	A518 (SLAP Tracer)	A525	A557
Diphenyl amine		---	---	---	---	---	---	---	---	---	---	---	---	---	1.70E-07	---
Ethylbenzene	X	6.90E-09	---	2.00E-09	2.10E-09	---	---	1.60E-09	7.20E-09	3.20E-09	3.20E-09	1.50E-09	2.20E-08	---	1.20E-08	3.00E-08
Ethylene		4.40E-06	4.50E-06	6.70E-07	4.80E-07	6.90E-07	8.90E-07	3.80E-07	1.00E-06	5.10E-07	9.70E-07	5.20E-07	1.60E-06	1.80E-06	1.10E-06	4.00E-06
bis-(2-Ethylhexyl)phthalate	X	1.60E-08	---	---	---	---	---	3.00E-08	---	1.90E-07	---	---	3.00E-08	---	---	---
Fluoranthene	X	1.50E-10	1.30E-10	3.90E-10	6.30E-10	3.80E-10	---	---	---	1.50E-09	6.40E-10	4.50E-10	4.80E-08	6.10E-08	---	3.10E-09
Fluorene	X	3.50E-10	---	2.30E-10	2.60E-10	5.50E-11	5.80E-10	4.40E-10	1.20E-09	6.90E-10	1.90E-10	1.10E-10	3.60E-08	2.60E-08	4.60E-09	3.40E-09
Formaldehyde	X	5.10E-07	3.90E-07	1.80E-07	4.50E-08	5.10E-08	4.70E-07	1.60E-07	8.00E-07	4.00E-07	8.40E-08	5.20E-08	5.80E-07	7.00E-07	8.10E-07	4.50E-07
1,2,3,4,6,7,8-Heptachlorodibenzo-p-dioxin		---	---	8.20E-15	---	---	---	4.00E-14	---	---	9.60E-15	---	1.30E-13	---	2.20E-13	---
1,2,3,4,6,7,8-Heptachlorodibenzofuran		---	1.00E-13	1.20E-15	---	---	5.00E-16	3.00E-14	---	---	2.50E-15	---	---	---	---	---
1,2,3,4,7,8,9-Heptachlorodibenzofuran		---	---	---	---	---	---	---	4.70E-15	---	---	---	---	---	---	---
1,2,3,4,7,8-Hexachlorodibenzo-p-dioxin		---	---	---	---	---	---	---	6.00E-15	---	---	---	1.30E-14	---	---	---
1,2,3,6,7,8-Hexachlorodibenzo-p-dioxin		---	---	---	---	---	---	1.00E-14	1.30E-14	---	---	---	1.70E-14	---	5.50E-14	---
1,2,3,7,8,9-Hexachlorodibenzo-p-dioxin		---	---	---	---	---	---	6.20E-17	5.30E-15	---	---	---	1.80E-14	---	2.30E-14	---
1,2,3,4,7,8-Hexachlorodibenzofuran		---	---	---	---	---	---	1.00E-14	1.10E-14	---	---	---	---	---	---	---
1,2,3,6,7,8-Hexachlorodibenzofuran		---	---	---	---	---	---	2.40E-15	4.10E-15	---	---	---	---	---	2.70E-15	---
2,3,4,6,7,8-Hexachlorodibenzofuran		---	---	---	---	---	---	---	2.50E-15	---	---	---	---	---	---	---
Hexane	X	---	---	3.40E-07	2.60E-07	---	---	---	---	---	2.00E-07	4.90E-07	---	---	---	---
Hydrochloric Acid	X	1.20E-09	---	---	---	---	---	---	1.30E-06	---	---	---	3.30E-07	1.60E-06	1.30E-05	---
Hydrogen Cyanide	X	1.80E-07	1.20E-06	2.20E-05	6.00E-06	1.20E-06	2.40E-05	3.00E-06	1.40E-05	1.90E-05	4.50E-06	1.80E-06	6.20E-05	9.90E-05	2.10E-05	1.60E-04
Hydrogen Fluoride	X	---	---	---	---	---	---	---	---	---	---	---	1.50E-06	---	---	---
Indeno[1,2,3-cd]pyrene	X	6.00E-10	1.10E-09	3.50E-10	4.60E-10	4.40E-10	---	---	---	6.30E-10	4.60E-10	3.00E-10	2.60E-08	2.00E-08	2.10E-09	3.00E-09
Lead	X	2.00E-05	7.40E-06	5.10E-06	2.70E-06	3.10E-06	1.30E-05	2.80E-06	7.80E-06	6.20E-06	4.90E-06	6.80E-06	2.00E-05	1.70E-04	2.10E-05	1.30E-05
Manganese	X	---	1.70E-09	---	---	---	---	---	---	---	---	---	---	3.60E-07	---	---
Methylene chloride	X	7.60E-07	2.50E-06	1.00E-07	7.80E-08	1.80E-07	---	---	---	---	1.00E-07	2.30E-07	---	2.10E-07	8.10E-07	8.00E-07
2-Methyllactonitrile		---	---	3.10E-08	6.60E-09	---	---	---	---	---	---	---	---	---	---	---
Methyl tert-butyl ether	X	---	---	---	---	---	---	6.70E-10	---	---	---	---	---	---	7.90E-08	---
Naphthalene	X	3.70E-08	4.40E-08	9.30E-09	7.80E-09	5.90E-09	2.20E-08	1.30E-08	5.00E-08	2.70E-08	2.40E-08	4.50E-09	4.40E-07	4.20E-07	9.70E-08	1.80E-07
Nickel	X	---	1.60E-09	---	---	---	---	---	---	---	---	---	---	2.80E-06	---	---
Nitric Acid		2.40E-07	---	4.40E-07	---	7.50E-07	---	2.50E-07	---	---	---	1.90E-07	---	---	---	---
Nitroglycerine		2.00E-07	6.60E-09	---	---	---	---	---	---	---	---	---	2.40E-10	4.30E-08	---	---
1,2,3,4,6,7,8,9-Octachlorodibenzo-p-dioxin		2.90E-14	---	---	---	---	---	---	4.90E-13	---	---	---	3.40E-13	4.40E-12	1.70E-12	---
1,2,3,4,6,7,8,9-Octachlorodibenzofuran		---	---	---	---	---	---	---	---	---	---	---	---	---	6.70E-14	6.50E-14
1,2,3,7,8-Pentachlorodibenzo-p-dioxin		---	---	---	---	---	---	4.00E-15	3.70E-15	---	---	---	---	---	---	---
1,2,3,7,8-Pentachlorodibenzofuran		---	---	---	---	---	1.80E-15	9.30E-15	8.80E-15	---	---	---	---	---	---	---

Table 19-3. Speciated VOC Emission Factors for Cartridges Used at Small Arms Firing Ranges (cont.)

Pollutant	HAP[a]	Emission Factors (lb/item)														
		DODIC: A011	A017	A059	A063	A065	A066	A068	A131	A136	A143	A363	A518 (SLAP Ball)	A518 (SLAP Tracer)	A525	A557
2,3,4,7,8-Pentachlorodibenzofuran		---	---	---	---	---	1.10E-16	1.00E-14	7.50E-15	---	---	---	---	---	---	---
Phenanthrene	X	4.30E-10	---	3.00E-10	3.90E-10	1.10E-10	---	---	---	1.20E-09	3.10E-10	2.40E-10	5.20E-08	7.00E-08	---	3.50E-09
Phenol	X	---	---	---	---	---	---	---	---	---	---	---	2.10E-07	1.50E-07	---	---
Propionaldehyde	X	---	---	1.00E-08	8.60E-09	---	2.10E-08	---	2.80E-08	---	---	---	---	---	1.90E-07	---
Propylene		5.90E-07	6.50E-07	1.20E-07	8.30E-08	5.60E-08	8.50E-08	5.30E-08	1.50E-07	---	1.80E-07	1.50E-07	---	---	---	1.10E-06
Pyrene	X	3.40E-10	---	9.50E-10	1.30E-09	1.20E-09	2.20E-10	---	4.10E-10	7.70E-09	2.20E-09	1.00E-09	5.10E-08	1.10E-07	2.40E-09	8.20E-09
Selenium	X	---	3.10E-09	9.90E-09	---	---	---	---	---	---	---	---	---	5.10E-08	---	---
Styrene	X	1.50E-08	2.00E-08	8.30E-09	6.20E-09	7.50E-10	7.90E-09	7.90E-09	8.20E-09	7.10E-09	9.30E-09	2.10E-09	2.10E-07	2.10E-07	3.60E-08	1.30E-07
Sulfuric Acid		1.20E-06	---	2.90E-07	2.90E-08	1.00E-07	---	3.50E-07	---	---	---	6.40E-08	1.60E-06	---	2.90E-06	---
2,3,7,8-Tetrachlorodibenzo-p-dioxin	X	---	---	---	---	---	---	2.90E-14	---	---	---	---	---	---	---	---
2,3,7,8-Tetrachlorodibenzofuran		---	---	---	---	---	4.30E-15	2.20E-14	1.70E-14	---	---	---	---	---	---	---
1,1,2,2-Tetrachloroethane	X	2.70E-09	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Toluene	X	8.40E-08	1.00E-07	3.00E-08	3.00E-08	1.30E-08	2.70E-08	1.50E-08	4.90E-08	4.20E-08	4.40E-08	3.10E-08	9.10E-07	1.10E-06	2.50E-07	4.00E-07
1,1,1-Trichloroethane	X	---	---	1.60E-09	1.80E-09	1.50E-10	---	---	---	---	---	1.90E-10	---	---	---	---
1,2,4-Trimethylbenzene		6.80E-08	---	1.90E-09	---	8.20E-10	---	---	5.50E-09	---	---	8.50E-10	3.00E-09	---	---	7.10E-09
Xylenes (mixed isomers)	X	1.30E-08	---	6.30E-09	4.20E-09	1.52E-09	---	---	2.56E-08	---	9.50E-09	7.50E-09	5.10E-08	---	4.30E-08	5.80E-08

SOURCE: Section 15.1- “Cartridges Smaller than 30mm," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, February 2008.

a) HAP = Hazardous Air Pollutant. An “X” indicates that this compound is a Hazardous air pollutant (HAP).

“---” - No data available.

19.3 Control Techniques

Emissions from indoor ranges may be controlled using a combination of an air ventilation system and a filtration system prior to releasing the air into the atmosphere. The two main types of ventilation systems include mixed ventilation and displacement ventilation. Mixed ventilation systems work by blowing clean air at high speeds into the range to create turbulent air flow. Displacement ventilation systems, by contrast, do not use turbulent air flow or counter currents so that contaminated air can move directly to the filtration system with little dilution beforehand. No matter the ventilation system used, the air may pass through an air filter prior to ventilation outside of the indoor range. While the ventilation systems may limit the exposure of people to the hazardous pollutants, the filter removes those substances from the air prior to exhausting to the atmosphere. It may be necessary to contact the filtration system manufacturer to determine the control efficiency of the filter for each pollutant.

19.4 Emissions Calculation

Emissions from small arms are the product of the number of total rounds fired and the appropriate EF. For indoor ranges, it may be possible to have some sort of control device to filter emissions before they are released to the atmosphere. Emissions from small arms are calculated as follows:

$$\boldsymbol{E_{Pol} = Q \times EF_{Pol} \times \left[1 - \left(\frac{CE}{100}\right)\right]}$$

Equation 19-1

Where,

E_{Pol} = Annual emissions of the pollutant of concern (lb/yr)
Q = Quantity of the same type of ammunition fired during the year (item/yr)
EF_{Pol} = Pollutant emission factor for that ammunition type (lb/item)
CE = Control device efficiency, if present (%)
100 = Factor converting percent to fraction (%)

A detailed control volume depicting the emissions from small arms stationary ranges is provided in Figure 19-2.

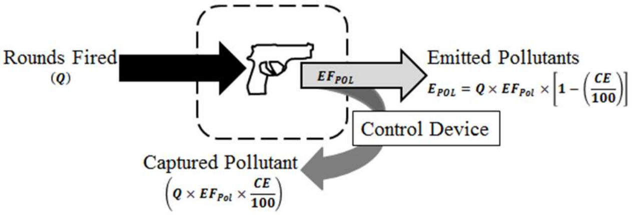

Figure 19-2. Small Arms Stationary Ranges Control Volume

19.5 Information Resources

For information regarding the weapons used, ammunition types, and number of rounds fired, contact the Security Police organization. For indoor ranges equipped with a filtration system, contact BEE, base CE, or the filter manufacturer for assistance in determining the control efficiency of the filter.

19.6 Example Problem

A USAF base has an indoor range used for small arms firing. A total of 212,715 rounds of 5.56mm ball cartridges (DODIC A059) and 97,275 rounds of 9mm ball cartridges (DODIC A363) were fired at this range during the year. If the indoor range has a stated control efficiency of 90 percent for Pb and 0 percent for CO, calculate the total CO and Pb emissions at this range.

<u>Step 1</u> – **Select and record the appropriate EFs.** For the A059 rounds, the EFs for CO and Pb are **1.60E-03** and **5.10E-06** lb/item, respectively. For the A363 rounds, the CO and Pb EFs are **3.10E-04** and **6.80E-06** lb/item, respectively.

<u>Step 2</u> – **Calculate CO emissions for each ammunition type.** Use the EFs recorded in Step 1, the number of rounds fired as given in the problem statement, and Equation 19-1 as shown:

$$E_{Pol} = Q \times EF_{Pol} \times \left[1 - \left(\frac{CE}{100}\right)\right]$$

<u>For A059 rounds:</u>

$$E(A059)_{CO} = 212{,}715\ \frac{item}{yr} \times 0.0016\frac{lb}{item} \times \left[1 - \left(\frac{0\cancel{\%}}{100\cancel{\%}}\right)\right]$$

$$\boldsymbol{E(A059)_{CO}} = 212{,}715\ \frac{\cancel{item}}{yr} \times 0.0016\frac{lb}{\cancel{item}} \times [1] = \mathbf{340.34}\boldsymbol{\frac{lb}{yr}}$$

<u>For A363 rounds:</u>

$$E(A363)_{CO} = 97{,}275\ \frac{item}{yr} \times 0.00031\frac{lb}{item} \times \left[1 - \left(\frac{0\cancel{\%}}{100\cancel{\%}}\right)\right]$$

$$\boldsymbol{E(A363)_{CO}} = 97{,}275\ \frac{\cancel{item}}{yr} \times 0.00031\frac{lb}{\cancel{item}} \times [1] = \mathbf{30.16}\boldsymbol{\frac{lb}{yr}}$$

<u>Step 3</u> – **Calculate total CO emissions.** Sum the CO emissions calculated in Step 2 as follows:

$$E(Total)_{CO} = 340.34\frac{lb}{yr} + 30.16\frac{lb}{yr}$$

$$\boxed{\boldsymbol{E(Total)_{CO} = 370.5\,\frac{lb}{yr}}}$$

<u>Step 4</u> – Calculate Pb emissions for each round. Use the EFs recorded in Step 1, the number of rounds fired, the filter control efficiency, and Equation 19-1 as shown:

$$E_{Pol} = Q \times EF_{Pol} \times \left[1 - \left(\frac{CE}{100}\right)\right]$$

<u>For the A059 rounds:</u>

$$E(A059)_{Pb} = 212{,}715\,\frac{item}{yr} \times 0.0000051\,\frac{lb}{item} \times \left[1 - \left(\frac{90\cancel{\%}}{100\cancel{\%}}\right)\right]$$

$$\boldsymbol{E(A059)_{Pb}} = 212{,}715\,\frac{\cancel{item}}{yr} \times 0.0000051\,\frac{lb}{\cancel{item}} \times [0.1] = \boldsymbol{0.11\,\frac{lb}{yr}}$$

<u>For the A363 rounds:</u>

$$E(A363)_{Pb} = 97{,}275\,\frac{item}{yr} \times 0.0000068\,\frac{lb}{item} \times \left[1 - \left(\frac{90\cancel{\%}}{100\cancel{\%}}\right)\right]$$

$$\boldsymbol{E(A363)_{Pb}} = 97{,}275\,\frac{item}{yr} \times 0.0000068\,\frac{lb}{item} \times [0.1] = \boldsymbol{0.07\,\frac{lb}{yr}}$$

<u>Step 5</u> – Calculate total Pb emissions. Sum the Pb emissions calculated in Step 4 as follows:

$$E(Total)_{Pb} = 0.11\,\frac{lb}{yr} + 0.07\,\frac{lb}{yr}$$

$$\boxed{\boldsymbol{E(Total)_{Pb} = 0.18\,\frac{lb}{yr}}}$$

19.7 References

40 CFR 98 Subpart A, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 98-Mandatory Greenhouse Gas Reporting, Subpart A-General Provision," U.S. Environmental Protection Agency

USEPA 2008, Section 15.1-“Small Cartridges Smaller than 30mm," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, February 2008

Williams, Anthony W., Brant, Andrew L., Kaste, Pamela J., Colburn, Joseph W., “Experimental Studies of the No. 41 Primer and Ignition of 5.56-mm Ammunition,” Army Research Laboratory, September 2006

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20 STATIC ROCKET ENGINE TESTING (RTST)

- *Point source* – if testing occurs in an enclosure
- *Fugitive source* – if testing is not performed in an enclosure

20.1 Introduction

Rocket engine testing is performed at certain USAF installations on a routine basis. A typical solid-fuel rocket motor consists of a motor body, a nozzle, an igniter assembly, and a propelling charge. The igniter assembly may also include an ignition charge, an initiation charge, a black powder charge, and a black powder booster charge. The rockets are tested under controlled conditions, either under ambient pressure or over a wide range of simulated altitude pressures. Emissions from static rocket engine testing are regarded as stationary since the rocket is affixed to a test stand.

Emissions of concern from rocket engine testing include criteria pollutants, HAPs, and GHGs. Emissions from rocket engine testing are facility-specific, and **can be either point or fugitive sources of emissions,** depending on whether the testing is performed in an enclosed facility or not. A simple control volume for rocket engine testing is provided in Figure 20-1.

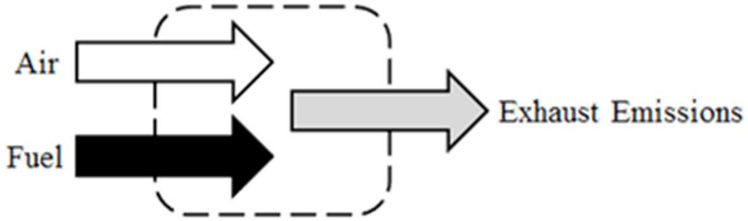

Figure 20-1. Simplified Rocket Engine Test Control Volume

20.2 NESHAP Applicability

The EPA has determined that rocket engine test firing facilities have the potential to be major sources for emissions of criteria pollutants and HAPs. 40 CFR 63 Subpart PPPPP, *National Emission Standards for Hazardous Air Pollutants for Engine Test Cells/Stands*, establishes emission limits as well as requirements for demonstrating compliance with these limits. This NESHAP applies to engines with a rated power of 25 horsepower or more for those facilities that are major sources of HAPs. Additionally, 40 CFR 61 Subpart D, *National Emission Standard for Beryllium Rocket Motor Firing*, establishes a beryllium concentration threshold limit. This NESHAP states that air sampling emissions test results must be retained for a minimum of two years. For information regarding the emission limits as well as compliance and reporting requirements, refer to 40 CFR 63 Subpart PPPPP and 40 CFR 61 Subpart D.

20.3 Emission Factors

The EPA has developed EFs for a limited number of rocket motors available in Section 15.6 of AP-42, entitled “Rockets, Rocket Motors, and Igniters.” There is limited data regarding emissions from rocket engines. Criteria pollutant and GHG EFs for these rockets are provided in Table 20-1 and Table 20-2, respectively. EFs for speciated HAPs are provided in Table 20-3. **Note that these EFs are only associated with the use of the rocket motor; emissions associated with the impact and/or detonation of the warhead are not addressed here.** If an EF is unavailable for the rocket engine being tested, a surrogate engine may be used to calculate emissions. The EFs provided are in units of pounds per item, though AP-42 also provides EFs based on pounds per pound NEW. Refer to Section 15.6 of AP-42 for additional information.

