Air Emissions Guide for Air Force Stationary Sources

**Methods for Estimating Emissions
of Air Pollutants
for Stationary Sources at
U.S. Air Force Installations**

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AIR EMISSIONS GUIDE FOR AIR FORCE STATIONARY SOURCES

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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
ALAPCO	Association of Local Air Pollution Control Officials
AMX	Aircraft Maintenance Squadron
BEE	Bioenvironmental Engineer
BOOS	Burners Out Of Service
CAIR	Clean Air Interstate Rule
CAS	Chemical Abstracts Service
CONUS	Continental United States
DAC	Defense Ammunition Center
EPAct	Energy Policy Act
EPCRA	Emergency Planning and Community Right-to-Know Act
FESOP	Federally Enforceable State Operating Permit
FIRE	Factor Information Retrieval System
HAP	Hazardous Air Pollutant
HAZMAT	Hazardous Materials
HEPA	High Efficiency Particulate Air
HVAC	Heating, Ventilating, and Air Conditioning
ICAO	International Civil Aviation Organization
MAJCOM	Major Command
MEM	Mass of Energetic Material
MIDAS	Munitions Items Disposition Action System
NAAQS	National Ambient Air Quality Standards
NAICS	North American Industry Classification System
NASA	National Aeronautics and Space Administration
NEPA	National Environmental Policy Act
NESHAP	National Emission Standards for Hazardous Air Pollutants
OCONUS	Outside Continental United States
OTAG	Office of Transportation Quality
PEMS	Predictive Emission Monitoring System
RAP	Reclaimed Asphalt Pavement
SAR	Second Assessment Report
SAW	Submerged Arc Welding
SIC	Standard Industrial Classification
SIP	State Implementation Plan
SMAW	Shielded Metal Arc Welding

STAPPA	State and Territorial Air Pollution Program Administrators
TAR	Third Assessment Report
USAF	United States Air Force
VIN	Vehicle Identification Number

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.)

AB	Afterburner
AEI	Air Emissions Inventory
AFB	Air Force Base
AFI	Air Force Instruction
AFRL	Air Force Research Laboratory
AGSE	Aerospace Ground Support Equipment
APU	Auxiliary Power Unit
AVGAS	Aviation Gasoline
BMP	Best Management Practices
BSFC	Brake-Specific Fuel Consumption
CAA	Clean Air Act
CAAA	Clean Air Act Amendments (of 1990)
CBPO	Consolidated Base Personnel Office
CE	Civil Engineering
CEMS	Continuous Emission Monitoring System
CEV	Civil Engineering Environmental
CFC	Chlorofluorocarbon
CFR	Code of Federal Regulations
CFRM	Continuous Flow Rate Monitor
CI	Compression Ignition
CNG	Compressed Natural Gas
DCA	Defense Commissary Agency
DESC	Defense Energy Support Center
DLA	Defense Logistics Agency
DNA	Defense Nuclear Agency
DOD	Department of Defense
DOE	Department of Energy
EA	Environmental Assessment
EDMS	Emissions and Dispersion Modeling System
EDP	Electrodeposition
EF	Emission Factor
EGBE	Ethylene Glycol Butyl Ether
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
EPAct	Energy Policy Act
ERC	Emission Reduction Credit
ERP	Environmental Restoration Program
ESP	Electrostatic Precipitator
ESTCP	Environmental Security Technology Certification Program
FAA	Federal Aviation Administration
FBC	Fluidized Bed Combustor
FCAW	Flux-Cored Arc Welding
FF	Fabric Filter
FFV	Flexible Fuel Vehicles
FGD	Flue Gas Desulphurization
FGR	Flue Gas Recirculation
FT	Fischer-Tropsch
GHG	Greenhouse Gas
GMAW	Gas Metal Arc Welding
GOV	Government Owned Vehicles
GSA	General Services Administration
GSE	Ground Support Equipment
GVW	Gross Vehicle Weight
HBFC	Hydrobromofluorocarbons
HC	Hydrocarbon
HCFC	Hydrochlorofluorocarbons
HCP	Hard Chrome Plating
HEI	High Explosive Incendiary
HEV	Hybrid Electric Vehicles
HHV	High Heat Value
HMA	Hot Mix Asphalt
HVLP	High Volume Low Pressure
HVOF	High Velocity Oxy-Fuel
IC	Internal Combustion
ICAO	International Civil Aviation Organization
IPCC	Intergovernmental Panel on Climate Change
IRP	Installation Restoration Program
LDF	Liquid Drift Factors
LEL	Lower Explosive Limit
LFB	Low Flyby
LFG	Landfill Gas
LFP	Low Flight Pattern

LGRVM	Vehicle Management Flight Vehicle Maintenance
LNB	Low NO$_X$ Burner
LPG	Liquefied Petroleum Gas
LTO	Landing and Takeoff
MB	Material Burned
MC	Medium Cure
MEK	Methyl Ethyl Ketone
Mg	Megagram(s) [i.e., metric ton]
mg	Milligram(s)
MIDAS	Munitions Items Disposition Action System
MEK	Methyl Ethyl Ketone
MM	Minutemen Missiles
MMBtu	Million British Thermal Units
Mn	Manganese
MPF	Military Personnel Flight
MPO	Metropolitan Planning Office
MSDS	Material Safety Data Sheet
MSW	Municipal Solid Waste
NACAA	National Association of Clean Air Agencies
NDI	Non-destructive Inspection
NEI	National Emission Inventory
NMHC	Non-methane Hydrocarbons
NMOC	Non-methane Organic Compounds
NSCR	Nonselective Catalytic Reduction
NSPS	New Source Performance Standards
NSR	New Source Review
OB/OD	Open Burning/Open Detonation
OBODM	Open Burning/Open Detonation Model
OCA	Off-Site Consequences Analysis
ODS	Ozone Depleting Substances
OIAI	Once In Always In
OLVIMS	On-line Vehicle Interactive Management System
P2	Pollution Prevention
PAH	Polycyclic Aromatic Hydrocarbon
PBT	Persistent Bioaccumulative and Toxic
PEMS	Predictive Emission Monitoring System
PM	Particulate Matter – Aerodynamic diameter unspecified
PM$_{10}$	Particulate Matter – Aerodynamic diameter < 10 micrometers
PM$_{2.5}$	Particulate Matter – Aerodynamic diameter < 2.5 micrometers
POM	Polycyclic Organic Matter