Table 20-1. Criteria Pollutant Emission Factors for Rocket Engine Testing

DODIC	Item	Net Explosive Material (NEW)	Emission Factor (lb/item)						
			NO_X	CO	SO_X	Pb	VOC	PM_{10}	$PM_{2.5}$
H459	2.75-inch Fletchette, MK40 Mod 3 Motor	6.02E+00	2.60E-02	1.50E+00	---	5.10E-02	---	1.10E-01	1.00E-01
H557	66-mm High Explosive Antitank Rocket (M72A3)	1.34E-01	2.10E-03	5.80E-03	2.10E-05[(a)]	1.80E-05	---	8.10E-03	7.70E-03
H708	35-mm Subcaliber Practice Rocket (M73)	2.64E-02	---	2.50E-03	---	6.20E-06	---	1.20E-03	1.20E-03
H974	2.75-inch Practice Warhead, MK66 Mod 3 Motor (M267)	7.17E+00	---	5.30E-01	---	7.00E-02	---	1.60E-01	1.70E-01

SOURCE: Section 15.6 - “Rockets, Rocket Motors, and Igniters," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, July 2009.

a) Value given in AP-42 Document as SO_2 and assumed to be representative of SO_x emissions.

“---” – No data available.

Table 20-2. GHG Emission Factors for Rocket Engine Testing

DODIC	Item	Net Explosive Material (NEW)	Emission Factor (lb/item)			
			CO_2	CH_4	N_2O	CO_2e[(a)]
H459	2.75-inch Fletchette, MK40 Mod 3 Motor	6.02E+00	2.40E+00	2.20E-02	---	2.95E+00
H557	66-mm High Explosive Antitank Rocket (M72A3)	1.34E-01	8.50E-02	1.40E-04	---	8.85E-02
H708	35-mm Subcaliber Practice Rocket (M73)	2.64E-02	1.40E-02	7.10E-06	---	1.42E-02
H974	2.75-inch Practice Warhead, MK66 Mod 3 Motor (M267)	7.17E+00	4.80E+00	6.20E-03	---	4.96E+00

SOURCE: Section 15.6 - “Rockets, Rocket Motors, and Igniters," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, July 2009.

a) CO_2e calculated by summing the product of the default emission factors for CO_2, N_2O, and CH_4 and their respective Global Warming Potentials (GWP). The GWP for CO_2, N_2O, and CH_4 are 1, 298, and 25 respectively.

“---” – No data available.

Table 20-3. HAP Emission Factors for Rocket Engine Testing

Compound (CAS)	Emission Factor (lb/item)			
	2.75-inch Fletchette, MK40 Mod 3 Motor	2.75-inch Practice Warhead, MK66 Mod 3 Motor (M267)	M73 35-mm Subcaliber Practice Rocket	M72A3 66-mm High Explosive Antitank Rocket
Acenaphthene (83-32-9)	4.80E-07	3.80E-07	---	1.60E-10
Acenaphthylene (208-96-8)	3.00E-05	1.30E-05	---	2.00E-09
Acetaldehyde (75-07-0)	4.80E-04	2.00E-04	6.00E-07	2.60E-06
Acetonitrile (75-05-8)	2.20E-04	8.70E-05	---	1.50E-06
Acrylonitrile (107-13-1)	4.80E-05	2.60E-05	1.60E-06	6.80E-07
Anthracene (120-12-7)	1.20E-06	1.00E-06	---	5.00E-10
Antimony (7440-36-0)	---	---	2.10E-06	6.60E-06
Benzene (71-43-2)	1.70E-03	3.80E-04	6.80E-07	2.00E-06
Benzo[a]anthracene (56-55-3)	1.70E-06	7.60E-07	6.00E-10	5.00E-10
Benzo[b]fluoranthene (205-99-2)	2.00E-06	6.20E-07	---	4.70E-10
Benzo[k]fluoranthene (207-08-9)	1.50E-06	5.40E-07	---	2.10E-09
Benzo[g,h,i]perylene (191-24-2)	1.30E-05	2.50E-06	---	1.40E-09
Benzo[a]pyrene (50-32-8)	2.80E-06	1.20E-06	---	2.00E-09
Benzo[e]pyrene (192-97-2)	3.10E-06	8.00E-07	---	---
Cadmium (7440-43-9)	1.20E-03	6.60E-04	7.40E-05	1.10E-06
Carbon Disulfide (75-15-0)	---	---	4.30E-08	4.10E-08
Chloromethane (74-87-3)	1.20E-05	---	---	2.50E-08
Chromium (7440-47-3)	4.10E-06	1.40E-05	4.00E-06	7.30E-07
Chrysene (218-01-9)	2.10E-06	7.40E-07	---	1.10E-09
Cumene (98-82-8)	---	---	6.60E-08	---
Dibenz[a,h]anthracene (53-70-3)	1.00E-07	5.40E-08	---	---
1,2-Dichloroethane (107-06-2)	---	---	---	2.30E-08
Total Dioxin/Furan Compounds	1.70E-10	---	2.30E-14	2.20E-11
Ethylbenzene (100-41-4)	---	---	---	3.80E-08
Fluoranthene (206-44-0)	---	6.20E-06	2.50E-09	1.70E-09
Fluorene (86-73-7	3.70E-06	2.00E-06	9.50E-10	9.10E-10
Formaldehyde (50-00-0)	3.40E-04	2.50E-04	1.30E-06	1.30E-05
1,2,3,4,6,7,8-Heptachlorodibenzo-p-dioxin (35822-46-9)	1.80E-11	---	2.30E-14	1.40E-12
Hexane (110-54-3)	---	---	---	5.10E-06
Hydrochloric Acid (7647-01-0)	---	1.70E-03	1.40E-04	6.80E-04
Hydrogen Cyanide (74-90-8)	4.20E-03	7.40E-04	1.20E-07	2.10E-05
Hydrogen Fluoride (7664-39-3)	---	---	1.40E-06	---
Indeno[1,2,3-cd]pyrene (193-39-5)	4.20E-06	1.00E-06	---	---
Lead (7439-92-1)	5.10E-02	7.00E-02	6.20E-06	1.80E-05
Manganese (7439-96-5)	5.00E-05	4.70E-05	---	8.30E-07
Methylene Chloride (75-09-2)	2.80E-03	1.30E-04	---	1.70E-05
Methyl Isobutyl Ketone (108-10-1)	2.80E-03	---	6.20E-06	---
Methyl Methacrylate (80-62-6)	1.10E-04	---	4.00E-06	---
Naphthalene (91-20-3)	1.10E-04	8.60E-06	3.20E-08	3.00E-08
Nickel (7440-02-0)	1.50E-10	---	---	5.90E-07
1,2,3,4,6,7,8,9-Octachlorodibenzo-p-dioxin (3268-87-9)	1.50E-10	---	---	1.90E-11
Phenanthrene (85-01-8)	1.20E-05	7.40E-06	2.40E-09	2.40E-09
Phenol (108-95-2)	2.20E-05	---	---	1.40E-06
Propionaldehyde (123-38-6)	2.80E-05	---	3.90E-07	---
Pyrene (129-00-0)	2.80E-05	1.10E-05	2.90E-09	2.10E-09
Styrene (100-42-5)	3.50E-05	1.70E-05	8.70E-08	5.70E-07
Toluene (108-88-3)	1.10E-04	4.70E-05	1.50E-07	4.60E-08
2,3,7,8-Tetrachlorodibenzo-p-dioxin (1746-01-6)	---	---	---	1.30E-13
Tetrachloroethylene (127-18-4)	---	---	1.30E-08	---
1,1,1-Trichloroethane (71-55-6)	---	---	---	2.10E-07
Xylenes - Mixed Isomers (1330-20-7)	---	---	1.16E-06	3.00E-07

SOURCE: Section 15.6 - "Rockets, Rocket Motors, and Igniters," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, July 2009.

"---" - No data available.

20.4 Emission Calculations

Emissions from rocket engine testing may be calculated by multiplying the appropriate EF by the number of rocket engines tested per year, as shown in Equation 20-1:

$$\boldsymbol{E_{Pol} = \mathrm{Q} \times EF_{Pol}}$$

Equation 20-1

Where,

E_{Pol} = Pollutant emissions (lb/yr)
Q = Annual quantity of rocket engines tested (items/yr)
EF_{Pol} = Emission Factor (lb/item)

If the NEW value is available for the rocket being tested, Equation 20-2 can also be used to calculate the emissions for an individual rocket as shown below:

$$\boldsymbol{E_{Pol} = \mathrm{Q} \times EF_{Pol} \times NEW}$$

Equation 20-2

Where,

E_{Pol} = Pollutant emissions (lb/yr)
Q = Quantity of rocket engines tested (items/yr)
EF_{Pol} = Emission Factor (lb/lb NEW)
NEW = Net Explosive Weight (lb/item)

A detailed control volume describing the calculation of emissions from static rocket engine testing is provided in Figure 20-2:

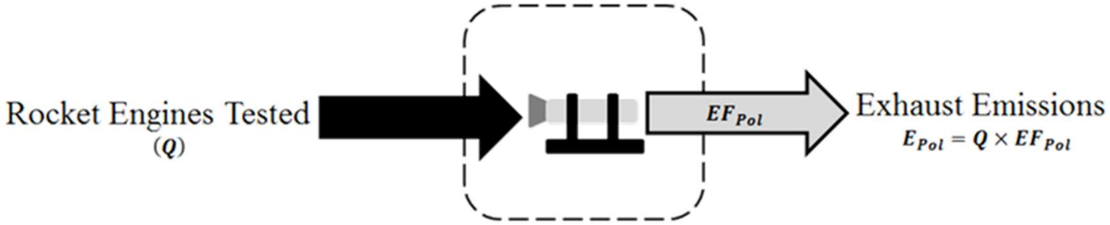

Figure 20-2. Static Rocket Engine Testing Control Volume

20.5 Information Resources

Information required for calculating emissions from rocket engine testing may be obtained directly from the facilities performing the tests. Since limited data is available regarding rocket engine emissions, it may be necessary to contact the engine manufacturer for emissions data. Contact the air quality SME prior to using any EFs not provided here for approval or guidance.

20.6 Example Problem

A USAF base needs to calculate emissions from all DODIC H459 rockets utilizing the MK40 Mod 3 motor tested on base during the last inventory period. The facility was contacted directly and reported that 23 of the DODIC H459 rockets were tested during the inventory period in question. Calculate the PM_{10}, $PM_{2.5}$, and benzene emissions from testing of these rocket engines.

Step 1 - Select and record the appropriate EFs. The particulate EFs are provided in Table 20-1 while the benzene EF is provided in Table 20-3. For PM_{10}, $PM_{2.5}$, and benzene, the EFs are **1.10E-01**, **1.00E-01**, and **1.70E-03 lb/item**, respectively.

Step 2 - Calculate emissions. This is accomplished by using the EFs recorded in Step 1 and Equation 20-1 as shown:

$$E_{Pol} = \mathrm{Q} \times EF_{Pol}$$

For PM_{10}:

$$E_{PM_{10}} = 23\,\frac{\cancel{items}}{yr} \times 0.11\,\frac{lb}{\cancel{item}}$$

$$\boxed{\boldsymbol{E_{PM_{10}} = 2.53\,\frac{lb}{yr}}}$$

For $PM_{2.5}$:

$$E_{PM_{2.5}} = 23\,\frac{\cancel{items}}{yr} \times 0.10\,\frac{lb}{\cancel{item}}$$

$$\boxed{\boldsymbol{E_{PM_{2.5}} = 2.30\,\frac{lb}{yr}}}$$

For Benzene:

$$E_{Benzene} = 23\,\frac{\cancel{items}}{yr} \times 0.0017\,\frac{lb}{\cancel{item}}$$

$$\boxed{\boldsymbol{E_{Benzene} = 0.04\,\frac{lb}{yr}}}$$

20.7 References

40 CFR 98 Subpart A, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 98-Mandatory Greenhouse Gas Reporting, Subpart A-General Provision," U.S. Environmental Protection Agency

40 CFR 61 Subpart D, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 61-National Emission Standards for Hazardous Air Pollutants, Subpart D-National Emission Standard for Beryllium Rocket Motor Firing," U.S. Environmental Protection Agency

40 CFR 63 Subpart PPPPP, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 63-National Emission Standards for Hazardous Air Pollutants for Source Categories, Subpart PPPPP-National Emission Standards for Hazardous Air Pollutants for Engine Test Cell/Stands," U.S. Environmental Protection Agency

USEPA 2009, Section 15.6-“Rockets, Rocket Motors, and Igniters," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, July 2009

21 STORAGE TANKS (AST, UST)

- *Point Source*

21.1 Introduction

Storage tanks located on USAF installations are used for storage of materials, including fuels such as JP-8, Jet A, automotive gasoline (MOGAS), and diesel, asphalt, or solvents. These compounds are composed of VOCs and HAPs which are released into the atmosphere as the liquid evaporates. The storage tanks may contain anywhere from a few hundred to over a million gallons of material and may be above ground (AST) or underground (UST). According to the EPA, a UST is defined as a tank or piping system that has 10 percent or more of its combined volume underground, while an AST has more than 90 percent of their volume above the ground surface. **Note that emissions from storage tanks located at gasoline dispensing facilities are also addressed here rather than in the fuel dispensing section of this guide.**

Emissions from storage tanks are generated as vapor escapes from the higher-pressure environment inside the tank to the lower pressure of the outside atmosphere. The roof design of each storage tank will have a significant effect on the amount of vapor released into the atmosphere. **Storage tanks are regarded as point sources of VOCs and HAPs**. A graphic representation of emissions from fuel storage tanks is given in Figure 21-1.

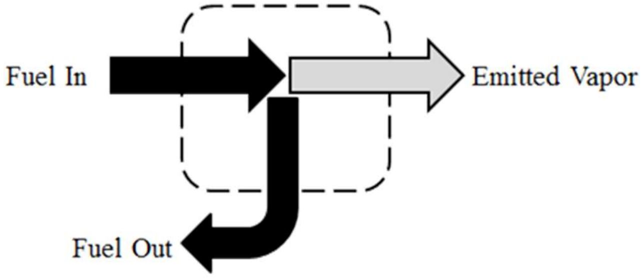

Figure 21-1. Simplified Control Volume for Emissions from Storage Tanks

21.1.1 Tank Types

Calculation of emissions from storage tanks takes many factors into consideration. These factors include the quality of the storage tank and its physical traits such as the age of the tank, the paint color, and the type of tank. The three most common types of tanks are: fixed-roof, external floating roof, and internal floating roof. Other types of tanks include, variable vapor space and pressure tanks.

A fixed roof tank has a permanent, dome- or cone- shaped roof with a cylindrical body shape made of steel. A breather valve is usually placed on a fixed-roof tank that opens to equalize pressure when an imbalance occurs due to changes in temperature or pressure. The vapor expansion results in the release of vapor and is known as "breathing loss" or "storage loss". "Working losses" are those emissions resulting from the filling and emptying of the storage tanks. Air saturation emissions occur during liquid removal from vapor pressure imbalance. Displacement emissions occur when the vapor is displaced due to the addition of liquid during tank filling. Fixed-roof tanks can either be situated horizontally or vertically and the type is important to note for the emission calculations. Fixed-roof tanks are an older design and tend to produce the most vapors compared to other tank types.

Floating roof tanks have an open cylindrical base with a roof that floats above the liquid level surface so it rises and falls with the liquid volume. Floating roof tanks may have an internal or external floating roof. An external floating roof is composed of a deck, fittings, and a rim seal system that slides against the shell wall to limit both evaporative and standing losses. The three types of decks for an external floating roof are pan, pontoon, or double deck. An internal floating roof tank has both a permanent and floating roof. Two basic types of internal floating roof storage tanks include a roof supported by vertical columns within the tank versus a roof that is self-supported. The primary function of the fixed dome roof is to block wind to reduce vapor loss. These tanks are freely vented by circulation vents at the top of the dome.

Variable vapor space tanks have features that accommodate vapor volume fluctuations attributable to temperature and pressure changes called expandable vapor reservoirs. Normally, variable vapor space tanks are connected to the vapor spaces of a fixed roof tank. The two types of variable vapor space tanks consist of lifter roof tanks that have a telescoping roof around the outside of the main tank wall, and a flexible diaphragm tank that uses flexible membranes for volume expansion. Loss from variable vapor space tanks occur during tank filling, when vapor is displaced by liquid.

Pressure tanks are characterized as either low or high pressure. Liquids and gases that have high vapor pressures are most commonly used in pressure tanks. A pressure/vacuum vent is used on pressure tanks to prevent venting losses and breathing losses, so no appropriate correlations are available to estimate vapor losses from pressure tanks.

21.2 NSPS Applicability

There are several NSPS set by the EPA that apply to storage tanks. 40 CFR 60 Subpart K, *Standards of Performance for Storage Vessels for Petroleum Liquids for Which Construction, Reconstruction, or Modification Commenced After June 11, 1973, and Prior to May 19, 1978,* outlines the required standards each facility must meet if the storage tank has a storage capacity greater than 40,000 gallons. These tanks are required to meet these standards if their construction or modification commenced after March 8, 1974 and before May 19, 1978, or between June 11, 1973 and May 19, 1978 for storage tanks with a capacity greater than 65,000 gallons. This standard states that if the true vapor pressure of the liquid is between 1.5 psia (pounds per square inch absolute) and 11.1 psia, the tank must be equipped with a floating roof, vapor recovery system, or their equivalents. Storage tanks whose contents have a true vapor pressure exceeding 11.1 psia, must be equipped with a vapor recovery system. Similarly, 40 CFR 60 Subpart Ka, *Standards of Performance for Storage Vessels for Petroleum Liquids for Which Construction, Reconstruction, or Modification Commenced After May 18, 1978, and Prior to July 23, 1984,* specifies the design standards of storage tanks containing petroleum liquids with a true vapor pressure between 1.5 psia and 11.1 psia. These standards apply to those storage tanks whose construction, reconstruction, or modification occurred after May 18, 1978 and prior to July 23, 1984. Finally, 40 CFR 60 Subpart Kb, *Standards of Performance for Volatile Organic Liquid Storage Vessels (Including Petroleum Liquid Storage Vessel) for Which Construction, Reconstruction, or Modification Commence After July 23, 1984,* outlines the storage tank design requirements for volatile organic liquid containing tanks whose construction, reconstruction, or modification commenced after July 23, 1984. These standards apply to those storage tanks with a capacity greater than 75 cubic meters (though some tanks may be exempt from these requirements). Refer to these CFRs for more information or to verify that the facility adheres to these standards.

The EPA has established a NESHAP that specifically addresses gasoline dispensing facilities. This standard is provided in 40 CFR 63 Subpart CCCCCC, *National Emission Standards for Hazardous Air Pollutants for Source Category: Gasoline Dispensing Facilities*. and states that each gasoline dispensing facility whose monthly throughput is more than 100,000 gallons is required to use submerged filling when loading gasoline into onsite storage tanks. To verify that the facility complies with the requirements outlined in this NESHAP, refer to 40 CFR 63 Subpart CCCCCC.

21.3 Emissions Calculation

Emissions are generated from storage tanks by ways of losses of vapors such as working losses and breathing losses. Features on tanks, such as gauge hatches/sample wells, float gauges, and roof manholes, serve as a potential source of hydrocarbon emissions to escape. The presence of a volume of vapor space above the level of liquid in the tank promotes evaporation of the fuel hydrocarbons and their subsequent release to the atmosphere through the breather valve. Tanks equipped with a floating roof are able to reduce evaporative emissions by eliminating the vapor space between the liquid level in the tank and the tank roof. However, some emissions do occur through various seals and openings and from fuel clinging to the tank walls as the liquid level and roof are lowered.

The EPA has developed TANKS which is a computer software program that estimates volatile organic compounds and HAP emissions from fixed and floating roof storage tanks based on tank characteristics input and location. The TANKS program is based on the emission estimation procedures from Chapter 7 of EPA's *Compilation of Air Pollutant Emission Factors* (USEPA 2006), and is used for performing AEIs. The EPA has issued a warning stating that "the TANKS model is not reliably functional on computers using certain operating systems such as Windows Vista or Windows 7". **The TANKS program is no longer compatible with computer operating systems in use by the USAF. Therefore, use of either ACAM or APIMS is advised for all storage tank emissions calculations. Both ACAM and APIMS utilize emissions estimation procedures from Chapter 7 of AP-42.**

21.4 Information Resources

For a complete list of storage tanks located on base, as well as information concerning the tank contents and throughput, contact the Base Supply Fuels Management or Civil Engineering Liquid Fuels shop. These offices should also be able to provide tank characteristic data such as the tank type, dimensions, volume, paint color, and tank condition. For information pertaining to fuel service stations, it may be necessary to also contact the service station supervisor.