POTW	Publicly Owned Treatment Works
POV	Privately Owned Vehicles
PTE	Potential-To-Emit
RC	Rapid Cure
REO	Regional Environmental Offices
REEDM	Rocket Exhaust Effluent Diffusion Model
RMP	Risk Management Plan
RVP	Reid Vapor Pressure
SC	Slow Cure
SCC	Source Classification Code
SCR	Selective Catalytic Reduction
SI	Spark Ignition
SOCMI	Synthetic Organic Chemical Manufacturing Industry
SVE	Soil Vapor Extraction
TCLP	Toxicity Characteristics Leaching Procedure
TDS	Total Dissolved Solids
TGO	Touch-and-Go
THC	Total Hydrocarbons
TIM	Time In Mode
TLG	Total Landfill Gas
TNMOC	Total Non-methane Organic Compounds
TO	Technical Order
TOC	Total Organic Compounds
TRI	Toxic Release Inventory
TSD	Treatment, Storage, & Disposal
TSP	Total Suspended Particulate
ULSD	Ultra Low Sulfur Diesel
US	United States
UST	Underground Storage Tanks
VKT	Vehicle Kilometers Traveled
VMIF	Vehicle Maintenance Index File
VMT	Vehicle Miles Traveled
VOC	Volatile Organic Compound

ABBREVIATIONS

(Shortened form of a word or phrase)

µg	Microgram(s)
µm	Micrometer(s)
A-hr	Ampere-hours
Btu	British Thermal Unit
ºC	Degrees Celsius
CH_4	Methane
CO	Carbon Monoxide
Co	Cobalt
Cr	Chromium
dscf	Dry Standard Cubic Feet
dscfm	Dry Standard Cubic Feet per Minute
EtO	Ethylene Oxide
ºF	Degrees Fahrenheit
ft.	Foot (Feet)
g/L	Grams per Liter
gal	Gallon(s)
HCl	Hydrochloric Acid
hp	Horse Power
hr	Hour(s)
kW	Kilowatt(s)
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
Pb	Lead
ppm	Parts per Million
ppmv	Parts per Million by Volume
psi	Pounds per Square Inch
ºR	Degrees Rankin
scf	Standard Cubic Foot
SO_2	Sulfur Dioxide

SO$_X$	Sulfur Oxides
tpy	Tons per Year
yr	Year(s)

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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 Clean Air Act, 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 know at all times if their facility operates in accordance with air regulations.

The quantification of air pollutant emissions from a typical Air Force base is accomplished by conducting an **Air Emissions Inventory (AEI)**. An 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 abide by the requirements of the host government.

This document 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 Air Force installations. This document describes recommended methodologies for calculating **actual** pollutant emissions from these sources. It includes most air emission sources that might be found on an Air Force installation as well as brief discussions regarding emissions sources which have historically been regarded as stationary, but have since been deemed as either: **mobile, transitory**, or simply insignificant.

Any questions concerning this document, calculation methodologies for sources not provided here, and/or requests for additional information pertaining to Air Force air emission inventories, should be directed to the Air Quality Subject Matter Expert; AFCEC, Compliance Technical Support Branch; 250 Goodrich Drive; Building #1650San 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 document is concerned only with emissions from stationary sources likely to be found at an Air Force base. For emissions

calculation methodologies for mobile or transitory sources, refer to the Mobile or Transitory Guide.

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 of the 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). In regards to 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" and further subdivided based on engine size, vehicle weight, equipment type, and/or horsepower. 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.

Transitory sources are non-routine and/or seasonal sources (may be stationary, mobile or neither) that are short-term in nature. While historically transitory source have been erroneously included as stationary or mobile sources in AEIs, transitory source emissions should generally only be accounted for in evaluating potential air quality impacts of proposed action under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA); National Environmental Policy Act (NEPA), General Conformity, etc.

Non-routine sources are irregular, non-continuous, and/or infrequent sources of emissions. Generally air quality concerns for non-routine sources are addressed as Applicable or Relevant and Appropriate Requirements (ARAR) under other environmental laws (e.g., CERCLA for all sources associated with site restoration/remediation). Examples of non-routine sources typically associated with an Air Force 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 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 an Air Force installations include: seasonal equipment, hot mix asphalt plants, and all sources associated with construction. Seasonal mobile sources are those that are non-stationary and include both "on-road" and "off-road" engines and equipment. Data for mobile sources are based on engine size, vehicle weight, equipment type, and/or horsepower. 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.

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 document addresses stationary emissions sources typically found on Air Force installations. Sources of emissions may be further subdivided as either being point, fugitive, biogenic, or area sources. A point source of pollution may be attributed to a specific physical location, while fugitive sources are those which result from leaks and other unintended releases of vapor. Only point and fugitive source emissions are applicable to Air Force installations because of their direct bearing on the determination of major source status. Biogenic (i.e. natural) sources and area sources are not addressed in any great detail within this document. Biogenic sources of air emissions are naturally occurring sources such as plants and trees. The definition of an area source varies by pollutant group and regulation (i.e., criteria pollutants versus hazardous air pollutants [HAPs]). An area source is generally considered to be stationary and "non-road" types of sources that are too small and too numerous to be individually included in a stationary source emissions inventory. These are sources for which emissions are estimated as a group rather than individually, such as residential wood heating and consumer solvent use.

1.3   Actual vs. Potential to Emit (PTE)

This document 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. According to 40 CFR 70.2, 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 millions of dollars in manpower costs, equipment modifications, and fees, AEIs sometimes contain overly conservative (and sometimes unrealistic) calculation methods, which result in greatly inflated PTEs and an inaccurate classification of the facility as a major source of emissions.

1.4   Pollutants

The primary pollutants addressed in this document include: criteria pollutants, Hazardous Air Pollutants (HAPs), Ozone Depleting Substances (ODS), and Greenhouse Gases (GHGs). Depending on available data, several sections within this document 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 Environmental Protection Agency (EPA) established National Ambient Air Quality Standards (NAAQS) for six pollutants which are termed 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]):
- Includes the very fine dust, soot, smoke, and droplets formed from chemical reactions and incomplete burning of fuels.
- The fine particles can get deep into the lungs, causing increased respiratory illnesses and tens of thousands of deaths each year.
- Particulate matter is defined as any particle with an equivalent diameter of ≤ 10 microns (**PM_{10}**) and is further subdivided to include a separate standard for particles with an equivalent aerodynamic diameter of ≤ 2.5 microns (**$PM_{2.5}$**).

Ground-Level Ozone (O_3):

- A primary component of smog which can cause human health problems and damage forests and agricultural crops.
- Repeated exposure to ozone can make people more susceptible to respiratory infections and lung inflammation.
- Though there is a NAAQS, **ozone is not emitted directly into the air**.
- Two types of chemicals that are the main ingredients (precursors) in forming ground-level ozone in the presence of ultraviolet (UV) light include:
    - **Volatile organic compounds (VOCs):** Defined as "any compound of carbon, excluding carbon monoxide, carbon dioxide, carbonic acid, metallic carbides or carbonates, and ammonium carbonate, which participates in atmospheric photochemical reactions" (40 CFR 51.100). Sources include cars burning gasoline, petroleum refineries, chemical manufacturing plants, industrial plants, solvents used in paints, and an assortment of consumer and business products containing VOCs.
    - **Nitrogen oxides (NOx):** Produced when cars and other sources like power plants and industrial boilers burn fuels such as gasoline, coal, or oil. Nitrogen Oxides produce the reddish-brown tint in smog.

Carbon Monoxide (CO):
- Produced when fossil fuel burns incompletely due because of insufficient oxygen.
- Wood, coal, and charcoal fires and gasoline engines always produce carbon monoxide.
- In the United States, particularly in urban areas, the majority of CO air emissions are from mobile sources.
- Can cause harmful health effects by reducing oxygen delivery to the body's organs (like the heart and brain) and tissues.

Sulfur Oxides (SOX):
- A group of highly reactive gases known as "oxides of sulfur", of which SO_2 is the most common component.
- Emissions are produced from fossil fuel combustion at power plants (73%) and other industrial facilities (20%).
- SO_2 is linked to a number of adverse effects on the respiratory system.
- SO_2 in the ambient air is just one of several oxides of sulfur that contribute to air quality issues.

Nitrogen Oxides (NOX):

- A subgroup of nitrogen oxides, NO_2 is the component of greatest interest and the indicator for the larger group of nitrogen oxides.
- NO_2 forms quickly from vehicle, power plant, and off-road equipment emissions.
- Also contributes to the formation of ground-level ozone and fine particle pollution.
- Linked to a number of adverse effects on the respiratory system.

Lead (Pb):
- 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 is commonly provided in both the criteria pollutant and speciated HAPs tables within this document. Care should be taken to avoid the overestimation of this pollutant from duplication of these emission factors. For a current list of the NAAQS for the criteria pollutants, refer to 40 CFR 50.

Since ozone is not directly emitted into the air, but rather 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, this document provides emission factors for a list of criteria pollutants which differ slightly from those regulated by the NAAQS. The list of "criteria pollutants" for emissions inventory purposes includes the following:

- 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 which includes 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 in Appendix A – EPA HAP List.

1.4.3   Ozone Depleting Substances (ODSs)

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. ODSs 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 ODSs 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 ODSs, respectively. Despite their regulation, ODSs 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 (GHGs)

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

CO_2 is the primary greenhouse gas emitted through human activity, accounting for 82% of all U.S. greenhouse gas emissions from human activities. 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 activities, as well as during combustion of fossil fuels and solid waste.

Greenhouse gases 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, which is 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 CH_4 and N_2O may be converted into equivalent CO_2 (CO_2e) by taking the product of each GHG emissions and its respective GWP. Table A-1 of 40 CFR 98 provides the GWPs for several greenhouse gases.

1.5   Air Emission Inventories (AEIs)

An Air Emission Inventory (AEI) is a compilation of the air pollutant emissions in a given area over a given period of time, typically one year. Prior to conducting an AEI, consult the local air quality regulatory agency to confirm that the state is in agreement with what constitutes an emission source and that the appropriate methodology for performing the AEI is being used. Additionally, 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 as :

1.5.1   Air Emissions Reporting Requirements (AERR) Rule

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 but not HAPs or GHGs, though reporting these emissions is encouraged.

1.5.2   Air Force Instruction (AFI) 32-7040

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

> "…prepare and periodically update an AEI of all installation stationary and Air Force owned or operated mobile sources at the frequency required by federal, state, and local regulations, via the Air Program Information Management System (APIMS).   If no periodic emission inventory requirements apply, it is recommended that APIMS be updated no less frequently than every three years to accurately reflect current emissions. Overseas installations shall conduct AEIs in accordance with Foreign Governing Standards or Host Nation agreements. GHG reporting mandated by Title 40, Code of Federal Regulations, Part 98, *Mandatory Reporting of Greenhouse Gases* shall be accomplished by the affected installations. Installation AEI data stored in APIMS are available for use as needed by AFCEC and higher headquarters." (AFI 2007)

1.5.3   Clean Air Act (CAA)

The Clean Air Act (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, whereas those areas that do not meet the NAAQS are classified as *nonattainment* for that pollutant. A nonattainment area which meets the NAAQS, and any additional requirements, will be redesignated 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, 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 which are in nonattainment for that particular pollutant.

- Section 182(a)(1) of the CAA requires each state to submit a current inventory of actual VOCs and NO_X emissions (from sources in areas that are in nonattainment for ozone) and of actual CO emissions (from sources in areas that are in nonattainment for CO). Subsequent to the baseline inventory, states must submit periodic inventories every three years until the area reaches attainment.