21.5 References

40 CFR 60 Subpart K, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New Stationary Sources, Subpart K-Standards of Performance for Storage Vessels for Petroleum Liquids for Which Construction, Reconstruction, or Modification Commenced After June 11, 1973, and Prior to May 19, 1978," U.S. Environmental Protection Agency

40 CFR 60 Subpart Ka, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New Stationary Sources, Subpart Ka-Standards of Performance for Storage Vessels for Petroleum Liquids for Which Construction, Reconstruction, or Modification Commenced After May 18, 1978, and Prior to July 23, 1984," U.S. Environmental Protection Agency

40 CFR 60 Subpart Kb, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New Stationary Sources, Subpart Kb-Standards of Performance for Volatile Organic Liquid Storge Vessels (Including Petroleum Liquid Storage Vessels) for Which Construction, Reconstruction, or Modification Commenced After July 23, 1984," U.S. Environmental Protection Agency

40 CFR 63 Subpart CCCCCC, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 63-National Emission Standards for Hazardous Air Pollutants for Source Categories, Subpart CCCCCC-National Emission Standards for Hazardous Air Pollutants for Source Category: Gasoline Dispensing Facilities," U.S. Environmental Protection Agency

USEPA 2005, TANKS, Version 4.09d, U.S. Environmental Protection Agency, October 2005

USEPA 2006, Section 7.1-“Organic Liquid Storage Tanks," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, November 2006

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22 SURFACE COATINGS (SURF)

- *Point Source* – When performed using an industrial (non-HVAC) ventilation system
- *Fugitive Source* – When not using an industrial (non-HVAC) ventilation system

22.1 Introduction

Surface coatings involve a wide range of coating materials and application processes. A surface coating may be applied to a part for decorative purposes or to improve its corrosion resistance or wear characteristics. Surface coatings include the application of conventional coatings such as paints, primers, or varnishes. Note that electroplating, chromic acid anodizing, and thermal metal spraying are not addressed in this section, but may be found in the "Corrosion Control" section of this guide. Also, emissions from architectural coatings are not addressed here, but may be found in the "Construction" section of the *Air Emissions Guide for Air Force Transitory Sources*.

Paints, primers, varnishes and stains used in surface coatings typically contain solvents that are composed of VOCs and HAPs. Emissions from surface coating operations are dependent on the operation type, application method, and presence of an emissions control device. Surface coating operations are conducted either in a paint booth, dip tank, hangar, or applied outdoors. **Surface coating applications that occur indoors and use an industrial (non-HVAC) ventilation system are considered point sources. The emissions from surface coatings applied in the absence of a ventilation system are categorized as fugitive. The emissions of concern include HAPs, VOCs, and PM.** A graphic representation of the emissions from surface coating operations is given in Figure 22-1.

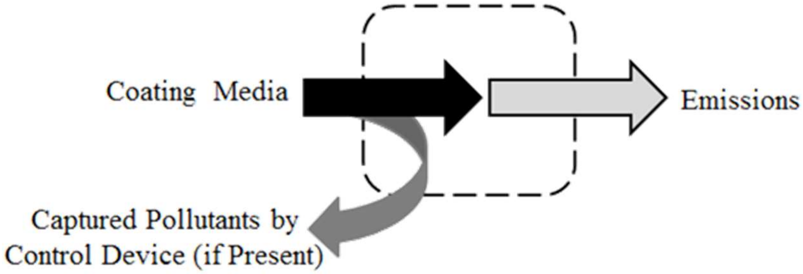

Figure 22-1. Simplified Control Volume for Emissions from Surface Coating Operations

Surface coating operations are those that involve the application of, but not limited to paints, primers, thinners, stains, varnishes, shellacs, and glazes. These coatings may be in liquid or powder form to a substrate for decorative and/or protective purposes. The coating material may contain significant amounts of solvents that are emitted into the air as they evaporate. The type

and quantity of emitted pollutants are dependent on the composition of the surface coating, the application technique used, and if a control device is used.
Conventional coatings contain a minimum of 30 percent solvents by volume, but commonly contain as much as 70 percent to 85 percent solvents by volume. The solvents in conventional coatings provide a liquid medium for synthetic polymers that form a film over the surface to which they are applied. Following application of the conventional coating, the solvent evaporates. The solvents may contain one or more components such as acetates, aromatics, glycol ethers, aliphatic hydrocarbons, or water. Increased environmental awareness has led to a steady reduction in the amount of solvents in surface coatings. Those coatings which contain 30 percent solvent by volume or less are referred to as low solvent or “high solid” coatings. Increasing the amount of solids in the coating may reduce VOC emissions, but will increase emissions of PM from overspray.

Powder coatings can produce coatings that are thicker than conventional liquid applications without any running or sagging. Powder coatings are often applied electrostatically and heated to melt the powder, allowing it to flow together and form an even coat. Alternatively, the substrate to which the powder coating will be applied may be heated prior to coating application allowing for the powder to melt as it is applied. Since powder coating does not require a liquid carrier, there are few VOCs emitted from the application of this type of coating, though particulate emissions may still be a concern. Stack testing may be more frequently employed for powder coatings, and serves as the most accurate method for estimating emissions over those presented in the following sections.

The reduction of the amount of solvent use in surface coatings has encouraged the manufacture of waterborne coatings. Waterborne coatings use water as the liquid medium, but still contain co-solvents and additional additives to have the same, if not better, cosmetic appearance and physical performance than those of solvent based coatings. Waterborne coatings may be cured through evaporation, oven baking, or the application of UV light.

Except for touch-up painting, coating operations involving spray applications (e.g. conventional spraying, electrostatic spraying, airless spraying, etc.) are usually performed in either a spray booth or a spray hangar. A typical spray booth/hangar is equipped with a ventilation system that draws air either across or downward onto the object being coated. The air then moves through a PM/inorganic HAP control device, such as a dry filter system or water-wash system. After passing through the PM/inorganic HAP control device, the air is either vented directly into the atmosphere or is vented to a VOC/organic HAP control device such as a carbon absorption system or an incinerator. Coating applications include conventional spraying, airless spraying, air assisted airless spray, electrostatic spray, roller coating, dip coating, flow coating, and brush coating.

Conventional spraying is usually hand operated and employs a spray gun which atomizes the coating media and is air propelled. Surface coating colors can be changed easily, and a variety of shapes and sizes can be painted under many operating conditions, making conventional spraying one of the most versatile coating application methods available. However, a substantial amount of atomized coating droplets tend to rebound off of the surface, resulting in low efficiency from what is known as overspray. Approximately 30 percent to 35 percent of the coating sticks to the intended surface, which results in increased application time and an increase in the energy requirements of the air compressor. These inefficiencies have led to the popularity of high volume, low pressure (HVLP) spray applications. HVLP applications have a higher coating efficiency, with approximately 60-90 percent of applied coating adhering to the intended surface, resulting in lower emissions.

For airless spray application, paint is forced through an atomizing nozzle. The emissions from airless spray applications are lower than conventional spraying because less solvent is required. VOC emissions are further reduced due to lower volumetric flow, which results in less overspray. Air-assisted airless spraying atomizes the coating material at a low pressure, while another low-pressure air stream is directed at the paint mist. This procedure offers similar advantages to airless spraying, but is a safer alternative since the procedure is performed at lower pressures.

Electrostatic spraying involves the application of charged paint particles to an oppositely charged surface. This procedure is most efficient when using low viscosity paints, and results in efficiencies between 90 to 95 percent with uniform coating along the edges. However, coating interiors and recessed surfaces is difficult with this application method.

Roller coating is an effective application method for coating flat surfaces. This method typically utilizes a machine that has three or more power-driven rollers. One roller spins while partially immersed in the coating and transfers it to a second, parallel roller. The strip or sheet to be coated is then run between the second and third roller and is coated by transfer of the coating from the second roller. The quantity of coating applied to the strip or sheet is determined by the distance between the rollers. If the cylindrical rollers move in the same direction as the surface to be coated, then the system is called a direct roll coater, otherwise it is classified as a reverse roll coater.

Dip coating involves the total immersion of parts into a dip tank that contains the coating material. The parts are then removed from, and suspended above the dip tank to allow any excess coating to drip back into the coating reservoir. The process of submerging and removing the part may be performed manually or with an automated conveyor system. Dip coating operations can be completely enclosed and vented by a roof exhaust system, or can have a ventilation system adjoining the dip tank.

For flow coating, the part to be coated is conveyed over an enclosed sink where 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.

Brush coating is the most basic of coating procedures. This application method involves the use of brushes or hand rollers to apply the coating to the part or surface. Although brush coating has a high transfer efficiency, it is not a practical method for projects consisting of large parts.

22.2 NESHAP Applicability

There are various NESHAPs applicable to surface coating. 40 CFR 63 Subpart GG, *National Emission Standards for Aerospace Manufacturing and Rework Facilities*, outlines those standards for aerospace vehicles and components that are considered major sources. This NESHAP applies to any method of surface coating when the item being treated is an aerospace vehicle or component. Note that there are additional NESHAPs which apply to the coating of metal or plastic components. These include 40 CFR 63 Subparts MMMM, *National Emission Standards for Hazardous Air Pollutants for Surface Coating of Miscellaneous Metal Parts and Products*, Subpart PPPP, *National Emission Standards for Hazardous Air Pollutants for Surface Coating of Plastic Parts and Products*, and Subpart HHHHHH, *National Emission Standards for Hazardous Air Pollutants: Paint Stripping and Miscellaneous Surface Coating Operations at Area Sources*. However, installations which are owned or operated by the Armed Forces of the United States are exempt from these requirements. To verify that the installation complies with the requirements of the aerospace NESHAP (should it apply), please review 40 CFR 63 Subpart GG. Furthermore, 40 CFR 59, *National Volatile Organic Compound Emission Standards for Consumer and Commercial Products*, provides VOC content limits for various coating categories, which may be used in lieu of SDS data.

22.3 Emission Factors

In 2001, the California Air Resources Board (CARB) conducted a survey to determine the sales weighted average densities and VOC weight percent of common surface coatings. Typical VOC content may be determined using the product of these two values. Table 22-1 gives the typical VOC content for the most common solvent-based and water-based surface coatings likely found at a USAF installation. Please note that if the SDS is available and the weight percent of VOC is provided, those values should be used in place of the values given in Table 22-1. VOC emissions calculation is discussed in Section 22.5 of this guide.

Table 22-1. VOC and PM Emission Factors for Surface Coatings

Coating Category		Emission Factors (lb/gal)					
		VOC		PM_{10}(a)		$PM_{2.5}$(a)	
		Solvent-Based	Water-Based	Solvent-Based	Water-Based	Solvent-Based	Water-Based
Concrete Coatings	Concrete Curing	1.9	0.34	3.1	1.3	3.0	1.2
	Concrete Curing and Sealing	3.8	0.44	5.3	3.9	5.1	3.5
	Concrete Protectants	3.3(b)		---	---	---	---
	Concrete Surface Retarders	6.5(b)		---	---	---	---
Fire Retardant/Resistive Coatings	Clear	7.1(b)	0.10	---	3.0	---	2.8
	Opaque	2.2	0.34	8.0	4.4	7.7	4.0
Flat Coatings	Interior/Exterior	2.1(b)	0.34	8.6	4.1	8.3	3.7
	Floor coatings	1.3	0.71	8.4	4.4	8.1	4.0
	Lacquers	4.8	1.0	2.9	1.9	2.8	1.7
	Magnesite cement coatings	2.6	2.6(c)	4.0	---	3.9	---
	Mastic texture coatings	1.7	0.43	5.6	4.4	5.4	4.0
Nonflat coatings	Interior/Exterior	3.2(b)		---	---	---	---
	High Gloss	2.8	0.81	6.8	3.2	6.6	2.9
	Medium Gloss	2.8	0.61	7.5	3.0	7.2	2.8
	Low Gloss	3.1	0.43	7.4	3.6	7.1	3.3
	Primers and undercoaters	2.9	0.42	7.6	3.5	7.3	3.2
Quick-dry coatings	Enamels	3.0	0.94	6.5	2.7	6.2	2.5
	Primers, sealers, and undercoaters	3.7	0.64	6.7	3.6	6.4	3.3
	Roof coatings	1.8	0.21	8.0	4.1	7.7	3.7
	Rust Preventative	3.3	0.54	7.0	3.2	6.8	2.9
	Sealers	3.3(b)	0.69	2.5	1.6	2.4	1.4
Shellacs	Clear	4.7	4.7(c)	2.2	---	2.1	---
	Opaque	4.2	4.2(c)	4.8	---	4.7	---
Stains	Clear and semitransparent	3.3	0.63	4.0	1.7	3.8	1.5
	Opaque	2.9	0.40	7.2	3.0	6.9	2.7
	Traffic marking coatings	0.7	0.68	11.6	6.9	11.2	6.3
	Varnishes - Clear	3.7	0.96	3.7	1.8	3.5	1.7
	Varnishes - Semitransparent	3.6	0.86	3.8	1.7	3.7	1.5
	Waterproofing sealers and treatments	2.9	0.38	4.8	1.7	4.7	1.5

SOURCE (unless otherwise stated): "2001 Architectural Coatings Survey Final Report," California Environmental Protection Agency, California Air Resources Board (CARB), October 2003. The values given are the product of the density and weight percent volatiles but exclude water and exempt compounds.

a) PM_{10} and $PM_{2.5}$ emission factors are the product of the density, solids weight percent, and the fraction of respective PM_{10} and $PM_{2.5}$ to total particulate. This fraction is provided by Krause, Mike and Steve Smith, "Methodology to Calculate Particulate Matter (PM) 2.5 and PM 2.5 Significance Thresholds," South Coast Air Quality Management District, October 2006.

b) SOURCE: Table 1 of Subpart D in "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 59-National Volatile Organic Compound Emission Standards for Consumer and Commercial Products," U.S. Environmental Protection Agency. The source document provides a VOC limit but does not differentiate between solvent-based and water based coatings.

c) Source document does not provide a value for this coating. Conservatively assumed to be equal to the solvent-based formulation.

“---” - No data available.

22.4 Control Techniques

Emissions from surface coatings result from the evaporation of the solvents involved in the coating process. The solvents involved in the coating process may be used for paint thinning, paint clean-up, or as a part of the paint formulation itself. When calculating VOC emissions from surface coating, the assumption is that all VOC's within the coating evaporate completely. There are three methods to reduce emissions from surface coating operations including: coating substitutions, process changes, and add-on control devices.

Substituting paint for more environmentally friendly coatings may greatly reduce the amount of VOCs emitted to the atmosphere. Using water based or low solvent coatings in place of typical solvent coatings may reduce VOC emissions significantly, but may also increase the amount of particulate emitted if the paint is considered "high solid." Process changes may not be feasible, but VOC, HAP, and/or particulate emissions vary depending on the application method used for surface coating operation. Using a method that reduces overspray may significantly reduce VOC and PM emissions. High volume surface coating installations should evaluate the advantages and disadvantages of modifying the application method for surface coatings on typical substrates. While it may be impractical to modify the application methods, evaluation is encouraged to determine any possible reductions in emissions. Finally, pollutant emissions may be controlled with activated carbon filters or incinerators. **Note that the control efficiency for surface coatings must consider the capture and removal efficiency of the device.** Contact the manufacturer of any control device used for an estimate of the control efficiency as needed.

22.5 Emissions Calculation

There are two methods for calculating emissions from surface coating operations. The first method is a simple mass balance, while the second method utilizes established EFs for emissions estimates. Both methods are described in the following subsections.

22.5.1 Calculations Using Mass Balance

Surface coatings produce VOC, HAP (both organic and inorganic), and PM emissions. Though the calculation of each pollutant is similar, the calculation of particulate matter and inorganic HAP emissions calculations are slightly more complicated. This is because these calculations employ additional terms to account for loss and recapture of particulates. Calculation of each pollutant is described below.

22.5.1.1 VOC and Organic HAP Emissions Calculation

The preferred method for calculating emissions from surface coating operations is through mass balance. To calculate VOC and organic HAP emissions using this method, the weight percent of the pollutant in the coating must be known. This information should be available in the product's SDS. Emissions are calculated according to Equation 22-1.

$$\boldsymbol{E_{Pol} = V \times D \times \left(\frac{WP_{Pol}}{100}\right) \times \left[1 - \left(\frac{CE}{100}\right)\right]}$$

Equation 22-1

Where,

E_{Pol} = Annual emissions of pollutant (lb/yr)
V = Volume of coating applied (gal/yr)
D = Density of the coating (lb/gal)
WP_{Pol} = Weight percent of the pollutant in the coating. This may refer to total VOC in the coating or for individual pollutant for speciation purposes (%)
100 = Factor for converting percent to a fraction (%)
CE = Efficiency of the control device, if any. Use 0 if none present (%)

A more detailed control volume representing the calculation of VOC and organic HAPs through mass balance is given in Figure 22-2.

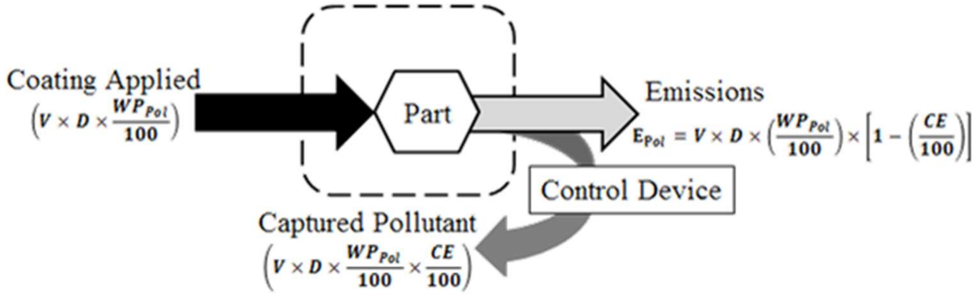

Figure 22-2. Surface Coatings Control Volume – Mass Balance Method

22.5.1.2 Particulate and Inorganic HAP Emissions Calculation

Particulate emissions calculations are more complex than organic HAP and VOC emissions due to the transfer efficiency associated with each process. Transfer efficiency refers to the fraction of coating solids which adhere to the part surface. There are several variables that affect the transfer efficiency including the application method, the size and surface area of the part, and even the skill of the person applying the coating. Each shop may be able to provide the transfer efficiency for emissions estimation purposes. In the absence of this data, typical transfer efficiencies for several coating application methods are given in Table 22-2. Due to the variability in the transfer efficiency, use of these values will be much less accurate than actual shop data, if available.

Table 22-2. Transfer Efficiencies for Various Surface Coating Application Methods

Coating Application Method	Typical Transfer Efficiency (%)
Air Atomizing	30
Airless	40
Air-Assisted Airless	45
High Volume, Low Pressure (HVLP)	65
Electrostatic	65
Dip Coating	85[(a)]
Flow Coating	85[(a)]
Electrodeposition	95[(a)]
Brush Coating	99[(b)]

SOURCE (Unless otherwise stated): Efficiencies provided are the lowest values of a range provided by "Surface Coating & Transfer Efficiency = Savings," Spokane Regional Clean Air Agency, Compliance Assistance Program (CAP), 2012 which cites the South Coast Air Quality Management District (SCAQMD) as the original source.

a) Value obtained from O'Brien, Robert J., Blasch, Kyle W., Johnson, Grant T., "Air Emissions Inventory Guidance Document for Stationary Sources at Air Force Installations," Air Force Institute for Environment, Safety and Occupational Health Risk Analysis (AFMC), May 1999. This document cites "Air Pollution Engineering Manual" by the Air and Waste Management Association as the original source.

b) Transfer efficiency for brush coating assumed to be 99%.

Using the transfer efficiency, the emissions of particulate and inorganic HAPs may be calculated using Equation 22-2 below.

$$\boldsymbol{E_{Pol} = Q \times \left(\frac{WP_{Pol}}{100}\right) \times \left[1 - \left(\frac{TE}{100}\right)\right] \times \left[1 - \left(\frac{CE}{100}\right)\right] \times C_{Pol}}$$

Equation 22-2

Where,

E_{Pol} = Pollutant emissions (lb/yr)

Q = Quantity of solvent used during the year (lb/yr)

WP_{Pol} = Weight percent of the pollutant in the coating. This may refer to total solids in the coating or for individual pollutant for speciation purposes. (%)

C_{Pol} = Fractional percentage of PM_{10} or $PM_{2.5}$ to total PM. **For solvent based surface coatings, this value is 0.960 for PM_{10} and 0.925 for $PM_{2.5}$. For water based surface coatings, this value is 0.680 for PM_{10} and 0.620 for $PM_{2.5}$. Use 1 for calculating inorganic HAPs.**

TE = Transfer efficiency (%)

CE = Efficiency of the control device, if any. Use 0 if none present (%)

A more detailed control volume representing the calculation of VOC and organic HAPs through mass balance is given in Figure 22-3.

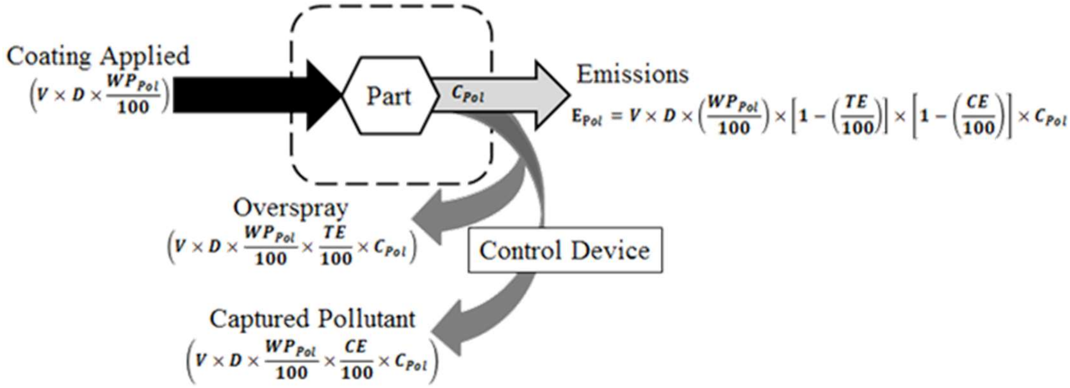

Figure 22-3. Surface Coatings Control Volume – Mass Balance Method

If emissions of a specific HAP are required but is unknown, yet the weight percent of the HAP containing compound is known, the weight percent of the specific HAP may be determined using Equation 22-3.

$$WP_{HAP} = \frac{MW_{HAP}}{MW_{Cmpd}} \times WP_{Cmpd}$$

Equation 22-3

Where,

WP_{HAP} = Weight percent of the specific HAP in the coating (%)
MW_{HAP} = Molecular weight of HAP in the coating compound (g)
MW_{Cmpd} = Molecular weight of the HAP containing compound (g)
WP_{Cmpd} = Weight percent of the HAP containing compound in the coating (%)

22.5.2 Calculations Using Emission Factors

The EF method is less accurate than the mass balance equation and should <u>not</u> be used as an alternative for use in an AEI. Rather, the EF method should be used only for NEPA assessments and should be used for that purpose only. EFs were developed using the sales weighted average density and the VOC and solids weight percent. The VOC, PM_{10}, and $PM_{2.5}$ EFs are provided in Table 22-1 and the calculation is described in Equation 22-4.

$$E_{Pol} = V \times EF_{Pol} \times \left[1 - \left(\frac{CE}{100}\right)\right]$$

Equation 22-4

Where,

$\mathbf{E_{Pol}}$ = Pollutant Emissions (lb/yr)
V = Volume of coating used per year (gal/yr)
$\mathbf{EF_{Pol}}$ = Pollutant emission factor (lb/gal)
CE = Efficiency of the control device, if any. Use 0 if none present (%)
100 = Factor converting percent to a fraction (%)

A more detailed control volume for surface coating using EFs is given in Figure 22-4.

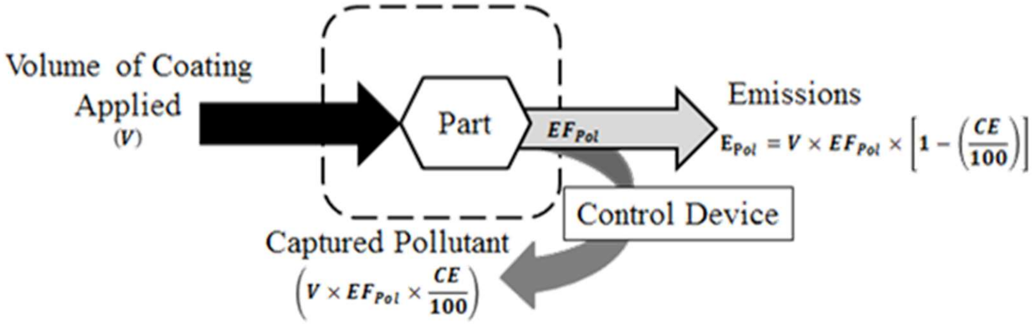

Figure 22-4. Surface Coatings Control Volume – Emission Factor Method

22.6 Information Resources

Most information required to calculate the emissions from surface coating applications can be obtained from the shops that apply the surface coatings. BEE should be able to provide a list of all shops that perform surface coating operations in a controlled space (e.g. paint booth). Information on the quantity of each coating delivered to a shop should be available from records/databases maintained by the HAZMART or EESOH-MIS. 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 or directly from the coating manufacturer. The product literature includes SDS, container label, or technical specification sheets. For surface coatings, if the solids content of a coating is unknown, it can be estimated by subtracting the weight percent of all volatiles in the coating. The total volatiles in surface coatings include all VOCs, the “exempt VOCs” and water. Many coatings used in the USAF are purchased through the GSA. Information on these coatings can be obtained from the GSAs Supply Catalog at http://www.gsa.gov/ggscatalog.

The efficiency of any control device which may be installed in the surface coating operation can be obtained from product literature or directly from the manufacturer of the control device. Additionally, the average transfer efficiency should be available from the paint shops, but the manufacturer of the spray equipment may be able to provide guidance. Note that transfer efficiency is directly correlated to the size and shape of the part being coated. Therefore, the manufacturer may need to know this information regarding the typical pieces being treated to provide an appropriate response. In the absence of this information, the efficiencies provided in Table 22-2 may be used.

22.7 Example Problems

22.7.1 Problem #1 - Mass Balance Method

A USAF base has a shop that applies a solvent based epoxy primer on aircraft parts in a spray booth prior to applying topcoats. The primer is applied using HVLP spray guns that, according to the manufacturer, have an average transfer efficiency of 75 percent. The spray booth is equipped with a particulate control device with a specified efficiency of 90 percent. The shop supervisor states that 95 gallons of the epoxy was used this past year. A review of the SDS for this epoxy reveals that it has a specific gravity of 1.2, a VOC content of 40 percent by weight, and a solids content of 55 percent by weight. Additionally, the coating label states that it has 8 percent xylene by weight. Determine the total VOC, PM_{10}, $PM_{2.5}$, and xylene emissions from the application of this epoxy.

Step 1 – **Gather data.** To calculate these emissions, the volume, weight percent, transfer and control efficiencies must be known. The total volume used was stated to be **95 gal per year.** The weight percent VOC, solids, and xylene are **40 percent, 55 percent, and 8 percent,** respectively. The transfer efficiency is **75 percent** and the control efficiency for the particulate filter is stated as **90 percent**.

Step 2 – **Calculate the coating density.** The problem stated that the specific gravity of the epoxy was **1.2**. Specific gravity is the ratio of the density of the coating to the density of water. Using the density of water as 8.33 lb/gal, the coating density may be calculated as follows:

$$D = SG \times D_{Water}$$

$$\boldsymbol{D} = 1.2 \times 8.33 \frac{lb}{gal} = \mathbf{9.996} \frac{\boldsymbol{lb}}{\boldsymbol{gal}}$$

Step 3 – **Calculate VOC and xylene emissions.** With the density calculated in Step 2 and the data collected in Step 1, there is sufficient information to calculate VOC and xylene emissions. Note that the control device only controls the emissions of particulate and inorganic HAPs, therefore, the control efficiency for VOCs and xylene is 0 percent. Using Equation 22-1, VOC and xylene emissions are calculated as follows:

$$E_{Pol} = V \times D \times \left(\frac{WP_{Pol}}{100}\right) \times \left[1 - \left(\frac{CE}{100}\right)\right]$$

<u>For VOC:</u>

$$E_{VOC} = 95\frac{gal}{yr} \times 9.996\frac{lb}{gal} \times \left(\frac{40\%}{100\%}\right) \times \left[1 - \left(\frac{0\cancel{\%}}{100\cancel{\%}}\right)\right]$$

$$E_{VOC} = 95\frac{gal}{yr} \times 9.996\frac{lb}{gal} \times \left(\frac{40\cancel{\%}}{100\cancel{\%}}\right) \times [1]$$

$$E_{VOC} = 95\frac{\cancel{gal}}{yr} \times 9.996\frac{lb}{\cancel{gal}} \times (0.4) \times [1]$$

$$\boxed{\boldsymbol{E_{VOC} = 379.8\frac{lb}{yr}}}$$

<u>For Xylene:</u>

$$E_{Xylene} = 95\frac{gal}{yr} \times 9.996\frac{lb}{gal} \times \left(\frac{8\%}{100\%}\right) \times \left[1 - \left(\frac{0\cancel{\%}}{100\cancel{\%}}\right)\right]$$

$$E_{Xylene} = 95\frac{gal}{yr} \times 9.996\frac{lb}{gal} \times \frac{8\cancel{\%}}{100\cancel{\%}} \times [1]$$

$$E_{Xylene} = 95\frac{\cancel{gal}}{yr} \times 9.996\frac{lb}{\cancel{gal}} \times (0.08) \times [1]$$

$$\boxed{\boldsymbol{E_{Xylene} = 76.0\frac{lb}{yr}}}$$

<u>Step 4</u> – Calculate the quantity of epoxy used. The volume of the epoxy used for the year was provided in the problem statement as 95 gal per year. The density of the coating was calculated in Step 2. The product of these values provides the quantity used in the appropriate units.

$$Q = V \times D$$

$$\boldsymbol{Q} = 95\frac{\cancel{gal}}{yr} \times 9.996\frac{lb}{\cancel{gal}} = \boldsymbol{949.6\frac{lb}{yr}}$$

<u>Step 5</u> – Calculate PM$_{10}$ and PM$_{2.5}$ emissions. Since the problem stated that the epoxy is solvent based, the fractional percentage (C_{pol}) of PM$_{10}$ and PM$_{2.5}$ to total PM is 0.960 and 0.925, respectively. Using Equation 22-2, and the data collected in Step 1, PM$_{10}$ and PM$_{2.5}$ emissions are calculated as follows:

$$E_{Pol} = Q \times \left(\frac{WP_{Pol}}{100}\right) \times \left[1 - \left(\frac{TE}{100}\right)\right] \times \left[1 - \left(\frac{CE}{100}\right)\right] \times C_{Pol}$$

For PM10:

$$E_{PM_{10}} = 949.6\frac{lb}{yr} \times \left(\frac{55\cancel{\%}}{100\cancel{\%}}\right) \times \left[1 - \left(\frac{75\cancel{\%}}{100\cancel{\%}}\right)\right] \times \left[1 - \left(\frac{90\cancel{\%}}{100\cancel{\%}}\right)\right] \times 0.960$$

$$E_{PM_{10}} = 949.6\frac{lb}{yr} \times (0.55) \times [1 - (0.75)] \times [1 - (0.90)] \times 0.960$$

$$E_{PM_{10}} = 949.6\frac{lb}{yr} \times (0.55) \times [0.25] \times [0.10] \times 0.960$$

$$\boxed{\boldsymbol{E_{PM_{10}} = 12.5\frac{lb}{yr}}}$$

For PM2.5:

$$E_{PM_{2.5}} = 949.6\frac{lb}{yr} \times \left(\frac{55\cancel{\%}}{100\cancel{\%}}\right) \times \left[1 - \left(\frac{75\cancel{\%}}{100\cancel{\%}}\right)\right] \times \left[1 - \left(\frac{90\cancel{\%}}{100\cancel{\%}}\right)\right] \times 0.925$$

$$E_{PM_{2.5}} = 949.6\frac{lb}{yr} \times (0.55) \times [1 - (0.75)] \times [1 - (0.90)] \times 0.925$$

$$E_{PM_{10}} = 949.6\frac{lb}{yr} \times (0.55) \times [0.25] \times [0.10] \times 0.925$$

$$\boxed{\boldsymbol{E_{PM_{2.5}} = 12.1\frac{lb}{yr}}}$$

22.7.2 Problem #2 - Emission Factor Method

A USAF base is interested in performing a NEPA assessment for a proposed project that will involve the application of several surface coatings. The base estimates the need for 25 gal of clear, water based fire retardant coatings. Similarly, several solvent based coatings, including 30 gal of concrete curing and sealing, 100 gal of interior flat, and 125 gal of quick dry latex enamel will be required. If no control devices are used, what are the estimated total VOC, PM_{10}, and $PM_{2.5}$ emissions from the surface coating portion of this proposed action?

Step 1 – **Select and record EFs.** Since this calculation is for a NEPA assessment on a proposed project, this problem is best suited to be calculated using the EF method. Knowing that the fire-retardant coating is water based, while the other coatings are solvent based, the EFs for each coating are selected from Table 22-1. These are provided in the following table.

Volume Used (gal/yr)	Coating Type	Emission Factors (lb/gal)		
		VOC	PM_{10}	$PM_{2.5}$
25	Fire Retardant - Clear	0.10	3.0	2.8
30	Concrete Curing & Sealing	3.8	5.3	5.1
100	Flat - Interior	2.1	8.6	8.3
125	Quick Dry Enamel - Latex	3.0	6.5	6.2

<u>**Step 2**</u> **– Calculate emissions from each coating.** Using Equation 22-4 and the data from the table above, emissions are calculated as follows:

$$E_{Pol} = V \times EF_{Pol} \times \left[1 - \left(\frac{CE}{100}\right)\right]$$

For Fire Retardant Coatings:

<u>For VOC:</u>

$$E_{VOC} = 25\frac{gal}{yr} \times 0.1\frac{lb}{gal} \times \left[1 - \left(\frac{0\cancel{\%}}{100\cancel{\%}}\right)\right]$$

$$\boldsymbol{E_{VOC}} = 25\frac{\cancel{gal}}{yr} \times 0.1\frac{lb}{\cancel{gal}} \times [1] = \mathbf{2.5}\,\boldsymbol{\frac{lb}{yr}}$$

<u>For PM_{10}:</u>

$$E_{PM_{10}} = 25\frac{gal}{yr} \times 3.0\frac{lb}{gal} \times \left[1 - \left(\frac{0\cancel{\%}}{100\cancel{\%}}\right)\right]$$

$$\boldsymbol{E_{PM_{10}}} = 25\frac{\cancel{gal}}{yr} \times 3.0\frac{lb}{\cancel{gal}} \times [1] = \mathbf{75.0}\,\boldsymbol{\frac{lb}{yr}}$$

<u>For $PM_{2.5}$:</u>

$$E_{PM_{2.5}} = 25\frac{gal}{yr} \times 2.8\frac{lb}{gal} \times \left[1 - \left(\frac{0\cancel{\%}}{100\cancel{\%}}\right)\right]$$

$$\boldsymbol{E_{PM_{2.5}}} = 25\frac{\cancel{gal}}{yr} \times 2.8\frac{lb}{\cancel{gal}} \times [1] = \mathbf{70.0}\,\boldsymbol{\frac{lb}{yr}}$$

Using this method, the VOC, PM_{10}, and $PM_{2.5}$ emissions from each coating were similarly calculated and are provided in the following table:

Coating Type	**Emissions (lb/yr)**		
	VOC	**PM$_{10}$**	**PM$_{2.5}$**
Fire Retardant	2.5	75.0	70.0
Concrete Curing and Sealing	114.0	159.0	153.0
Interior Flat	210.0	860.0	830.0
Quick Dry Latex Enamel	375.0	812.5	775.0

<u>**Step 3**</u> – **Sum emissions from each coating.** Using the values calculated and presented in Step 2, the total VOC, PM$_{10}$, and PM$_{2.5}$ emissions may be estimated by summing the emissions from the application of each coating as shown:

$$E_{Pol} = \sum_{i=1}^{n} \left(E_{Pol_{\text{i}}} + \cdots + E_{Pol_n} \right)$$

<u>For VOC:</u>

$$E_{VOC} = (2.5 + 114.0 + 210.0 + 375.0)\,\frac{lb}{yr}$$

$$\boxed{\boldsymbol{E_{VOC} = 701.5\,\frac{lb}{yr}}}$$

<u>For PM$_{10}$:</u>

$$E_{PM_{10}} = (75.0 + 159.0 + 860.0 + 812.5)\,\frac{lb}{yr}$$

$$\boxed{\boldsymbol{E_{PM_{10}} = 1,906.5\,\frac{lb}{yr}}}$$

<u>For PM$_{2.5}$:</u>

$$E_{PM_{2.5}} = (70.0 + 153.0 + 830.0 + 775.0)\,\frac{lb}{yr}$$

$$\boxed{\boldsymbol{E_{PM_{2.5}} = 1,828.0\,\frac{lb}{yr}}}$$

22.8 References

40 CFR 59, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 59-National Volatile Organic Compound Emission Standards for Consumer and Commercial Products," U.S. Environmental Protection Agency

40 CFR 63 Subpart GG, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 63-National Emission Standards for Hazardous Air Pollutants for Source Categories, Subpart GG-National Emission Standards for Aerospace Manufacturing and Rework Facilities," U.S. Environmental Protection Agency

40 CFR 63 Subpart MMMM, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 63-National Emission Standards for Hazardous Air Pollutants for Source Categories, Subpart MMMM-National Emission Standards for Hazardous Air Pollutants for Surface Coating of Miscellaneous Metal Parts and Products," U.S. Environmental Protection Agency

40 CFR 63 Subpart PPPP, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 63-National Emission Standards for Hazardous Air Pollutants for Source Categories, Subpart PPPP-National Emission Standards for Hazardous Air Pollutants for Surface Coating of Plastic Parts and Products," U.S. Environmental Protection Agency

40 CFR 63 Subpart HHHHHH, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 63-National Emission Standards for Hazardous Air Pollutants for Source Categories, Subpart HHHHHH-National Emission Standards for Hazardous Air Pollutants: Paint Stripping and Miscellaneous Surface Coating Operations at Area Sources," U.S. Environmental Protection Agency

CAP 2012, “Surface Coating & Transfer Efficiency = $avings,” Spokane Regional Clean Air Agency, Compliance Assistance Program (CAP), 2012

CARB 2003, "2001 Architectural Coatings Survey Final Report," California Environmental Protection Agency, California Air Resources Board (CARB), October 2003

Krause 2006, Krause, Mike and Steve Smith, "Methodology to Calculate Particulate Matter (PM) 2.5 and PM 2.5 Significance Thresholds," South Coast Air Quality Management District, October 2006

O’Brien 1999, O’Brien, Robert J., Blasch, Kyle W., Johnson, Grant T., “Air Emissions Inventory Guidance Document for Stationary Sources at Air Force Installations,” Air Force Institute for Environment, Safety and Occupational Health Risk Analysis (AFMC), May 1999

23 WASTEWATER COLLECTION AND TREATMENT (WWT)

- *Point/Fugitive Source* – Refer to permit for final determination

23.1 Introduction

Wastewater treatment incorporates chemical, biological, and mechanical procedures to remove, reduce, or neutralize contaminants found in industrial or household water discharge located on a USAF installation. Wastewater treatment plants may be classified as either primary, secondary, or tertiary plants depending on their design and application. Primary treatment involves the application of one or more methods to remove solids, floating material, and pathogens from the wastewater. Secondary treatment removes contaminants primarily through biological methods, though chemical treatments may also be utilized. Tertiary treatment refers to any additional treatment of wastewater that is performed after the secondary treatment stage. This treatment removes any contaminants remaining using more advanced treatment technologies. Nearly all wastewater will undergo collection, contaminant treatment, and/or storage operations that, at a minimum, include: aerating, sludge and scum removal, and disinfection. After contaminate wastewater is treated, it is discharged to either a receiving body of water or to a Publicly Owned Treatment Works (POTW) facility for further treatment. In a full-scale treatment operation, the wastewater must meet Federal and/or state quality standards before it is finally discharged into a receiving body of water.

The pollutants of concern from wastewater treatment include criteria pollutants, VOCs, HAPs, and GHGs. VOCs are emitted through the volatilization of organic compounds at the liquid surface during collection and storage or when the wastewater is subjected to air stripping. Air stripping is a process that injects gas (air) into wastewater to volatilize undesirable substances from the liquid into the air stream. Emissions can occur through diffusive and/or convective mechanisms. Diffusion occurs when organic concentrations at the water surface are much higher than ambient concentrations. Convection occurs when air flows over the water surface, thereby sweeping organic vapors from the surface into the air. The rate of volatilization is directly related to the speed of the air flow over the water surface. VOCs vary in their degree of volatility and can be classified into different groups based upon their Henry's Law constant that can be classified as low, medium, or high volatility. The amount of VOCs and HAPs within the water being treated depends both on the source of the wastewater and the storage and treatment performed. Chlorine may be added to the wastewater to act as a disinfectant and is often used when UV treatment is not performed.