- Section 182 of the CAA also requires stationary sources in ozone nonattainment areas to report their actual VOC and NO_X emissions to the state 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 which emit HAPs. The regulatory approach for HAPs is very different from criteria pollutants. Instead of regulating ambient air concentrations of HAPs, the CAA regulates individual pollutants and the sources that emit HAPs. Each NESHAP contains unique requirements, based on the source type, and each regulation contains specific monitoring, recordkeeping, and reporting requirements. Also, some NESHAPs only apply to sources which are 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.** In order for a source (e.g., military installation) to determine if it is a major source for HAPs, an inventory of HAP emissions must be accomplished.

It 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 even if it later becomes a non-major source (area source) for HAPs. This is known as the "Once In, Always In" (OIAI) policy.

On 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 (POM), xylene and creosol isomers, and the 16 "compounds" on the current HAP list (e.g., antimony compounds, arsenic compounds, beryllium compounds, chromium compounds, cadmium compounds, etc.) in aggregate when determining major source applicability. In other

words, the total emissions of the individual chemicals in these aggregate groups must be less than 10 tpy or the source will be considered major for HAPs.

1.5.3.3 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 potential to emit:

- 10 tpy or more of any HAP <u>or</u> 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" ozone nonattainment areas and in ozone transport regions.
  - 25 tpy of VOC and NO_X emissions in "severe" ozone nonattainment areas.
  - 10 tpy of VOC and NO_X emissions in "extreme" ozone nonattainment areas.
  - 50 tpy of CO emissions in "serious" CO nonattainment areas.
  - 70 tpy of PM_{10} emissions in "serious" PM_{10} nonattainment areas.

In order to determine if an Air Force 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 in an effort to ensure that air quality is not significantly degraded as a result 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 tons per year, **including fugitive emissions**, are regarded as PSD major sources. Sources which do not fall into one of the 28 categories are regarded as PSD major sources if they

emit 250 tons per year, **excluding fugitive emissions**. Typically, at an Air Force installation, the only two sources likely to be on base that falls into one of these categories are fossil fuel boilers greater than 250 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 stringent. 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 in the vicinity of the proposed construction which 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 which does not require PSD or nonattainment NSR permits. These permits contain requirements limiting the emissions to not only avoid PSD and nonattainment NSR, but also 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 emissions inventory 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 alternative.

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 as many as 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 which a previous agency has previously 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 no, 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 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 and the EPA 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 is allowed to 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). Air Force environmental impact analyses of actions outside the United States are to be in accordance with Executive Order (EO) 12114, Environmental Effects Abroad of Major Federal Actions and 32 CFR 187, Environmental Effects Abroad of Major Department of Defense Actions.

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

The purpose of EPCRA is to support emergency planning efforts at the local level by requiring facilities to provide the public with information regarding potentially harmful chemical hazards present in their communities. Under Section 313 of EPCRA, the EPA is required to establish and maintain a Toxic Release Inventory (TRI) which is a database that tracks the management of potentially hazardous chemicals. A facility is required to submit a "Form R" report if it meets the following criteria:

- The facility's six digit primary National American Industry Classification System (NAICS) code is a TRI-covered industry.

- The facility employs 10 or more full-time employees or equivalent. Full-time employee means 2,000 hours per year of full-time equivalent employment (40 CFR 372.3)

- The facility manufactures, processes, or otherwise uses a chemical on the TRI list in excess of the reporting threshold during the year.

The chemicals on the TRI list are continually updated to include chemicals that are known to either cause cancer, or have significant adverse acute human health or environmental effects. The reporting threshold for most of these chemicals is 25,000 lb for those chemicals manufactured or processed and 10,000 lb for those otherwise used. However, in January 2001, the EPA lowered the reporting threshold for Persistent Bioaccumulative Toxic (PBT) chemicals and added other PBT chemicals to the TRI list of toxic chemicals. PBTs are of concern because, not only are they toxic, these chemicals remain in the environment for long periods of time, are not readily destroyed, and can accumulate in body tissue. The lowered thresholds require facilities, including DoD installations, to report the amount of PBT chemicals released into the air, land, and water at much lower levels than previously reported. EPA finalized additional thresholds for PBTs based on their potential to persist and bioaccumulate in the environment. The threshold for the manufacture, process, and otherwise use thresholds for most PBT chemicals is 100 lb, however, a subset of PBT chemicals regarded as highly persistent and highly bioaccumulative are assigned a reporting threshold of 10 lb. Additionally, dioxin and dioxin-like compounds have a reporting threshold of 0.1g.

Though this document does not specifically address all of the chemicals on the TRI list, most of these compounds are also identified as HAPs and an emission factor may be provided. Additional information regarding the TRI program and section 313 of EPCRA is provided by the EPA and 40 CFR 372.

1.5.6 State/Local Programs

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

1.5.7   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 include the following:

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

1.5.7.2 Risk Assessments

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

1.5.7.3 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 which may be used to create surplus emissions which may be traded within a source (e.g., within a facility, plant, installation) or between different sources in order to meet applicable air pollution control requirements. Though the majority of states have emissions trading programs, programs vary from state to state, as well as regionally or locally. In order 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 (NSR), and Title V Operating Permit Programs of the Clean Air Act" (Seitz 1996). This memo established several policies regarding major source determination at military installations. The following is 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 Air Force base, the emissions associated with the National Guard activities would not be counted towards the Air Force base's emissions when making a major source determination for that Air Force 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, an Air Force base is in the process of closing and no

longer needs the use of one of its hangars. The base then leases the hangar to an aircraft manufacturer who uses it only for their own aircraft (no Air Force aircraft). This hangar can therefore be considered to be under separate control from the military entity who owns the installation.

In contrast to leased activities, contract-for-service (or contractor-operated) activities at military installations are usually considered to be under the control of the military entity that 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 which are grouped together have the same two-digit SIC code. Historically, all activities at a military installation have been grouped under SIC code 97, "National Security and International Affairs." However, 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 considered to be 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 <u>not</u> be considered required support facilities. As such, these activities may be treated as separate sources for all purposes for which an industrial grouping distinction is

allowed. Such activities should be separately evaluated for common control, SIC code, and support facility linkages to determine if a major source is present. Many Air Force installations have been successful in "disaggregating" their AAFES gasoline stations resulting in a change to their major source status.