Criteria pollutants at wastewater treatment plants are produced after the wastewater has undergone the first or second clarification treatments. The sludge removed from the wastewater is taken to a sludge digester to undergo anaerobic digestion. The digestion typically results in the loss of about half of the solid sludge, and any remaining sludge becomes denser and easier to dispose. During this process, methane and hydrogen sulfide gas are produced. For this reason, sludge digesters are often equipped with a flare to burn the collected off-gas. The combustion of the off-gas is what results in the emissions of both criteria pollutants and HAPs. **The flares used to burn off-gas from sludge digesters are external combustion sources of air pollutants. Calculation of emissions from the use of flares is not addressed in this section, but is described in the "EXTERNAL COMBUSTION (ECOM)" chapter of this guide.**

Wastewater treatment plants serve as a source of GHG emissions, though the volume emitted is a function of the treatment system and wastewater itself. Anaerobic systems, as described above, produce primarily CH_4 as a byproduct and CO_2, whereas aerobic systems primarily produce CO_2. Both systems may also generate N_2O emissions depending upon the amount of nitrogen present in the influent wastewater. A graphic representation of emissions from wastewater treatment is provided in Figure 23-1.

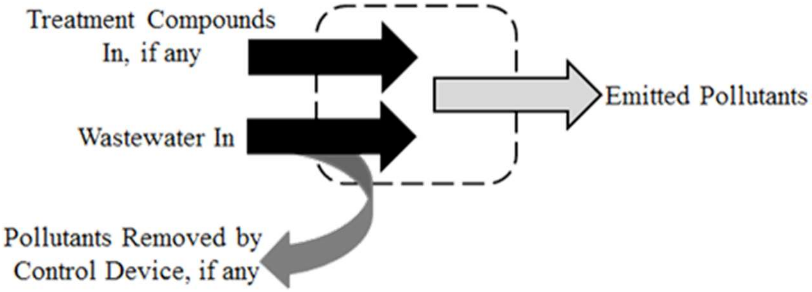

Figure 23-1. Simplified Control Volume for Emissions from Wastewater Collection and Treatment

23.2 NESHAP Applicability

The EPA has developed NESHAPs applicable to wastewater treatment plants. One standard, given in 40 CFR 63 Subpart DD, *National Emission Standards for Hazardous Air Pollutants from Off-Site Waste and Recovery Operations*, applies to wastewater treatment plants located at major sources for HAPs that also receive off-site materials. Additionally, POTW are subject to 40 CFR 63 Subpart VVV, *National Emission Standards for Hazardous Air Pollutants: Publicly Owned Treatment Works*, if the POTW includes an affected source and is a major source of HAP emissions, or at any industrial POTW regardless of whether it is a major source of HAPs or not. The POTW also must be required to develop and implement a pretreatment program as defined by 40 CFR 403.8. An industrial POTW is defined as a treatment facility that accepts a waste stream regulated by an industrial NESHAP (under 40 CFR 61 or 63) and provides treatment and controls as an agent for the industrial discharger. For additional information regarding the applicability of theses NESHAPs or to verify compliance, refer to 40 CFR 63 Subparts DD and VVV.

23.3 Emission Factors

EFs for the volatilization of the components of the influent wastewater have not been developed. Therefore, the calculation of these emissions is performed either by modeling or by using a mass balance approach. EFs from the use of flares burning digester gas have been developed by the San Diego Air Pollution Control District. The EFs and method of air emissions calculations for digester flares may be found in the "External Combustion" section of this guide.

23.4 Control Techniques

Air is often controlled at wastewater treatment plants to both reduce the amount of harmful pollutants emitted into the atmosphere and for odor control. These methods include the use of packed tower scrubbers, misting wet scrubbers, carbon adsorbers, filters, and thermal oxidizers. These methods each work in combination with a well-designed ventilation system. Packed tower scrubbers work by passing a contaminated air stream through a scrubbing liquor, which removes the air contaminants through absorption or chemical reaction. Fine-mist wet scrubbers eliminate contaminants from the air stream by applying a mist that traps the contaminants in water droplets. The water and contaminants are then separated by an entrainment separator. This method is more effective in removing VOCs than packed tower scrubbers, but requires that the water be softened prior to use. Carbon adsorbers, filters, and bio-filters are simple and cost-effective methods for filtration but may require consistent monitoring to determine when the filtering media needs to be replaced. Thermal oxidizers are extremely effective for destroying VOCs, but have a high capital and energy cost. Thermal oxidizers also require a heat exchanger and combustion chamber to reach a destruction efficiency of up to 99 percent.

Digester gases resulting from the degradation of sludge may be used as fuel for boilers, generators, or other internal combustion engines. Alternatively, these gases can be combusted to convert the CH_4 into CO_2 which is more environmentally friendly. In either case, the combustion results in air emissions which must be accounted for. Information regarding the calculation of these emissions is described either in the "External Combustion" section (for use in boilers or flaring) or "Stationary Internal Combustion Engines" section (for generators or any stationary internal combustion engines) of this guide.

23.5 Emissions Calculation

The most accurate wastewater emissions estimates can be obtained through on-site testing of a facility as the design and arrangement of collection, treatment, and storage systems, which may influence emissions, are facility-specific. On-site testing may include tracer studies or direct measurement of emissions from openings. If actual data is unavailable, emission models can be used. Calculating air emissions from wastewater collection, treatment, and storage systems is a complex procedure, especially if several systems are present. The EPA has developed a computer program (WATER9) that consists of analytical expressions for estimating air emissions of individual waste constituents in wastewater collection, storage, treatment, and disposal facilities. WATER9 includes a database of organic compounds as well as procedures for obtaining reports of constituent fates, including air emissions and treatment effectiveness. WATER9 is a significant upgrade of features previously obtained in the computer programs WATER8, Chem9, and Chemdat8.

As an alternative to using WATER9, VOC and organic HAP emissions from wastewater treatment plants may be calculated using a mass balance method. This method will likely result in conservative estimates since this method assumes that all pollutant removal is attributed entirely to evaporation. 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. Emissions are calculated as follows:

$$\boldsymbol{E_{Pol} = Q \times [IC_{Pol} - EC_{Pol}] \times 3.785 \times (2.205 \times 10^{-9})}$$

Equation 23-1

Where,

E_{Pol} = Annual emissions of pollutant (lb/yr)
Q = Annual quantity of wastewater treated (gal/yr)
IC_{Pol} = Influent concentration of the pollutant (μg/L)
EC_{Pol} = Effluent concentration of the pollutant (μg/L). **If effluent data is unavailable, assume concentration is 0 μg/L.**
3.785 = Factor for converting units from liters to gallons (L/gal)
2.205×10^{-9} = Factor for converting units from micrograms to pounds (lb/μg)

A more detailed control volume describing the air pollutants emitted during wastewater collection and treatment is provided in Figure 23-2:

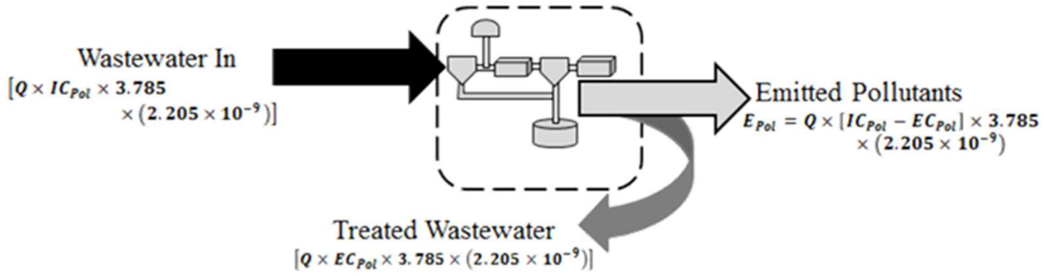

Figure 23-2. Wastewater Collection and Treatment Control Volume

23.6 Information Resources

The wastewater treatment plant should have most, if not all, of the information required to calculate emissions from their plant. If the plant has a sludge digester equipped with a flare, the plant should also know the number of days during the year the flare was in operation 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 BEE office should be contacted as they are usually responsible for performing the sampling.

23.7 Example Problem

A base has a wastewater treatment plant that treats both domestic and industrial wastewater. According to the plant supervisor, approximately 262,545,000 gal of wastewater were treated at the plant during the year. The wastewater treatment plant did not have analytical results of chemical sampling performed on the wastewater so the BEE was contacted for this information. A review of the BEEs 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. Using the following analytical results, calculate both VOC and individual HAP emissions from the plant.

Pollutant	Influent Concentration (µg/L)	Effluent Concentration (µg/L)
TOC (VOC)	225	102
Toluene	3	0.5
Xylenes	9	6

Step 1 **–Calculate emissions for each pollutant**. Using Equation 23-1 and the data provided above, the emissions of each pollutant is calculated as follows:

$$E_{Pol} = Q \times [IC_{Pol} - EC_{Pol}] \times 3.785 \times (2.205 \times 10^{-9})$$

For VOC:

$$E_{VOC} = 262{,}545{,}000 \frac{gal}{yr} \times [225 - 102] \frac{\mu g}{L} \times 3.785 \frac{L}{gal} \times (2.205 \times 10^{-9}) \frac{lb}{\mu g}$$

$$E_{VOC} = 262{,}545{,}000 \frac{\cancel{gal}}{yr} \times [123] \frac{\cancel{\mu g}}{\cancel{L}} \times 3.785 \frac{\cancel{L}}{\cancel{gal}} \times (2.205 \times 10^{-9}) \frac{lb}{\cancel{\mu g}}$$

$$\boxed{\boldsymbol{E_{VOC} = 269.52 \frac{lb}{yr}}}$$

For Toluene:

$$E_{Toluene} = 262{,}545{,}000\,\frac{gal}{yr} \times [3 - 0.5]\,\frac{\mu g}{L} \times 3.785\,\frac{L}{gal} \times (2.205 \times 10^{-9})\,\frac{lb}{\mu g}$$

$$E_{Toluene} = 262{,}545{,}000\,\frac{\cancel{gal}}{yr} \times [2.5]\,\frac{\cancel{\mu g}}{\cancel{L}} \times 3.785\,\frac{\cancel{L}}{\cancel{gal}} \times (2.205 \times 10^{-9})\,\frac{lb}{\cancel{\mu g}}$$

$$\boxed{\boldsymbol{E_{Toluene} = 5.48\,\frac{lb}{yr}}}$$

For Xylenes:

$$E_{Xylene} = 262{,}545{,}000\,\frac{gal}{yr} \times [9 - 6]\,\frac{\mu g}{L} \times 3.785\,\frac{L}{gal} \times (2.205 \times 10^{-9})\,\frac{lb}{\mu g}$$

$$E_{Xylene} = 262{,}545{,}000\,\frac{\cancel{gal}}{yr} \times [3]\,\frac{\cancel{\mu g}}{\cancel{L}} \times 3.785\,\frac{\cancel{L}}{\cancel{gal}} \times (2.205 \times 10^{-9})\,\frac{lb}{\cancel{\mu g}}$$

$$\boxed{\boldsymbol{E_{Xylene} = 6.57\,\frac{lb}{yr}}}$$

23.8 References

40 CFR 63 Subpart DD, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 63-National Emission Standards for Hazardous Air Pollutants for Source Categories, Subpart DD-National Emission Standards for Hazardous Air Pollutants From Off-Site Waste and Recovery Operations," U.S. Environmental Protection Agency

40 CFR 63 Subpart VVV, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 63-National Emission Standards for Hazardous Air Pollutants for Source Categories, Subpart VVV-National Emission Standards for Hazardous Air Pollutants: Publicly Owned Treatment Works," U.S. Environmental Protection Agency

40 CFR 403.8, “Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter N, Part 403-General Pretreatment Regulations for Existing and New Sources of Pollution-Pretreatment Program Requirements: Development and Implementation by POTW,” U.S. Environmental Protection Agency

40 CFR 61, “Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 61-National Emission Standards for Hazardous Air Pollutants,” U.S. Environmental Protection Agency

USEPA 1995, Section 4.3-“Waste Water Collection, Treatment and Storage," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, January 1995

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24 WELDING (WELD)

- *Fugitive Source*

24.1 Introduction

Welding operations may be performed at various maintenance, transportation, and CE shops on USAF installations. It is the process by which items are joined by melting the parts at the points of contact while simultaneously introducing molten metal from a consumable electrode that forms a strong bond once cooled. There are several types of welding processes such as oxy-fuel welding, arc welding, brazing, soldering, and thermal cutting; however, electric arc welding is by far the most common process. Electric arc welding operations also have the greatest potential for emissions, and are the only type of welding operations for which the EPA has issued EFs. Therefore, electric arc welding is typically the only type of welding operations addressed in an AEI.

The four main process types associated with electric arc welding include: Shielded Metal Arc Welding (SMAW), Gas Metal Arc Welding (GMAW), Flux Cored Arc Welding (FCAW), and Submerged Arc Welding (SAW). These processes are described below.

SMAW, also known as stick or rod welding, uses the heat produced by an electric arc to melt a coated electrode and the welding joint at the base metal. During operation, the rod core conducts an electric current to produce the arc while providing filler metal for the joint. The core of the electrode consists of either a solid metal rod or a rod fabricated by encasing metal powders within a metallic sheath. The electrode coating provides stability to the arc and protects the molten metal by generating shielding gases from the vaporization of the coating.

GMAW, also known as Metal Inert Gas or MIG welding, is a consumable electrode welding process that uses the heat generated by an arc between the continuously supplied filler metal and the weld pool to join the metals. Gas is supplied externally to shield the arc from atmospheric gases, which may result in fusion defects. The shielding gas used, which may be either a pure inert gas or a gas mixture, is selected based upon the type of material being welded.

FCAW is a consumable electrode welding process that uses the heat generated by an arc between the flux cored electrode and the weld pool to join the metals. During the welding process, the electrode core materials produce a slag cover on the face of the weld bead. Shielding gas is generated either from the flux contained within the electrode, or by an externally supplied gas.

SAW is a process that produces an arc between a bare metal electrode and the work, while the welding pool is submerged beneath a bed of granular fusible flux. The electrode generally serves as the filler material, while 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 due to the granular nature of the flux, but has much lower fume forming rates.

Welding results in the fugitive emissions of PM and inorganic HAPs. All PM emissions produced by welding are assumed to be PM_{10}, which is assumed to be equal to $PM_{2.5}$. The inorganic HAPs produced are typically manganese (Mn), nickel (Ni), chromium (Cr), cobalt (Co), and lead (Pb), depending upon the composition of the welding rods used. A simple control volume describing emissions from welding operations is provided in Figure 24-1.

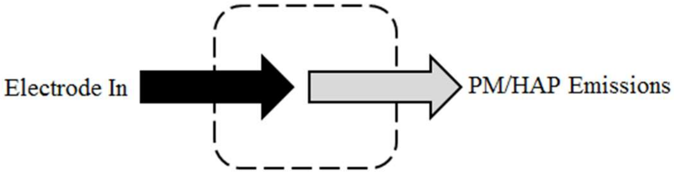

Figure 24-1. Simplified Welding Control Volume

24.2 Emission Factors

The main pollutants of concern associated with welding operations include PM_{10}, $PM_{2.5}$, and inorganic metallic HAPs. Most PM emissions from welding operations are less than one micron in size, so all the PM emissions associated with welding operations are assumed to be equal to PM_{10} and $PM_{2.5}$. AP-42 provides EFs for several electrode types and welding processes. However, it is important to note that each rod produces minimal emissions and it takes a large quantity of welding rods to emit a significant amount of emissions. Rather than calculate the emissions from each rod and welding process, the worst-case scenario for emissions for each pollutant should be assumed. This approach simplifies the process of data collection while still providing a conservative emissions estimate for a generally low emitting source. The worst case EFs for each pollutant are provided in Table 24-1.

Table 24-1. Particulate and Inorganic HAP Emission Factors for Welding Operations

Emission Factor (lb/10^3 lb)						
$PM_{10/2.5}$[(a)]	Co	Cr[(b)]	Cr^{+6}[(b)]	Mn[(a)]	Ni[(a)]	Pb[(c)]
8.16E+01	1.00E-03	2.53E+00	1.88E+00	2.32E+01	1.71E+00	1.62E-01

SOURCE: USEPA 1995, Section 12.19- "Electric Arc Welding," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, January 1995.

a) Electrode type: 14Mn-4Cr.
b) Electrode type: E310.
c) Electrode type: E7028.

24.3 Control Techniques

Emissions from welding operations results in the release of particulates that may be captured and controlled using scrubbers or filters. Scrubbers may be classified as either wet or dry, though wet scrubbers are traditionally used for particulate dust control. Wet scrubbers work by passing the exhaust gas through a scrubbing solution. For particulate control, the scrubbing solution may simply be water, though other reagents may be used to target specific compounds. The scrubber solution may be applied using a nozzle, or the exhaust stream may pass through a packed bed or aspirator. High efficiency particulate air, or HEPA, filters may also be used to control particulate emissions. The effectiveness of either HEPA filters or scrubbers in the reduction of particulate emissions from welding processes has not been quantified, though it is expected that the capture and control efficiencies are low for open operations and considerably higher for enclosed operations.

24.4 Emission Calculations

To calculate emissions from electric arc welding, the total mass of electrodes consumed by each process type must be known. This value may then be multiplied by the appropriate pollutant EF, and if a control device is present, then may be multiplied by the control efficiency of the control device. The calculation for emissions using EFs is as follows:

$$\boldsymbol{E_{Pol} = Q \times \frac{1}{1000} \times EF_{Pol} \times \left[1 - \left(\frac{CE}{100}\right)\right]}$$

Equation 24-1

Where,

E_{Pol} = Annual emissions of pollutant (lb/yr)
Q = Annual mass of electrode consumed (lb/yr)
1000 = Factor for converting pounds to 10^3 pounds (lb/10^3lb)
EF_{Pol} = Emission Factor (lb/10^3 lb)
CE = Efficiency of the control device for pollutant, if present (%)
100 = Factor for converting a percent to a fraction (%)

A detailed control volume for welding operations is provided in Figure 24-2.

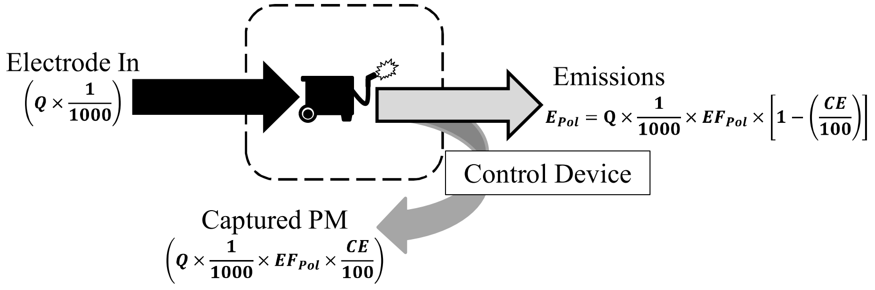

Figure 24-2. Welding Control Volume

24.5 Information Resources

The information required to calculate emissions from welding operations may be obtained directly from each individual shop that performs welding on base. These shops typically fall under Maintenance, CE, and Transportation organizations. If necessary, BEE may be able to help identify shops with welding operations. The efficiency of any control device used may be obtained from product literature or directly from the manufacturer of the control device.

24.6 Example Problem

A USAF base needs to calculate emissions from welding performed at a shop on base. The shop performs both SMAW and GMAW welding using a variety of electrodes. According to shop records, the total weight of all rods used for welding was 1,400lb. Calculate the annual emissions of PM_{10}, $PM_{2.5}$, and inorganic HAPs assuming no control devices were used.

<u>**Step 1**</u> – **Select and record emission factors.** The worst-case EFs are provided in Table 24-1. The EFs are: **81.6 lb/10^3lb** for $PM_{10/2.5}$, **0.001 lb/10^3lb** for Co, **2.53 lb/10^3lb** for Cr, **1.88 lb/10^3lb** for Cr^{+6}, **23.2 lb/10^3lb** for Mn, **1.71 lb/10^3lb** for Ni, and **0.162 lb/10^3lb** for Pb.

<u>**Step 2**</u> – **Calculate emissions.** Using the data provided in the problem statement and the EFs recorded in Step 1, the emissions for each pollutant may be calculated using Equation 24-1 as follows:

$$E_{Pol} = Q \times \frac{1}{1000} \times EF_{Pol} \times \left[1 - \left(\frac{CE}{100}\right)\right]$$

<u>Since the emission factor is the same, for $PM_{10/2.5}$:</u>

$$E_{PM_{10/2.5}} = 1400\,\frac{\text{lb}}{yr} \times \frac{1}{1000}\frac{10^3 lb}{lb} \times 81.6\,\frac{lb}{10^3 lb} \times \left[1 - \left(\frac{0\cancel{\%}}{100\cancel{\%}}\right)\right]$$

$$E_{PM_{10/2.5}} = 1400\frac{\cancel{\text{lb}}}{yr} \times \frac{1}{1000}\frac{10^3 lb}{\cancel{lb}} \times 81.6\frac{lb}{10^3 lb} \times [1]$$

$$E_{PM_{10/2.5}} = 1.400\frac{\cancel{10^3 lb}}{yr} \times 81.6\frac{lb}{\cancel{10^3 lb}} \times [1]$$

$$\boxed{\boldsymbol{E_{PM_{10/2.5}} = 114.24\frac{\textbf{lb}}{yr}}}$$

For Co:

$$E_{Co} = 1400\frac{lb}{yr} \times \frac{1}{1000}\frac{10^3 lb}{lb} \times 0.001\frac{lb}{10^3 lb} \times \left[1 - \left(\frac{0\cancel{\%}}{100\cancel{\%}}\right)\right]$$

$$E_{Co} = 1400\frac{\cancel{lb}}{yr} \times \frac{1}{1000}\frac{10^3 lb}{\cancel{lb}} \times 0.001\frac{lb}{10^3 lb} \times [1]$$

$$E_{Co} = 1.400\frac{\cancel{10^3 lb}}{yr} \times 0.001\frac{lb}{\cancel{10^3 lb}} \times [1]$$

$$\boxed{\boldsymbol{E_{Co} = 0.0014\frac{lb}{yr}}}$$

For Cr:

$$E_{Cr} = 1400\frac{lb}{yr} \times \frac{1}{1000}\frac{10^3 lb}{lb} \times 2.53\frac{lb}{10^3 lb} \times \left[1 - \left(\frac{0\cancel{\%}}{100\cancel{\%}}\right)\right]$$

$$E_{Cr} = 1400\frac{\cancel{lb}}{yr} \times \frac{1}{1000}\frac{10^3 lb}{\cancel{lb}} \times 2.53\frac{lb}{10^3 lb} \times [1]$$

$$E_{Cr} = 1.400\frac{\cancel{10^3 lb}}{yr} \times 2.53\frac{lb}{\cancel{10^3 lb}} \times [1]$$

$$\boxed{\boldsymbol{E_{Cr} = 3.54\frac{lb}{yr}}}$$

For Cr^{+6}:

$$E_{Cr^{+6}} = 1400\frac{lb}{yr} \times \frac{1}{1000}\frac{10^3 lb}{lb} \times 1.88\frac{lb}{10^3 lb} \times \left[1 - \left(\frac{0\cancel{\%}}{100\cancel{\%}}\right)\right]$$

$$E_{Cr^{+6}} = 1400\frac{\cancel{lb}}{yr} \times \frac{1}{1000}\frac{10^3 lb}{\cancel{lb}} \times 1.88\frac{lb}{10^3 lb} \times [1]$$

$$E_{Cr^{+6}} = 1.400\frac{\cancel{10^3 lb}}{yr} \times 1.88\frac{lb}{\cancel{10^3 lb}} \times [1]$$

$$\boxed{\boldsymbol{E_{Cr^{+6}} = 2.63\,\frac{lb}{yr}}}$$

For Mn:

$$E_{Mn} = 1400\,\frac{lb}{yr} \times \frac{1}{1000}\,\frac{10^3\,lb}{lb} \times 23.2\,\frac{lb}{10^3\,lb} \times \left[1 - \left(\frac{0\cancel{\%}}{100\cancel{\%}}\right)\right]$$

$$E_{Mn} = 1400\,\frac{\cancel{lb}}{yr} \times \frac{1}{1000}\,\frac{10^3\,lb}{\cancel{lb}} \times 23.2\,\frac{lb}{10^3\,lb} \times [1]$$

$$E_{Mn} = 1.400\,\frac{\cancel{10^3\,lb}}{yr} \times 23.2\,\frac{lb}{\cancel{10^3\,lb}} \times [1]$$

$$\boxed{\boldsymbol{E_{Mn} = 32.48\,\frac{lb}{yr}}}$$

For Ni:

$$E_{Ni} = 1400\,\frac{lb}{yr} \times \frac{1}{1000}\,\frac{10^3\,lb}{lb} \times 1.71\,\frac{lb}{10^3\,lb} \times \left[1 - \left(\frac{0\cancel{\%}}{100\cancel{\%}}\right)\right]$$

$$E_{Ni} = 1400\,\frac{\cancel{lb}}{yr} \times \frac{1}{1000}\,\frac{10^3\,lb}{\cancel{lb}} \times 1.71\,\frac{lb}{10^3\,lb} \times [1]$$

$$E_{Ni} = 1.400\,\frac{\cancel{10^3\,lb}}{yr} \times 1.71\,\frac{lb}{\cancel{10^3\,lb}} \times [1]$$

$$\boxed{\boldsymbol{E_{Ni} = 2.39\,\frac{lb}{yr}}}$$

For Pb:

$$E_{Pb} = 1400\,\frac{lb}{yr} \times \frac{1}{1000}\,\frac{10^3\,lb}{lb} \times 0.162\,\frac{lb}{10^3\,lb} \times \left[1 - \left(\frac{0\cancel{\%}}{100\cancel{\%}}\right)\right]$$

$$E_{Pb} = 1400\,\frac{\cancel{lb}}{yr} \times \frac{1}{1000}\,\frac{10^3\,lb}{\cancel{lb}} \times 0.162\,\frac{lb}{10^3\,lb} \times [1]$$

$$E_{Pb} = 1.400\,\frac{\cancel{10^3\,lb}}{yr} \times 0.162\,\frac{lb}{\cancel{10^3\,lb}} \times [1]$$

$$\boxed{\boldsymbol{E_{Pb} = 0.23\,\frac{lb}{yr}}}$$

24.7 References

USEPA 1995, Section 12.19-“Electric Arc Welding," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, January 1995

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25 WET COOLING TOWERS (COOL)

- *Fugitive Sources*

25.1 Introduction

A wet cooling tower relies on the latent heat of water evaporation to exchange heat between an industrial or commercial process and the air passing through the tower. In a cooling tower, warmer water is brought into direct contact with the cooler air. When the air enters the cooling tower, its moisture content is generally below saturation. When the air exits, it emerges at a higher temperature and with its moisture content at or near saturation. Even when the air is at saturation, cooling can still take place due to a rising temperature that results in an increase in heat capacity that allows more sensible heat to be absorbed.

There are two main types of cooling towers: natural draft and mechanical draft cooling towers. A natural draft cooling tower receives its air supply from natural wind currents that generates a convective flow up the tower; this air convection cools the water on contact. A mechanical draft cooling tower is much more widely used and employs large fans to either force or induce a draft. These systems increase the contact time between the water and the air, effectively maximizing the heat transfer. Virtually all USAF cooling towers are the induced (mechanical) draft type.

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. These "drift" droplets from cooling towers may contain dissolved solids (e.g., mineral matter, chemicals for corrosion inhibition, ambient air dust, etc.). Therefore, the emissions are not from the drift droplets themselves, but rather the minerals or other particulates found within the drift droplets. The particulates that are suspended in the drift droplet have the same chemical makeup as the cooling water and are assumed to become suspended PM once the water contained in the drift droplet evaporates. **Particulate emissions from wet cooling towers are fugitive in nature.** A graphical representation of this is provided in Figure 25-1.

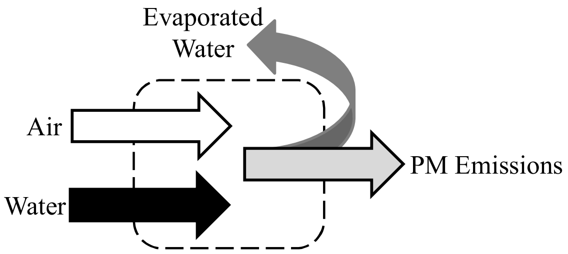

Figure 25-1. Simplified Control Volume for Emissions from Wet Cooling Towers

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.

25.2 NESHAP Applicability

Although USAF installations are not likely to have Industrial Process Cooling Towers (IPCTs), 40 CFR 63 Subpart Q states that existing, affected IPCTs must terminate the use of chromium-based water treatment chemicals. This NESHAP states that existing IPCTs (and new IPCTs with a startup before September 8, 1994) must comply by September 8, 1994. New IPCTs with an initial startup after this date are required to comply at the time of startup. Refer to Subpart Q of 40 CFR 63 for information regarding the compliance schedule or demonstration requirements.

25.3 Emission Calculations

Emissions of PM_{10} from wet cooling towers may be calculated using the methodology presented in Section 13.4 of AP-42. This methodology assumes that all Total Dissolved Solids (TDS) emitted in “drift” particles (liquid water entrained in the air stream and carried out of the tower through the induced draft fan stack) are considered PM_{10}. However, this method has been shown to be overly conservative and predicts significantly higher PM_{10} emissions than would occur.

When possible, the TDS content should be based on source-specific data. The two principal methods of measuring total dissolved solids (TDS) are gravimetric analysis and conductivity. Gravimetric methods are direct measurement of TDS and are the most accurate and performed in a laboratory which involves evaporating the liquid solvent and measuring the mass of residues left.

Another common and acceptable indirect method of measuring TSD is the conductivity which involves measuring the specific conductance of an electrolyte solution. The electrical conductivity of a solution is a measure of the solution’s ability to carry an electric current. The greater the concentration of ionic solutes, the more electrically conductive the solution becomes. TDS may be calculated by taking the product of the measured electrical conductivity of the solution and an appropriate correlation factor as shown in the equation below. It is up to the operator to select the appropriate correlation factor when using the EC meter. Many EC meters will convert the conductivity (often measured in μS/cm) to TDS in parts per million (ppm) using this correlation factor.

$$TDS = EC \times k_e$$

Where,

TDS = Total dissolved solids
EC = Electrical conductivity
k_e = Correlation factor

If the TDS of the circulating water is not known, AP-42 states it can be estimated by obtaining the TDS data for the make-up water and multiplying it by the cooling tower cycles of concentration. The cycles of concentration ratio is the ratio of a measured parameter for the cooling tower water (such as conductivity, calcium, chlorides, or phosphate) to that parameter for the make-up water. This estimation method should only be used if the TDS of the circulating water is not available. Additionally, the AP-42 method does not provide an approach for the estimation of $PM_{2.5}$. Therefore, the AP-42 13.4 methodology has been supplemented with *Methodology to Calculate Particulate Matter (PM) 2.5 and PM 2.5 Significant Thresholds* (Krause 2006) to get the best estimate of PM_{10} and $PM_{2.5}$ emissions.

Another variable used in calculating emissions from wet cooling towers is the Total Liquid Drift (TLD). This is the percentage of circulating water flow which result in liquid drift in the cooling tower exit stream. A TLD factor may then be calculated by taking this value and multiplying it by the density of water. AP-42 “provides available particulate emission factors for wet cooling towers, however, these values only have an emission factor rating of ‘E’ (the lowest level of confidence acceptable). They are also rather high, compared to typical present-day manufacturers’ guaranteed drift rates, which are on the order of 0.0006%” (Reisman and Frisbie 2002).

The TLD factor, which may be provided by the manufacturer, and is dependent upon the cooling tower design, including the configuration. Cooling towers are designed as either a crossflow or counterflow which indicate the direction of the air flow in relation to the water flow. Each design configuration has advantages and disadvantages inherent to their respective designs and may also be provided by the manufacturer.

Based on AP-42, PM emissions from cooling towers can be calculated by multiplying the total amount of circulation water (Q) by TLD and then multiplying the concentration of TDS in the circulating water. With the addition of incorporating the fractional concentration of the pollutants, the product is then multiplied by the corresponding value of fractional concentration. The fraction concentration of the pollutants is given by California Emission Inventory Development and Reporting System (CEIDARS). This is shown in Equation 25-1.

$$\boldsymbol{E_{Pol} = Q \times \frac{TLD}{100} \times 8.345 \times TDS \times \frac{1}{10^6} \times C_{Pol}}$$

Equation 25-1

Where,

E_{Pol} = Annual emissions of pollutant (lb/yr)
Q = Quantity of circulating water per year (gal/yr)
8.345 = Density of water (lb/gal)
TLD = Total liquid drift. **Contact the manufacturer for this data. The value is typically between 0.0005 – 0.001*. AP-42 provides a conservative estimate of 0.02** (%)
100 = Factor converting percent to a fraction
TDS = Total dissolved solids. **Use on-site measurement data. In the absence of data, AP-42 recommends 12,000 (ppm)**
10^6 = Factor converting from ppm to a weight fraction
C_{Pol} = Fractional concentration of the pollutant. **Use 0.700 for PM_{10} and 0.420 for $PM_{2.5}$**

*Contact cooling tower manufacturer for TLD data. Data obtained from Evapco, a wet cooling tower manufacturer, indicates a TLD between 0.0005% and 0.001% for their counterflow wet cooling towers. AP-42 provides a value of 0.02, but this value is considered very conservative.

If the quantity of circulating water per year is unknown, it may be calculated by multiplying the flow rate by the number of days the wet cooling tower was in operation for the year. This is shown in Equation 25-2.

$$\boldsymbol{Q = WFR \times D}$$

Equation 25-2

Where,

WFR = Circulating water flow rate (gal/day)
D = Number of days cooling tower was in operation during the year (day/yr)

A more detailed representation of the emissions from wet cooling towers is provided in Figure 25-2.

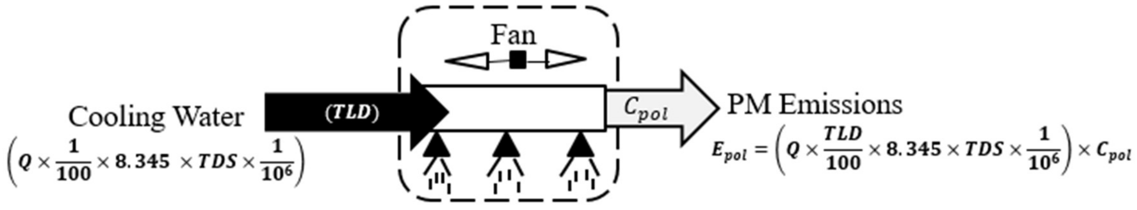

Figure 25-2. Wet Cooling Towers Control Volume

25.4 Information Resources

The base HVAC shop should be contacted for the information needed to calculate PM emissions from air conditioning cooling towers. If the base has any industrial cooling towers, the shop(s) responsible for operating the cooling tower(s) should be contacted for the necessary information.

25.5 Example Problem

A base has a cooling tower located at the BEE shop. According to the shop supervisor, the cooling tower uses induced (mechanical) draft, is in constant operation for seven months out of the year, and has an average circulating water flow rate of approximately 20,100 gal per day. The circulating water TDS was determined to be 1,500 ppm and the manufacturer stated the TLD is 0.001%. Determine the PM_{10} and $PM_{2.5}$ emissions.

Step 1 – **Calculate the annual circulating water flow rate**. If an average month has 30 days, the annual circulating water flow rate is calculated using Equation 25-2 as follows:

$$\boldsymbol{Q} = 20{,}100\left(\frac{gal}{\cancel{day}}\right) \times 7\left(\frac{\cancel{mont}}{yr}\right) \times 30\left(\frac{\cancel{day}}{\cancel{mont}}\right) = \mathbf{4{,}221{,}000}\,\boldsymbol{\frac{gal}{yr}}$$

Step 2 – **Calculate PM_{10} and $PM_{2.5}$ emissions.** Insert the Q value calculated in Step 1 and the C_{Pol} values for PM_{10} and $PM_{2.5}$ (which are stated as 0.700 and 0.420 respectively) into Equation 25-1.

For PM_{10}:

$$E_{Pol} = Q \times \frac{\text{TLD}}{100} \times 8.345 \times TDS \times \frac{1}{10^6} \times Cpol$$

$$E_{PM_{10}} = 4{,}221{,}000\frac{\cancel{gal}}{yr} \times \frac{0.001}{100}\frac{\cancel{\%}}{\cancel{\%}} \times 8.345\,\frac{lb}{\cancel{gal}} \times 1{,}500\,ppm \times \frac{1}{10^6} \times 0.700$$

$$\boxed{\boldsymbol{E_{PM_{10}} = 0.37\,\frac{lb}{yr}}}$$

For $PM_{2.5}$:

$$E_{PM_{2.5}} = 4{,}221{,}000\frac{\cancel{gal}}{yr} \times \frac{0.001}{100}\frac{\cancel{\%}}{\cancel{\%}} \times 8.345\,\frac{lb}{\cancel{gal}} \times 1{,}500\,ppm \times \frac{1}{10^6} \times 0.420$$

$$\boxed{\boldsymbol{E_{PM_{2.5}} = 0.22\,\frac{lb}{yr}}}$$

25.6 References

40 CFR 63 Subpart Q, “Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency Subchapter C-Air Programs,Part 63-National Emission Standards for Hazardous Air Pollutants for Source Categories, Subpart Q-National Emission Standards for Hazardous Air Pollutants for Industrial Process Cooling Towers,” U.S. Environmental Protection Agency

Krause 2006, Krause, Mike and Steve Smith, "Methodology to Calculate Particulate Matter (PM) 2.5 and PM 2.5 Significance Thresholds," South Coast Air Quality Management District, October 2006

Reisman, J. and Frisbie, G. 2002, “Calculating Realistic PM10 Emissions from Cooling Towers,” Environ. Prog., 21: 127 – 130. Doi:10.1002/ep.670210216

USEPA 1995, Section 13.4 - “Wet Cooling Towers," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, January 1995

26 WOODWORKING (WOOD)

- *Point Source*

26.1 Introduction

Woodworking, as termed in this section, includes any operation that involves the generation of small wood waste particles (shavings, sander dust, sawdust, etc.) by any kind of mechanical manipulation of wood, bark, or wood byproducts. Common woodworking operations include sawing, planing, chipping, shaping, molding, hogging, lathing, and sanding.

Some USAF installations have operations that generate airborne particulate in the form of dust from woodworking. Typical woodworking shops on a USAF base include Wood Hobby, Packing & Crating, and some CE shops such as Vertical Construction. 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, a cyclone, a baghouse (FF), or a cyclone and baghouse in series. The dust captured by the control device is collected in a bin or other container that is emptied when full. **Woodworking is categorized as a point source of particulate emissions since a ventilation system is typically employed**. Figure 26-1 provides a graphic representation of emissions from woodworking operations.

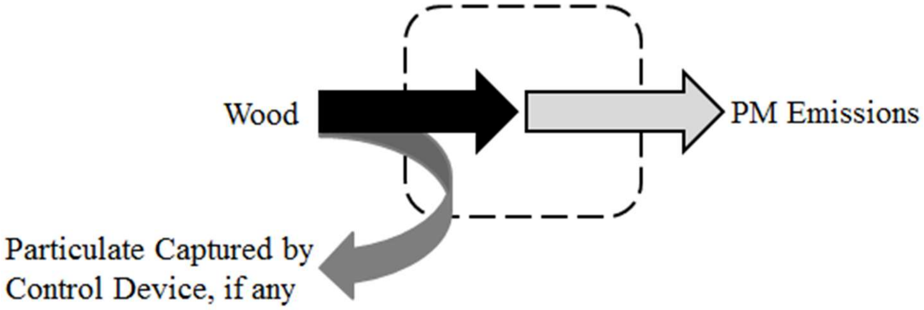

Figure 26-1. Simplified Control Volume for Emissions from Woodworking

26.2 Control Techniques

In general, there are three major types of dust control systems available to reduce the amount of particulate emitted to the atmosphere. These systems include dust collection, wet dust suppression, and airborne dust capture. Dust collection systems refer to a local exhaust ventilation system, which typically consists of an exhaust hood, a fan, and a dust collector. Wet dust suppression systems may be an inexpensive method for suppressing dust and works by wetting the surface material so that dust settles when saturated. Airborne dust capture systems may also use a water-spray technique to collide with dust particles that become too heavy to remain airborne.