1.7   Emissions Inventory Methodologies

The purpose of this document is to provide a uniform approach to calculating air emissions inventories. This effort is due to the errors which are common to emissions inventories such as missing or duplicate facilities, missing operating or technical data, data entry and transportation 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, emission factors and/or material balance calculations are frequently the best or only method available for estimating emissions, in spite of their limitations. In all cases, managers must analyze the tradeoffs between the cost of the emissions estimates and the quality of the resulting estimates. Where risks of either adverse environmental effects or adverse regulatory outcomes are high, more sophisticated and more costly emission determination methods may be necessary. Though most emission calculation methods presented in this document use either emission factor estimates, material balance calculations, or even available modeling software, they are not meant to suggest these are the only alternatives available.

An emission factor is a representative value that attempts to relate the quantity of a pollutant released with the activity associated with the release of that pollutant. These factors are usually expressed as the weight of pollutant released per a unit weight, volume, distance, or duration of the activity emitting the pollutant. 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.

Many emission factors found in this document were taken from the EPA document *Compilation of Air Pollutant Emission Factors* (AP-42). The emission factors provided in this document are 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 emission factors may be available from other sources, most notably the California Air Resource Board (CARB). If an emission factor 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 emission factors in APIMS are those found in this document. However, alternative emission factors, such as those requested by state and local air regulators, may be used as long as the alternative emission factor is submitted and approved by the air quality Subject Matter Expert (SME). The general equation for emission estimation using an emission factor is:

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

Equation 1-1

Where,

E	=	Emissions
A	=	Activity rate
EF	=	Emission factor
ER	=	Overall emission reduction efficiency (%)

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 time 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 would. In general, material balances are appropriate for use in situations where a high percentage of material is lost to the atmosphere. As the term implies, all the materials going into and coming out of the process must be taken into account to allow an emission estimation to be credible.

1.8   Document Organization

This document is organized into chapters which are specifically related to facilities or processes typically found at Air Force installations. Chapter topics may or may not correspond directly to source types identified in EPA, state, or local guidance documents, but the intent is to consider

sources usually associated with a particular facility/activity/process. This document specifically addresses stationary sources of air emissions. Guidance for addressing mobile or transitory sources of air pollutants may be found in the Air Force Mobile Guide or Air Force Transitory Guide respectively.

1.9 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 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 372, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 372-Toxic Chemical Release Reporting: Community Right-To-Know," U.S. Environmental Protection Agency

40 CFR Chapter V, "Title 40-Protection of the Environment, Chapter V-Council on Environmental Quality," U.S. Environmental Protection Agency

AFI 2007, "Air Force Instruction (AFI) 32-7040," Air Quality Compliance and Resource Management, August 27, 2007

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   ABRASIVE BLASTING (ABCL)

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

2.1 Introduction

Abrasive blasting operations involve the use of a hard, abrasive material (e.g. sand, garnet, glass beads) on 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 Aircraft 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.**

Depending on the coatings (paint and primer) being stripped, the material 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 (i.e., baghouse) to remove particulate. A cyclone may precede the fabric filter 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 ensure the material is not 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 buildings or water towers, and blasting of road surfaces. The location of the operation is important in making the designation between fugitive and point source emissions. **Blasting operations performed indoors (cabinet, booth, hangar) typically employ a non-HVAC industrial ventilation system, and are therefore considered point sources; whereas, 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 given in Figure 2-1.
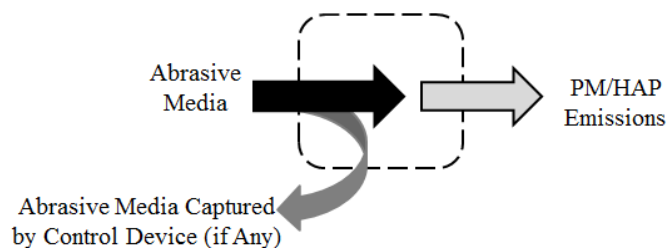
Figure 2-1. Simplified Abrasive Blasting Control Volume

2.2   NESHAP Applicability

Abrasive blasting operations for aerospace vehicles are subject to the National Emission Standards for Hazardous Air Pollutants (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 Air Force Installation adhere to the NESHAP requirements, consult 40 CFR 63 subpart GG.

2.3   Emission Factors

Air emissions from abrasive blasting operations are dependent on the blasting media, wind speed, and emissions control efficiency. Currently, few emission factors have been developed for abrasive blasting, and therefore, emission calculations using mass balances may be a more viable option when determining emissions for abrasive blasting operations. PM emission factors have been developed by AP-42 and the Air Pollution Control District of San Diego County. These emission factors are presented in Table 2-1.

Calculating emission factors for HAPs from abrasive blasting is considerably more difficult because of 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 2-1. PM Emission Factors for Abrasive Blasting

Abrasive Media	Emission Factors (lb/10^3lb Blasting Media)	
	PM_{10}[1]	$PM_{2.5}$[2]
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[2]	0.55
Glass Beads	7.50	6.89
Sand	13.00[3]	1.30
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

1. SOURCE (unless otherwise stated): "Abrasive Blasting," Air Pollution Control District (APCD), County of San Diego, August 1999.
2. 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, October 2006. Value calculated using the PM fractions given in this document.
3. SOURCE: Section 13.2.6-"Abrasive Blasting," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, September 1997.

2.4   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 one type of media may have a significant effect on the total particulate or HAP emissions. In addition to a simple change in the blast media used, however, 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 fabric filter in blast enclosures, vacuum blasters, drapes, water curtains, wet blasting, and reclaim systems. Depending on the type of control system used, the efficiency may range from 50% to over 96% of total particulate matter. 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.

2.5   Emissions Calculation

2.5.1   Calculations Using Mass Balance (Controlled Operations)

Algorithms and Emission Factors (EFs) used by the Air Force are generally from AP-42; however, EFs for Air Force-unique sources have been developed by the Air Force. The only algorithms and

EFs authorized for use in estimating Air Force emissions are those maintained within the Air Program Information Management System (APIMS).