26.3 Emissions Calculation

The only pollutant of concern in woodworking waste collection operations is PM. Given there are no longer algorithms or EFs for woodworking in AP-42, PM emissions from woodworking operations can be calculated using a mass balance approach. This approach is based on the estimated efficiency of the control device and the amount of woodworking waste collected during the year. If all PM that is released into the air from woodworking operations passes through the dust collection system**,** PM emissions may be estimated as follows:

$$\boldsymbol{E_{PM} = (MS_{Tot} - MS_{Col}) \times C_{Pol}}$$

Equation 26-1

Where,

E_{PM} = Annual emissions of particulate matter (lb/yr)
MS_{Tot} = Mass of total sawdust produced. This may be calculated in Equation 26-2. (lb/yr)
MS_{Col} = Mass of sawdust collected by the control device (lb/yr)
C_{Pol} = Fractional concentration of the pollutant. This is provided in Table 26-1.

If the total sawdust produced from woodworking operations is unknown, it can be estimated using the amount of sawdust collected and the control efficiency of the collection device. This is shown in Equation 26-2.

$$\boldsymbol{MS_{Tot} = \frac{MS_{Col}}{CE/100}}$$

Equation 26-2

Where,

CE = Efficiency of control device (%)
100 = Factor for converting a percent to a fraction

The fractional concentration is a measure of the amount of PM_{10} or $PM_{2.5}$ to the total PM that is produced in woodworking operations. PM fractional concentrations have been published by *Methodology to Calculate Particulate Matter (PM) 2.5 and PM 2.5 Significance Thresholds* (Krause 2006) and are reproduced in Table 26-1.

Table 26-1. Fractional Concentrations of Woodworking Dusts

Process Type	PM_{10}	$PM_{2.5}$
Sanding	0.920	0.885
Sawing	0.400	0.283
General Woodworking[(a)]	0.452	0.343

SOURCE: Mike and Steve Smith, "Methodology to Calculate Particulate Matter (PM) 2.5 and PM 2.5 Significance Thresholds," South Coast Air Quality Management District, October 2006.

a) Assumed a conservative 90% sawing and 10% sanding.

If the mass of sawdust collected during the year is not directly known, it must be calculated based on the volume collected and the density of the sawdust. This is shown in Equation 26-3.

$$\boldsymbol{MS_{Col} = VS_{Col} \times D}$$

Equation 26-3

Where,

VS_{Col} = Volume of sawdust collected (ft^3/yr)

D = Density of the sawdust. Provided in Table 26-2 (lb/ft^3)

The density of the sawdust is dependent on the wood being used. Typical sawdust densities for a variety of woods are provided in Table 26-2.

Table 26-2. Typical Sawdust Densities

Wood (Air dried)	Sawdust Density (lb/ft^3)
Elm	14.0
Fir, Balsam	10.0
Fir, Douglas	12.8
Hemlock	11.6
Hickory	19.2
Maple, Sugar	17.2
Maple, White	13.2
Oak, Red	16.8
Oak, White	19.2
Pine, Southern	16.0
Average	**15.0**

SOURCE: Briggs, David George, “Forest Products Measurements and Conversion Factors with Special Emphasis on the U.S. Pacific Northwest,” University of Washington, College of Forest Resources, 1994. Sawdust density based on a 2.5 expansion factor from solid wood. Air dried density values from AP-42 divided by expansion factor to calculate sawdust density.

A more detailed representation of the emissions from woodworking is provided in Figure 26-2.

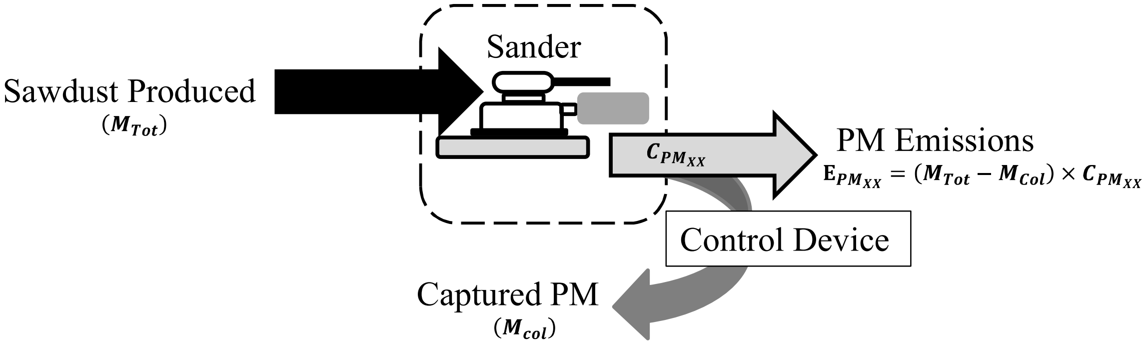

Figure 26-2. Woodworking Control Volume

26.4 Information Resources

Information on woodworking operations can be obtained from the specific shops/organizations that operate woodworking equipment (e.g., Wood Hobby Shop, CE, Packing & Crating Shop, etc.). The BEE shop on base may be able to help identify the shops with these operations. Contact the control device manufacturer to determine the control efficiency as needed.

26.5 Example Problem

A base has a Wood Hobby Shop that vents sawdust from ripping and cutting with table saws and sanders through a cyclone separator followed by a FF. The cyclone/filter manufacturer estimates the efficiency of the combined cyclone and filter (regarding sawdust collection) to be approximately 95 percent. 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_{10} and $PM_{2.5}$ emissions.

<u>Step 1</u> – Calculate the volume of sawdust collected. 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. **Note – at the time that the sawdust is emptied, it is typically at a height of 5 ft, therefore, that height should be used when calculating the sawdust volume, not the bin height.**

$$\mathbf{VS_{Col}} = (3\text{ft} \times 4\text{ft} \times 5\text{ft}) \times 12\frac{1}{\text{yr}} = \mathbf{720\frac{\mathit{ft}^3}{\mathit{yr}}}$$

<u>Step 2</u> – Select and record the density of the sawdust. The type of wood that is used in the Wood Hobby Shop is not provided so an average sawdust density should be selected. Table 26-2 states that the average sawdust density is **15.0 lb/ft^3**.

<u>Step 3</u> - Calculate the mass of sawdust collected. The mass of sawdust collected is then calculated by inserting the total volume of collected sawdust (calculated in Step 1) and the density of sawdust (recorded in Step 2) into Equation 26-3 as shown:

$$\text{MS}_{\text{Col}} = \text{VS}_{\text{Col}} \times \text{D}$$

$$\mathbf{MS_{Col}} = 720\frac{\cancel{\text{ft}^3}}{\text{yr}} \times 15.0\frac{\text{lb}}{\cancel{\text{ft}^3}} = \mathbf{10,800\frac{\mathit{lb}}{\mathit{yr}}}$$

<u>Step 4</u> – Calculate the total mass of the sawdust produced. The total mass of the sawdust produced is a function of the control device efficiency and the amount of sawdust collected. The total sawdust produced is estimated using Equation 26-2.

$$\text{MS}_{\text{Tot}} = \frac{MS_{Col}}{{}^{CE}/_{100}}$$

$$\text{MS}_{\text{Tot}} = \frac{10{,}800\frac{\text{lb}}{\text{yr}}}{{}^{95\cancel{\%}}/_{100\cancel{\%}}}$$

$$\mathbf{MS_{Tot}} = \frac{10{,}800\frac{lb}{yr}}{0.95} = \mathbf{11,368.4\frac{\mathit{lb}}{\mathit{yr}}}$$

<u>Step 5</u> – Select and record the fractional concentrations of PM$_{10}$ and PM$_{2.5}$. These values are given as **0.452 and 0.343** respectively.

<u>Step 6</u> – Calculate PM$_{10}$ and PM$_{2.5}$ emissions. Insert the MS$_{\text{Col}}$ calculated in Step 3, the MS$_{\text{Tot}}$ calculated in Step 4, and the aerodynamic ratios recorded for PM$_{10}$ and PM$_{2.5}$ in Step 5 into Equation 26-1:

$$\text{E}_{\text{Pol}} = (MS_{Tot} - MS_{Col}) \times C_{Pol}$$

<u>For PM$_{10}$:</u>

$$\text{E}_{\text{PM}_{10}} = \left(11{,}368.4\frac{lb}{yr} - 10{,}800\ \frac{\text{lb}}{\text{yr}}\right) \times 0.452$$

$$\mathrm{E}_{\mathrm{PM}_{10}} = \left(568.4\,\frac{\mathrm{lb}}{\mathrm{yr}}\right) \times 0.452$$

$$\boxed{\mathbf{E}_{\mathbf{PM_{10}}} = \mathbf{256.9}\,\frac{\boldsymbol{lb}}{\boldsymbol{yr}}}$$

For $\mathrm{PM}_{2.5}$:

$$\mathrm{E}_{\mathrm{PM}_{2.5}} = \left(11{,}368.4\,\frac{lb}{yr} - 10{,}800\,\frac{\mathrm{lb}}{\mathrm{yr}}\right) \times 0.343$$

$$\mathrm{E}_{\mathrm{PM}_{2.5}} = \left(568.4\,\frac{\mathrm{lb}}{\mathrm{yr}}\right) \times 0.343$$

$$\boxed{\mathbf{E}_{\mathbf{PM_{2.5}}} = \mathbf{195.0}\,\frac{\boldsymbol{lb}}{\boldsymbol{yr}}}$$

26.6 References

Briggs 1994, Briggs, David George, "Forest Products Measurements and Conversion Factors with Special Emphasis on the U.S. Pacific Northwest," University of Washington, College of Forest Resources, 1994

Krause 2006, Krause, Mike and Steve Smith, "Methodology to Calculate Particulate Matter (PM) 2.5 and PM 2.5 Significance Thresholds," South Coast Air Quality Management District, October 2006

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27 AIRCRAFT AND RUNWAY DEICING OPERATIONS (DICE) – NOT A STATIONARY SOURCE

- *Neither point nor fugitive source*

Not included in a USAF AEI

27.1 Introduction

Deicing operations involve the removal of frost, snow, or ice from aircraft surfaces or from paved areas including runways, taxiways, and gate areas. Deicing operations may be performed using mechanical means (e.g., brooms, brushes, plows) or through the application of deicing fluids. Most aircraft deicing fluids are a mixture of H_2O and propylene glycol (a.k.a. 1, 2-propanediol) or ethylene glycol. Though ethylene glycol is considered both a VOC and a HAP, **the emissions from aircraft and runway deicing operations are below de minimis levels. DO NOT calculate air emissions from aircraft and runway deicing operations.**

27.2 Insignificant Source

Deicing operations are an environmental concern due to the components of common fluids applied; however, the concerns should be regarding water and soil, but not air. Deicing operations do not impact air quality due to the relatively low vapor pressure of the fluid components. Vapor pressure is defined as the constant pressure for which the gas and liquid phase of a compound are at equilibrium for a given temperature. Vapor pressure is used to estimate a compound's tendency to volatilize and partition into the gaseous phase. The rate of evaporation is directly proportional to vapor pressure. As vapor pressure increases, the rate of evaporation proportionally increases. This relationship is given below:

$$Q \propto (VP \times P)$$

Where,

Q = Rate of evaporation (mass/time)
VP = Vapor pressure (atm)
P = Partial pressure of the compound above the liquid (atm). **If open air, P=0**.

The relationship between vapor pressure and temperature is explained by the Antoine equation which exists in two forms – the standard Antoine equation and the expanded Antoine equation. The standard Antoine equation is valid over a relatively small temperature range. The expanded Antoine equation, which adds additional constants and terms, is valid over a larger temperature range, including lower temperatures in which deicing operations may occur. The expanded Antoine equation is provided below.

$$P = e^{\left(C_1 + \frac{C_2}{T} + C_3 \times \ln(T) + C_4 \times T^{C_5}\right)}$$

Where,

P = Vapor Pressure (Pa)
C_1-C_5 = Equation constants specific to each chemical.
T = Temperature (°K)

Equation constants for ethylene glycol and propylene glycol are provided in Table 27-1.

Table 27-1. Equation Constants for Expanded Antoine Equation

Compound	C_1	C_2	C_3	C_4	C_5
Ethylene Glycol	79.276	-10,105	-7.521	7.3408E-19	6
Propylene Glycol	212.8	-15,420	-28.109	2.1564E-05	2

SOURCE: Green, Don W. and Robert H. Perry, Perry's Chemical Engineers' Handbook: Seventh Edition, 1997. Table 2-6.

A graph of vapor pressure versus temperature for these two chemicals is given in Figure 27-1.

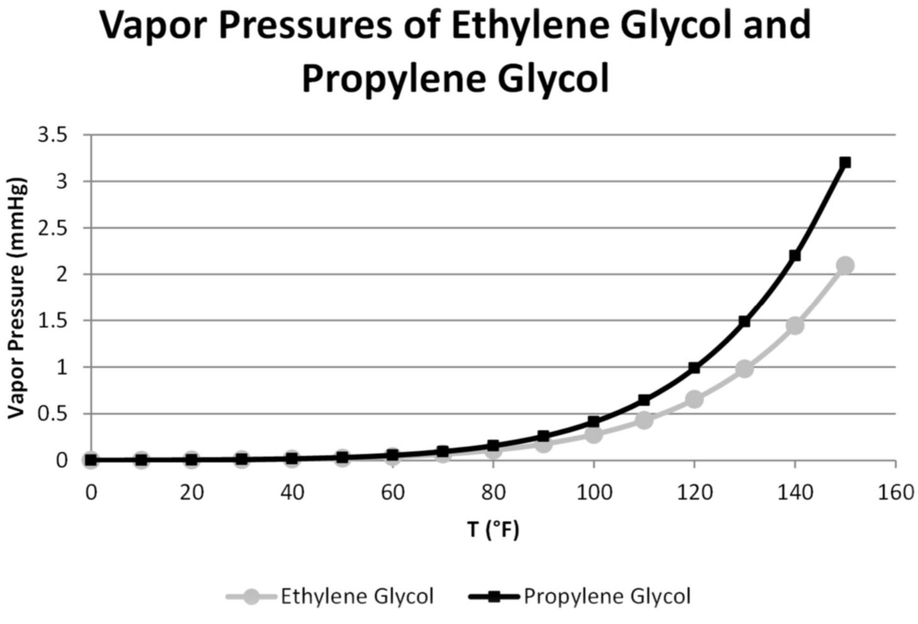

Figure 27-1. Vapor Pressures of Ethylene Glycol and Propylene Glycol

Previous documentation regarding air emissions from deicing operations assumed that 100 percent of the harmful components in the deicing fluid completely evaporates. However, deicing operations occur at or below freezing temperatures. The graph above clearly shows that as the temperature approaches freezing, the vapor pressures for both ethylene glycol and propylene glycol approaches zero. Therefore, given that the rate of evaporation is directly proportional to vapor pressure, the rate of evaporation becomes zero.

27.3 References

Green 1997, Green, Don W. and Robert H. Perry, “Perry's Chemical Engineers' Handbook: Seventh Edition,” 1997

28 ASPHALT PAVING OPERATIONS (ASPH) - NOT A STATIONARY SOURCE

- *Fugitive Source*
- *Transitory Source*

Air Force policy does not consider this a stationary source of emissions and is not included in an AEI. However, if the regulator requires this category be included as a stationary source, contact the USAF air quality SME for permission/guidance on emissions calculations

28.1 Introduction

Most USAF installations require the construction and repair of asphalt paved roads. Asphalt surfaces and pavements consist of compacted aggregate materials (stones, gravel, recycled asphalt, etc.) and an asphalt binder. Asphalt may be "cutback" by adding petroleum distillate to the asphalt cement. The petroleum distillate serves as a significant source of VOCs as it evaporates; therefore, the use of cutback asphalt is decreasing. Emulsified asphalts and asphalt cement do emit significant amounts of VOCs. Asphalt paving is a transitory source and, therefore, not included in stationary source AEIs or PTEs.

Transitory sources are non-routine and/or seasonal stationary or mobile sources that are short-term in nature. Non-routine sources are irregular, non-continuous, and/or infrequent sources of emissions. Seasonal sources are portable or semi-portable sources that are set up at a site for a specific temporary purpose before being re-located and used at another site.

Typically, transitory emissions are not included in annual stationary or mobile AEIs. Transitory sources are only included in AEIs if they become routine or year-round emitters, which excludes the sources from being transitory. A source is considered routine if (for non-emergencies) it emits regularly and/or frequently (recurrent) in nature. A source is considered year-round if (for non-emergencies) it emits continuous and/or frequently for more than three months in a year.

Since asphalt paving is a transitory source and traditionally not included in a stationary AEI, this section has been moved to the *Air Emissions Guide for Air Force Transitory Sources*.

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29 CONSTRUCTION (CNST) – NOT A STATIONARY SOURCE

- *Point Source* – Mobile Equipment
- *Fugitive Source* – Construction Activity
- *Transitory Source* – All Operations

USAF policy does not consider this a stationary source of emissions. However, if the regulator requires this category be included as a stationary source, contact the USAF air quality SME for permission/guidance on emissions calculations

29.1 Introduction

Although construction activities are temporary in nature, they have the potential to substantially impact local air quality. Heavy construction may be separated into six phases: demolition, site grading, excavating/trenching, building construction, architectural coatings, and asphalt paving. The total emissions resulting from heavy construction operations are the sum of the emissions resulting from pollutant emitting activities that occur during each phase. Emissions of concern include criteria pollutants and GHGs. Depending on the construction activity, the emissions source may be either point or fugitive.

Transitory sources are non-routine and/or seasonal stationary or mobile sources that are short-term in nature. Non-routine sources are irregular, non-continuous, and/or infrequent sources of emissions. Seasonal sources are portable or semi-portable sources that are set up at a site for a specific temporary purpose before being re-located and used at another site. Transitory sources are only included in AEIs if they are no longer classified as transitory (i.e., become routine or year-round emitters). A source is considered routine if (for non-emergencies) it emits regularly and/or frequently (recurrent) in nature. A source is considered year-round if (for non-emergencies) it emits continuous and/or frequently for more than three months in a year.

Since each of the phases/activities which comprise heavy construction are temporary and require a permit, heavy construction is regarded as a transitory source of air emissions. **Emissions calculations from heavy construction activities are not described here, but may be found in latest version of the *Air Emissions Guide for Air Force Transitory Sources*.**

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30 EQUIPMENT LEAKS (SPRL) – NOT A STATIONARY SOURCE

- *Fugitive Source* – Do Not Calculate

30.1 Introduction

Previous source guides outlined the calculation of emissions from equipment leaks using the quantity of system components and their respective EF. However, the EFs developed for equipment leaks were calculated using data collected from segments of the petroleum industry, such as petroleum refineries and oil and gas production facilities, not found at USAF installations. Additionally, a mass balance approach is commonly used for estimating emissions for several processes where equipment leaks are encountered. This approach inherently accounts for leaks that may occur when making emissions estimates. **For these reasons, calculating emissions from equipment leaks is not recommended; and therefore, not provided in this guide.**

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31 FUEL CELL MAINTENANCE AND TESTING (CELL, FCT) – NOT A STATIONARY SOURCE

- *Neither Point nor Stationary Source*

USAF policy does not consider this a stationary source of emissions. However, if the regulator requires this category be included as a stationary source, contact the USAF air quality SME for permission to calculate these emissions

31.1 Introduction

USAF personnel will occasionally enter aircraft fuel cells (tanks) for maintenance, repair, and routine inspection purposes. This process involves the removal of fuel from the fuel cell into bowsers. The fuel cell is then purged with clean air and at this point, explosion suppression foam may be removed if needed. The procedure for fuel cell maintenance is outlined in Technical Order (T.O.) 1-1-3, “Inspection, and Repair of Aircraft Integral Tanks and Fuel Cells.”

Originally identified as a source of air pollution, **fuel cell maintenance is no longer regarded as a stationary source of air emissions.** The method for estimating emissions is still presented in this guide as a reference for those bases that are still required to calculate this source. **However, it is still required that the USAF air quality SME is contacted for permission prior to calculating and reporting these emissions.**

When performing fuel cell maintenance and testing, the procedure typically involves the following steps:

- Fuel is removed from the fuel cell and placed into bowsers.
- The fuel cell is purged with fresh air until the O_2 levels and the Lower Explosive Limits (LEL) fall to acceptable levels.
- Explosion suppression foam may be removed if needed.
- The fuel cell is de-puddled to remove clinging fuel.
- The fuel cell is ventilated and continuously monitored to verify that the O_2 and LEL allow for safe entry and continued maintenance by personnel.

Traditionally, fuel cell maintenance and testing has been regarded as a fugitive source of VOC and HAP emissions. Emissions essentially came from three steps – the unloading of the fuel into the bowsers (and back again), the purging and ventilating of the fuel cell, and the evaporation of the fuel from the removed explosion suppression foam. The emissions from the loading and unloading of fuel to and from the bowsers are addressed in the “Fuel Transfer” section of this guide. Emissions from the evaporation of the fuel from the removed foam is assumed to be negligible due to the stringent requirements that all removed foam must be immediately sealed to prevent fuel vaporization. Therefore, the purging and ventilation of the fuel cell are the only source of emissions from fuel cell maintenance and testing.

31.2 Emissions Calculation

Algorithms and EFs used by the USAF are generally from AP-42; however, EFs for USAF-unique sources have been developed by the USAF. The only algorithms and EFs authorized for use in estimating USAF emissions are those maintained within the APIMS.

31.2.1 VOC Emissions Calculations

Since both the vapor concentration of the fuel and amount of fuel clinging to the fuel cell are difficult to estimate, calculation of emissions from fuel cell maintenance and testing is complex. For simplicity, the VOC emissions may be conservatively estimated to be equal to the product of the saturation concentration of the vapor in the fuel cell and two times the fuel cell volume. A factor of 2 represents the conservative estimation of emissions specifically from any fuel clingage, as well as any liquid fuel remaining in the fuel cell that would lead to VOC emissions.

$$\boldsymbol{E_{VOC} = 2 \times C_{VOC} \times 0.13368 \times \sum_{i=1}^{n} (V_i \times N_i)}$$

Equation 31-1

Where,

E_{VOC} = Annual emissions of VOC (lb/yr)
2 = Factor used for the conservative estimate of emissions representing twice the fuel cell volume
C_{VOC} = VOC concentration in the fuel cell (lb/ft^3)
0.13368 = Factor for converting cubic feet to gallons (ft^3/gal)
V = Fuel cell volume (gal/unit)
N = Number of fuel cells purged/ventilated in a year (units/yr)
i = Index which refers to specific aircraft/airframe, i.e. C-5, C-17, etc

The vapor saturation concentration (C_{VOC}) is first estimated using the vapor molecular weight, vapor pressure and temperature. For JP-8, a common aircraft fuel, the typical vapor pressures and vapor molecular weight are provided in Table 6-2. These values may be used to calculate C_{VOC} as shown:

$$C_{VOC} = \frac{M_V \times P_{VA}}{R \times T_{LA}}$$

Equation 31-2

Where,

C_{VOC} = VOC concentration in the fuel cell (lb/ft^3)
M_V = Vapor molecular weight (lb/lb-mol)
P_{VA} = Vapor pressure at the daily average liquid surface temperature (psia)
R = Ideal gas constant (10.732 psia•ft^3/°R•lb-mol)
T_{LA} = Daily average liquid surface temperature (°R). **Note that °R = °F +460.**

31.2.2 HAP Emissions Calculations

The amount of HAPs released into the atmosphere from the testing and maintenance of fuel cells is a function of the weight percent of the HAPs in the fuel. Typical HAP constituents in JP-8 are provided in Table 6-5. HAP emissions from fuel cell maintenance and testing are calculated as follows:

$$E_{HAP} = E_{VOC} \times \frac{WP_{HAP}}{100}$$

Equation 31-3

Where,

E_{HAP} = Annual emissions of speciated HAP (lb/yr)
E_{VOC} = Annual emissions of VOC (lb/yr)
WP_{HAP} = Weight percent of the speciated HAP in JP-8 (%)
100 = Factor for converting from a percent to a fraction (%)

31.3 Information Resources

Any information needed to calculate emissions from fuel cell maintenance should be available from the fuels maintenance shop. For increased accuracy, the fuel supplier may need to be contacted for updated HAP vapor weight percent data. Also, to calculate the number of purge gas volumes, it may be necessary to contact the aircraft manufacturer to obtain the fuel volume capacity or the blower manufacturer to determine the air flow rate in cubic feet per minute.

31.4 Example Problem

The base fuels maintenance shop performs maintenance on C-17 aircraft fuel cells that usually holds JP-8 fuel. The C-17 is equipped with two outboard and two inboard fuel tanks with capacities of 5,637 and 7,857 gal respectively. For the year, the fuels maintenance shop logged 43 outboard fuel cells and 49 inboard fuel cells for routine maintenance and repairs. With an average temperature of 60°F, calculate total VOC and xylene emissions from the maintenance and testing of these fuel cells.

<u>Step 1</u> – **Convert the temperature into the correct units.** To calculate the initial VOC concentration, the temperature must be converted to units of °R as shown:

$$°\boldsymbol{R} = 60 + 460 = \mathbf{520°}\boldsymbol{R}$$

<u>Step 2</u> – **Select and record the vapor molecular weight and vapor pressure**. These values are provided in Table 6-2. The vapor molecular weight is given as **130 lb/lb-mol** while the vapor pressure, at 60°F is given as **3.01E-02 psia**.

<u>Step 3</u> – **Calculate the vapor saturation concentration.** Using the temperature from Step 1, the parameters recorded in Step 2, and Equation 31-2, the saturation concentration is calculated as shown:

$$C_{VOC} = \frac{M_V \times P_{VA}}{R \times T_{LA}}$$

$$\boldsymbol{C_{VOC}} = \frac{130\left(\frac{lb}{\cancel{lb-mol}}\right)\times 0.0301(\cancel{psia})}{10.732\left(\frac{\cancel{psia}\,ft^3}{\cancel{°R}\,\cancel{lb-mol}}\right)\times 520(\cancel{°R})} = \mathbf{0.0007012}\,\boldsymbol{\frac{lb}{ft^3}}$$

<u>Step 4</u> – **Calculate VOC emissions**. Using the VOC vapor concentration calculated in Step 3 and the number of fuel cells and their respective volumes, the total VOC emissions are calculated using Equation 31-1:

$$E_{VOC} = 2 \times C_{VOC} \times 0.13368 \times \sum_{i=1}^{n} (V_i \times N_i)$$

$$E_{VOC} = 2 \times 0.0007012 \frac{lb}{ft^3} \times 0.13368 \frac{ft^3}{gal} \times \left[\left(5{,}637 \frac{gal}{\cancel{unit}} \times 43 \frac{\cancel{units}}{yr}\right) + \left(7{,}857 \frac{gal}{\cancel{unit}} \times 49 \frac{\cancel{units}}{yr}\right)\right]$$

$$E_{VOC} = 2 \times 0.0007012 \frac{lb}{ft^3} \times 0.13368 \frac{ft^3}{gal} \times \left[\left(242{,}391 \frac{gal}{yr}\right) + \left(384{,}993 \frac{gal}{yr}\right)\right]$$

$$E_{VOC} = 2 \times 0.0007012 \frac{lb}{\cancel{ft^3}} \times 0.13368 \frac{\cancel{ft^3}}{\cancel{gal}} \times \left[627{,}384 \frac{\cancel{gal}}{yr}\right]$$

$$\boxed{\boldsymbol{E_{VOC} = 117.62 \frac{lb}{yr}}}$$

<u>Step 5</u> – Select and record the weight percent of xylenes in the vapor. This value is given as **5.61E-02%.**

<u>Step 6</u> – Calculate xylene emissions. Using the total VOCs emitted as calculated in Step 4 and the weight percent xylenes recorded in Step 5, the total xylenes emitted are calculated using Equation 31-3:

$$E_{HAP} = E_{VOC} \times \frac{WP_{HAP}}{100}$$

$$E_{Xylenes} = 117.62 \frac{lb}{yr} \times \frac{0.0561\cancel{\%}}{100\cancel{\%}}$$

$$E_{Xylenes} = 117.62 \frac{lb}{yr} \times 0.000561$$

$$\boxed{\boldsymbol{E_{Xylenes} = 6.60\text{E} - 02 \frac{lb}{yr}}}$$

31.5 References

Mayfield 1996, Mayfield, Howard T., “JP-8 Composition and Variability,” Armstrong Laboratory, Environics Directorate, Environmental Research Division, May 1996

SWRI 2001, “JP-8 Volatility Study,” Southwest Research Institute (SWRI), March 2001

T.O. 2015, “Techincal Order 1-1-3 (w/ Change-19), Technical Manual: Inspection and Repair of Aircraft Integral Tanks and Fuel Cells,” October 2015

USEPA 2006, Section 7.1-“Organic Liquid Storage Tanks," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, November 2006

32 FUEL SPILLS (SPRL) – NOT A STATIONARY SOURCE

- *Fugitive Source*
- *Transitory Source*

USAF policy does not consider this a stationary source of emissions. However, if the regulator requires this category be included as a stationary source, contact the USAF air quality SME for permission/guidance on emissions calculations

32.1 Introduction

Significant fuel spills are not common occurrences at any USAF installation. However, minor fuel spills occasionally occur during fuel transfer activities despite precautions. For example, accidental venting of fuel and inadequate connections between fueling hoses and aircraft can result in a minor fuel spill. In the event of a minor fuel spill, most fuel is recovered during clean up. The remaining fuel which is not recovered is assumed to completely evaporate. This assumption allows for a conservative estimate of pollutant emissions. Fuel spills result in the fugitive emissions of VOCs and organic HAPs in the fuel.

Due to infrequency, fuel spills are classified as transitory emission sources and therefore not included in stationary source AEIs or PTEs. Transitory sources include non-routine and/or seasonal stationary or mobile sources that are short term in nature.

However, the quantification of emissions from fuel spills is extremely important. CERCLA and EPCRA requires immediate reporting to appropriate authorities whenever a hazardous substance is released in quantities equal to or greater than the reporting quantities as defined under CERCLA. Additionally, Section 313 of EPCRA outlines the TRI program which requires facilities to annually submit a toxic chemical release form.

Though important for EPCRA and TRI reporting, their infrequency means that fuel spills will not be found in a typical AEI. Therefore, this section has been moved to the *Air Emissions Guide for Air Force Transitory Sources*, which describes those stationary emission sources considered non-traditional operations. For guidance in calculating emissions for fuel spills, refer to the latest version of the *Air Emissions Guide for Air Force Transitory Sources*.

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33 HOT MIX ASPHALT PLANTS (HMA) – NOT A STATIONARY SOURCE

- *Point/Fugitive Source*
- *Transitory Source* – If plant is active for less than a year
- *Stationary Source* – If plant is active for a year or more

33.1 Introduction

Hot Mix Asphalt (HMA) paving operations on USAF installations are typically associated with large-scale paving actions. Although uncommon and generally short-term, HMA has the potential to be a substantial contributor to air emissions during the year. The primary source of emissions includes fugitive and ducted (those vented to the atmosphere through some type of stack, vent, or pipe) emissions from dryers, hot screens, and mixers associated with production of the HMA.

Transitory sources are non-routine and/or seasonal stationary or mobile sources that are short-term in nature. Non-routine sources are irregular, non-continuous, and/or infrequent sources of emissions. Seasonal sources are portable or semi-portable sources that are set up at a site for a specific temporary purpose before being re-located and used at another site. Transitory sources are only included in AEIs if they are no longer classified as transitory (i.e., become routine or year-round emitters). A source is considered routine if (for non-emergencies) it emits regularly and/or frequently (recurrent) in nature. A source is considered year-round if (for non-emergencies) it emits continuous and/or frequently for more than three months in a year.

Typically, the paving operations occurring at a USAF installation are temporary and non-routine in nature. **For this reason, this section has been moved to a supplemental guide that describes those emission sources that are considered non-traditional operations. For guidance in calculating the emissions from hot mix asphalt plants, refer to the latest version of the *Air Emissions Guide for Air Force Transitory Sources*. However, note that if the hot mix asphalt plant is active for at least a year, it must be considered stationary and not transitory.**

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34 PRESCRIBED BURNS (BURN) – NOT A STATIONARY SOURCE

- *Fugitive Source*
- *Transitory Source*

USAF policy does not consider this a stationary source of emissions. However, if the regulator requires this category be included as a stationary source, contact the USAF air quality SME for permission/guidance on emissions calculations

34.1 Introduction

Prescribed burns are used for management reasons to minimize future hazards or damage to the surrounding area. Although prescribed burns are planned, they are not a common method used at USAF installations, therefore, it is classified as a transitory emission source. Transitory sources include non-routine and/or seasonal stationary or mobile sources that are short term in nature. Prescribed burns can be implemented for the management of forests, ranges, and wetlands to accomplish natural resource management objectives. These objectives may include the treatment of an area for reducing the potential for wildfires, for removing logging residues, for controlling insects and disease, for increasing water yield or for controlling insect population and plant overgrowth without the use of herbicides and pesticides. **Prescribed burns result in the fugitive emissions of the criteria pollutants and GHGs.**

Due to the infrequent application, prescribed burns will not be found in a typical AEI. Therefore, this section has been moved to the *Air Emissions Guide for Air Force Transitory Sources*, which describes those stationary emission sources considered non-traditional operations. For guidance in calculating emissions for prescribed burns, refer to the latest version of the *Air Emissions Guide for Air Force Transitory Sources*.

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35 SITE REMEDIATION (RDL) – NOT A STATIONARY SOURCE

- *Point/Fugitive Source*
- *Transitory Source*

USAF policy does not consider this a stationary source of emissions. However, if the regulator requires this category be included as a stationary source, contact the USAF air quality SME for permission/guidance on emissions calculations

35.1 Introduction

USAF installations occasionally have sites that are contaminated with hazardous substances because of chemical leaks, spills, or prior disposal practices. Identification, investigation, and cleanup of these contaminants on active USAF and Base Realignment and Closure (BRAC) installations falls under the jurisdiction of the DODs Environmental Restoration Program (ERP).

USAF site remediation sources are considered transitory because they produce emissions from non-routine sources that are irregular, non-continuous, and/or infrequent sources of emissions. The requirements for air quality are addressed under the USAF Installation Restoration Program (IRP) and performed under the authority of the CERCLA or as a RCRA permit. Additionally, all Environmental Restoration Program (ERP) activities must meet the substantive requirements of the CAA and, if non-CERCLA, must meet the permitting requirements of the CAA. Therefore, emissions from site remediation should normally not be part of a stationary air emissions inventory. Rather, these emissions are addressed under the *Air Emissions Guide for Air Force Transitory Sources*.

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APPENDIX A - EPA HAP LIST

CAS No.	Chemical/Compound
75070	Acetaldehyde
60355	Acetamide
75058	Acetonitrile
98862	Acetophenone
53963	2-Acetylaminofluorene
107028	Acrolein
79061	Acrylamide
79107	Acrylic Acid
107131	Acrylonitrile
107051	Allyl Chloride
92671	4-Aminobiphenyl
62533	Aniline
90040	o-Anisidine
1332214	Asbestos
71432	Benzene
92875	Benzidine
98077	Benzotrichloride
100447	Benzyl Chloride
92524	Biphenyl
117817	Bis(2-ethylhexyl)phthalate
542881	Bis(chloromethyl)ether
75252	Bromoform
106990	1,3-Butadiene
156627	Calcium Cyanamide
133062	Captan
63252	Carbaryl
75150	Carbon Disulfide
56235	Carbon Tetrachloride
463581	Carbonyl Sulfide
120809	Catechol
133904	Chloramben
57749	Chlordane
7782505	Chlorine
79118	Chloroacetic Acid
532274	2-Chloroacetophenone
108907	Chlorobenzene
510156	Chlorobenzilate
67663	Chloroform
107302	Chloromethyl methyl ether
126998	Chloroprene
1319773	Cresylic Acid
95487	o-Cresol
108394	m-Cresol
106445	p-Cresol
98828	Cumene
94757	2,4-D
3547044	DDE
334883	Diazomethane

CAS No.	Chemical/Compound
132649	Dibenzofurans
96128	1,2-Dibromo-3-chloropane
84742	Dibutylphthalate
106467	1,4-Dichlorobenzene
91941	3,3-Dichlorobenzidene
111444	Dichloroethyl ether
542756	1,3-Dichloropropene
62737	Dichlorvos
111422	Diethanolamine
121697	N,N-Dimethylaniline
64675	Diethyl Sulfate
119904	3,3-Dimethoxybenzidine
60117	Dimethyl Aminoazobenzene
119937	3,3'-Dimethyl Benzidine
79447	Dimethyl Carbamoyl Chloride
68122	Dimethyl Formamide
57147	1,1-Dimethyl Hydrazine
131113	Dimethyl Phthalate
77781	Dimethyl Sulfate
534521	4,6-Dinitro-o-cresol
51285	2,4-Dinitrophenol
121142	2,4-Dinitrotoluene
123911	1,4-Dioxane
122667	1,2-Diphenylhydrazine
106898	Epichlorohydrin
106887	1,2-Epoxybutane
140885	Ethyl Acrylate
100414	Ethyl Benzene
51796	Ethyl Carbamate
75003	Ethyl Chloride
106934	Ethylene Dibromide
107062	Ethylene Dichloride
107211	Ethylene Glycol
151564	Ethylene Imine
75218	Ethylene Oxide
96457	Ethylene Thiourea
75343	Ethylidene Dichloride
50000	Formaldehyde
76448	Heptachlor
118741	Hexachlorobenzene
87683	Hexachlorobutadiene
77474	Hexachlorocyclopentadiene
67721	Hexachloroethane
822060	Hexamethylene-1,6-diisocyanate
680319	Hexamethylphosphoramide
110543	Hexane
302012	Hydrazine
7647010	Hydrochloric Acid

CAS No.	Chemical/Compound
7664393	Hydrogen Fluoride
123319	Hydroquinone
78591	Isophorone
58899	Lindane
108316	Maleic Anhydride
67561	Methanol
72435	Methoxychlor
74839	Methyl Bromide
74873	Methyl Chloride
71556	Methyl Chloroform
60344	Methyl Hydrazine
74884	Methyl Iodide
108101	Methyl Isobutyl Ketone
624839	Methyl Isocyanate
80626	Methyl Methacrylate
1634044	Methyl tert Butyl Ether
101144	4,4-Methylene bis(2-Chloroaniline)
75092	Methylene Chloride
101688	Methylene Diphenyl Diisocyanate
101779	4,4'-Methylenedianiline
91203	Naphthalene
98953	Nitrobenzene
92933	4-Nitrobiphenyl
100027	4-Nitrophenol
79469	2-Nitropropane
684935	N-Nitroso-N-Methylurea
62759	N-Nitrosodimethylamine
59892	N-Nitrosomorpholine
56382	Parathion
82688	Pentachloronitrobenzene
87865	Pentachlorophenol
108952	Phenol
106503	p-Phenylenediamine
75445	Phosgene
7803512	Phosphine
7723140	Phosphorus
85449	Phthalic Anhydride
1336363	Polychlorinated Biphenyls
1120714	1,3-Propane Sultone
57578	beta-Propiolactone
123386	Propionaldehyde
114261	Propoxur
78875	Propylene Dichloride
75569	Propylene Oxide
75558	1,2-Proplenimine
91225	Quinoline
106514	Quinone
100425	Styrene

APPENDIX A - EPA HAP List (cont.)

CAS No.	Chemical/Compound
96093	Styrene Oxide
1746016	2,3,7,8-Tetrachlorodibenzo-p-dioxin
79345	1,1,2,2-Tetrachloroethane
127184	Tetrachloroethylene
7550450	Titanium Tetrachloride
108883	Toluene
95807	2,4-Toluene Diamine
584849	2,4-Toluene Diisocyanate
95534	o-Toluidine
8001352	Toxaphene
120821	1,2,4-Trichlorobenzene
79005	1,1,2-Trichloroethane
79016	Trichloroethylene
95954	2,4,5-Trichlorophenol
88062	2,4,6-Trichlorophenol

CAS No.	Chemical/Compound
121448	Triethylamine
1582098	Trifluralin
540841	2,2,4-Trimethylpentane
108054	Vinyl Acetate
593602	Vinyl Bromide
75014	Vinyl Chloride
75354	Vinylidene Chloride
1330207	Xylenes
95476	o-Xylene
108383	m-Xylene
106423	p-Xylene
---	Antimony Compounds
---	Arsenic Compounds
---	Beryllium Compounds
---	Cadmium Compounds

CAS No.	Chemical/Compound
---	Chromium Compounds
---	Cobalt Compounds
---	Coke Oven Emissions
---	Cyanide Compounds
---	Glycol Ethers
---	Lead Compounds
---	Manganese Compounds
---	Mercury Compounds
---	Fine Mineral Fibers
---	Nickel Compounds
---	Polycyclic Organic Matter
---	Radionuclides (including Radon)
---	Selenium Compounds