2.5.1.1 PM Emissions

Mass balance emissions calculations for abrasive blasting require 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 may be estimated. Using the total waste material collected (particulate matter) and the control device efficiency, the total particulate matter 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:

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

Equation 2-1

Where,

E_{Pol} = Annual emissions of pollutant (lb/yr)
M_{Tot} = Mass of abrasive media applied. This is estimated in Equation 2-2. (lb/yr)
M_{Col} = Mass of waste material collected by the fabric filter (lb/yr)
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 2-2.

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

Equation 2-2

Where,

CE   = Efficiency of control device (%)
100   = Factor for converting a percent to a fraction (%)

2.5.1.2 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 fabric filter. The chemical analysis of the waste material is typically accomplished by the Toxicity Characteristic Leaching Procedure (TCLP). The results of the total constituent analysis are typically provided in units of 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 2-1. A more detailed control volume describing the calculation of emissions from abrasive blasting is given in Figure 2-2 below.
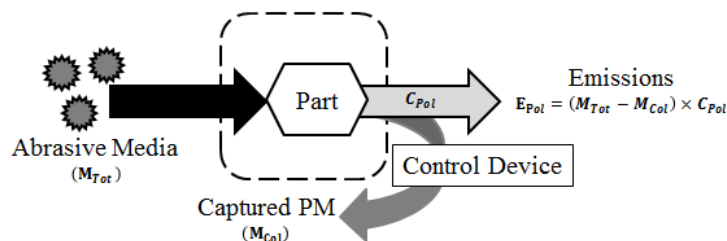
Figure 2-2. Abrasive Blasting Control Volume – Mass Balance Method

2.5.2   Calculations Using Emission Factors (Controlled or Uncontrolled Operations)

2.5.2.1   PM Emissions

As an alternative to the above method, emissions from both controlled and uncontrolled abrasive blasting operations may be calculated by using emission factors. If the emission factor is available, the emissions from an abrasive blasting operation may be estimated by simply multiplying the emission factor 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 2-3

Where,

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)

A more detailed control volume describing the calculation of emissions from abrasive blasting is given in Figure 2-3 below.
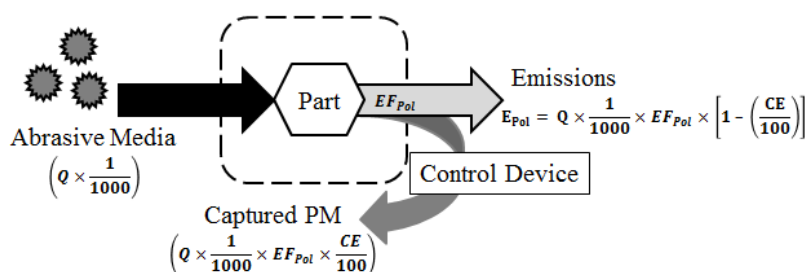
Figure 2-3. Abrasive Blasting Control Volume - Emission Factor Method

2.6 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 Civil Engineering). Information about the amount of abrasive blasting waste disposed off-site as hazardous waste, and the required chemical analysis of the waste for disposal may be available from the hazardous waste section of the Civil Engineering Environmental Quality Flight (CEV). Additionally, information regarding the NESHAP requirements specific to aerospace vehicles may be found in 40 CFR 63 subpart GG.

2.7 Example Problems

2.7.1 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 3,275.0 pounds of waste material was collected by the baghouse and disposed. Based on information supplied by the baghouse manufacturer, the estimated control efficiency of the baghouse for this material is 96%. A review of the Safety Data Sheets (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 content is 940 mg/kg. Calculate both the PM_{10} and chromium emissions.

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

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

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 2-2:

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

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

Step 3 – Calculate emissions. Use Equation 2-1 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}:

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

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

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

For Chromium:

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

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

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

2.7.2   Problem # 2 – Emission Factor Method

Base Civil Engineering used approximately 6,500 pounds of sand during the year to perform abrasive blasting on various parts in a blasting booth. Calculate the annual PM_{10} emissions assuming a fabric filter with 92% control efficiency is used.

Step 1 - Select and record the appropriate emission factor. Table 2-1 lists it as **12.50lb/10³lb**.

Step 2 – Determine PM₁₀ emissions. Use Equation 2-3 to determine the PM_{10} emissions:

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

$$E_{PM_{10}} = 6{,}500\frac{lb}{yr} \times \frac{1}{1000}\frac{10^3 lb}{lb} \times 12.50\frac{lb}{10^3\ lb} \times \left[1 - \left(\frac{92\%}{100\%}\right)\right]$$

$$E_{PM_{10}} = 6{,}500\frac{lb}{yr} \times \frac{1}{1000}\frac{10^3 lb}{lb} \times 12.50\frac{lb}{10^3\ lb} \times [1 - (0.92)]$$

$$E_{PM_{10}} = 6{,}500\,\frac{lb}{yr} \times \frac{1}{1000}\,\frac{10^3 lb}{lb} \times 12.50\,\frac{lb}{10^3\,lb} \times [0.08]$$

$$E_{PM_{10}} = 81.25\,\frac{lb}{yr} \times [0.08]$$

$$\boxed{E_{PM_{10}} = 6.50\,\frac{lb}{yr}}$$

2.8 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

APCD 1999, "Abrasive Blasting," Air Pollution Control District (APCD), County of San Diego, August 1999

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 1997, Section 13.2.6-"Abrasive Blasting," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, September 1997

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3   AIRCRAFT AND RUNWAY DEICING OPERATIONS (DICE) – NOT A STATIONARY SOURCE

> *Neither point nor fugitive source*

Not included in an Air Force AEI

3.1   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 water and propylene glycol (a.k.a. 1, 2-propanediol) or ethylene glycol. Though ethylene glycol is considered both a volatile organic compound (VOC) and a hazardous air pollutant (HAP), **the emissions from aircraft and runway deicing operations <u>are below de minimis levels</u>. DO NOT calculate air emissions from aircraft and runway deicing operations.**

3.2   Insignificant Source

Deicing operations are an environmental concern due to the components of common fluids applied; however, the concerns should be in regards to 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.

$$P = e^{(C_1+\frac{C_2}{T}+C_3\times \ln(T)+C_4\times T^{C_5})}$$

Where,

P   =   Vapor Pressure (Pa)
C_1-C_5 =   Equation constants specific to each chemical. These are provided in Table 3-1.
T   =   Temperature (°K)

Equation constants for ethylene glycol and propylene glycol are provided in Table 3-1.

Table 3-1. Equation Constants for Expanded Antoine Equation

Compound	C_1	C_2	C_3	C_4	C_5
Ethylene Glycol	79.276	-10105	-7.521	7.3408E-19	6
Propylene Glycol	212.8	-15420	-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 3-1.
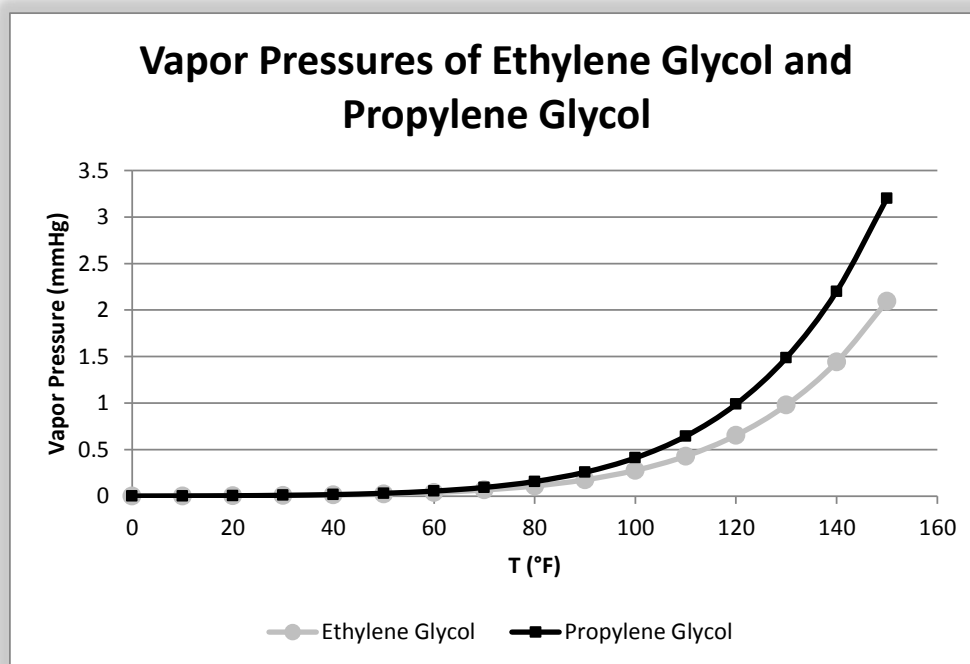
Figure 3-1. Vapor Pressures of Ethylene Glycol and Propylene Glycol

Previous documentation regarding air emissions from deicing operations made the assumption that 100% 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.

3.3 References

Green 1997, Green, Don W. and Robert H. Perry, "Perry's Chemical Engineers' Handbook: Seventh Edition," 1997

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 Air Force 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. This 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 it must be considered a mobile 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 ensure proper designation prior to performing an air emission inventory. **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.
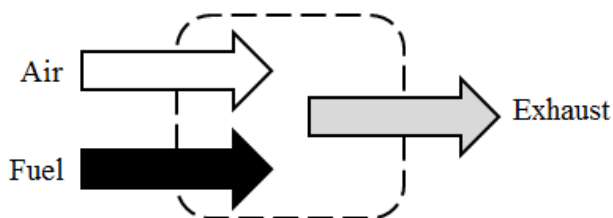
Figure 4-1. Simplified Aircraft Engine Testing Control Volume

4.2   NESHAP Applicability

National emission standards for hazardous air pollutants (NESHAP) 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

Emission factors for the calculation of emissions from aircraft engine testing have been calculated and may be obtained from the Mobile Source Guide. It is important to understand the differences in flight operations and engine testing so that the correct emission factor may be selected from the tables in the Mobile Guide. 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, fuel flow rate, and an emission factor 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 emission factors 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 for the power settings given are representative of that power setting, though a range of values are actually acceptable. For calculating emissions from jet engine testing, the flight mode may not apply. Rather, testing occurs across varying fuel flow rates which may be used to select the appropriate emission factors. Most likely, the fuel flow rate at which the engine is testing will not equal the fuel flow rate given in the table. In these cases, the nearest fuel flow rates' corresponding power setting and emission factors should be used.

4.4   Emissions Calculation

Algorithms and emission factors (EFs) used by the Air Force are generally from AP-42; however, EFs for Air Force-unique sources have been developed by the Air Force. The only algorithms and EFs authorized for use in estimating Air Force emissions are those maintained within the Air Program Information Management System (APIMS).

Emissions from the testing of a particular 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 emission factor by the actual fuel flow rate and 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:

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

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 Mobile Guide (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.
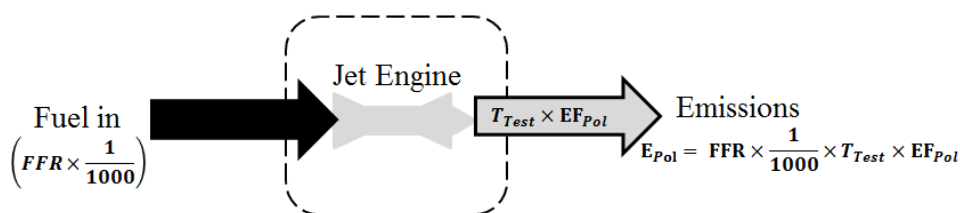
Figure 4-2. Aircraft Engine Testing Control Volume

The tables in the mobile guide provide SO_x emission factors 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 emission factors given in the tables assume a national average sulfur weight percent of 0.053%. For enhanced accuracy, if the sulfur weight percent of the fuel is known, a more accurate SO_x emission factor 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 sulfur dioxide 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 *Air Emissions Guide for Air Force Mobile Sources*. The Mobile Guide 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. Emission factors may then be found in the *Air Emissions Guide for Air Force Mobile Sources, 2014*.

4.6 Example Problem

An Air Force 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 Maintenance organization, 108 engine tests were performed during the year. Each test used JP-8 with an average sulfur content of 0.055%. 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
1333	30
2801	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:

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

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

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

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

Step 2 – Calculate the SO$_X$ emission factor. The problem stated that the average sulfur weight percent in the fuel was 0.055% which is different than the national average of 0.053%. Therefore, the SO$_X$ emission factor must be calculated using Equation 4-2:

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

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

Step 3 - Determine the appropriate emission factor to be used for each fuel flow rate. The emission factors (excluding SO$_X$) from the Air Emissions Guide for Air Force Mobile Sources (AFCEC, 2014) are as follows:

Aircraft Engine	Fuel Flow Rate(lb/hr)	Power Setting	Emission Factors (lb/1000lb fuel)						
			NO$_x$	CO	VOC	HAP	PM$_{10}$	PM$_{2.5}$	GHG
TF34-GE-100A	498	Idle (Taxi)	0.32	65.62	2.24	2.052	8.13	3.60	3255.41
	933	Approach	3.09	27.92	1.44	1.371	6.21	2.12	3255.41
	1512	Intermediate	5.61	8.88	0.13	0.095	8.93	6.95	3255.41
	2628	Military	9.11	3.94	0.07	0.098	2.66	1.68	3255.41

Comparing the fuel flow rates (FFR) from testing to those provided in the Mobile Guide, the appropriate emission factors to use in emissions calculations are given below:

FFR from testing (lb/hr)	Nearest FFR in Guide (lb/hr)	Emission Factors (lb/1000lb fuel)							
		NO$_x$	SO$_x$	CO	VOC	HAP	PM$_{10}$	PM$_{2.5}$	GHG
685	498	0.32	1.10	65.62	2.24	2.052	8.13	3.60	3255.41
915	933	3.09	1.10	27.92	1.44	1.371	6.21	2.12	3255.41
1333	1512	5.61	1.10	8.88	0.13	0.095	8.93	6.95	3255.41
2801	2628	9.11	1.10	3.94	0.07	0.098	2.66	1.68	3255.41

Step 4 - Calculate emission factors. Using Equation 4-1, the appropriate emission factors, 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$_X$:

$$E_{NO_X-685\frac{lb}{hr}} = 685\,\frac{lb}{hr} \times \frac{1}{1000}\,\frac{10^3 lb}{lb} \times 27\,\frac{hr}{yr} \times 0.32\,\frac{lb}{10^3 lb} = \mathbf{5.92}\,\frac{lb}{yr}$$

$$E_{NO_X-915\frac{lb}{hr}} = 915\,\frac{lb}{hr} \times \frac{1}{1000}\,\frac{10^3 lb}{lb} \times 72\,\frac{hr}{yr} \times 3.09\,\frac{lb}{10^3 lb} = \mathbf{203.6}\,\frac{lb}{yr}$$

$$E_{NO_X-1333\frac{lb}{hr}} = 1333\,\frac{lb}{hr} \times \frac{1}{1000}\,\frac{10^3 lb}{lb} \times 54\,\frac{hr}{yr} \times 5.61\,\frac{lb}{10^3 lb} = \mathbf{403.8}\,\frac{lb}{yr}$$

$$E_{NO_X-2801\frac{lb}{hr}} = 2801\,\frac{lb}{hr} \times \frac{1}{1000}\,\frac{10^3 lb}{lb} \times 27\,\frac{hr}{yr} \times 9.11\,\frac{lb}{10^3 lb} = \mathbf{689.0}\,\frac{lb}{yr}$$

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's	PM$_{10}$	PM$_{2.5}$	GHG
685	5.9	20.3	1213.6	41.4	38.0	150.4	66.6	60208.8
915	203.6	72.5	1839.4	94.9	90.3	409.1	139.7	214466.4
1333	403.8	79.2	639.2	9.4	6.8	642.8	500.3	234330.9
2801	689.0	83.2	298.0	5.3	7.4	201.2	127.1	246196.9

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$_X$:

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

$$\boxed{E_{NO_X} = \mathbf{1302.3}\,\frac{lb}{yr}}$$

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's	PM$_{10}$	PM$_{2.5}$	GHG
TF34-GE-100A	1302.3	255.2	3990.2	151.0	142.5	1403.5	833.7	755203.0

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 2014, "Air Emissions Guide for the Air Force Mobile Sources," Air Force Civil Engineer Center, Compliance Technical Support Branch, October 2014

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   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 it is not included in an AEI. However, if the regulator insists this category be included as a stationary source, contact the Air Force air quality Subject Matter Expert (SME) for permission/guidance on emissions calculations

5.1   Introduction

Most Air Force Base 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 and the use of cutback asphalt is decreasing for this reason. 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-locating and used at another site.

Typically, transitory emissions are not included in annual stationary or mobile air emissions inventories (AEIs). Transitory sources are ONLY included in AEIs if they become no longer 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 continuously 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 is being moved to the Air Force Transitory Guide.

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6   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

6.1   Introduction

Due to the nature of their operation, a wide variety of parts and equipment found at Air Force 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 coatings that may be performed at an Air Force base including electroplating (both hard and decorative), chromic acid anodizing, and thermal metal spraying. **Depending on whether or not 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 particulate matter emissions.** A graphic representation describing emissions from these processes is given in Figure 6-1.
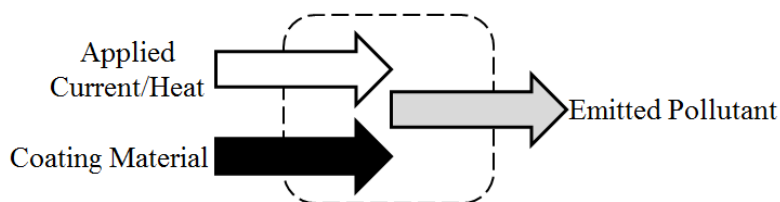
Figure 6-1. Simplified Corrosion Control Coatings Control Volume

6.1.1   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 which contains the metal ions that will coat the part. A source of the metal ion may be added to the bath to replenish the metal ions in the electrolyte solution. 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 particulate matter (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 plating efficiency of the cathode 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 themselves pose an environmental threat since they are classified as hazardous air pollutants 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 for the purpose of producing a bright surface with wear and tarnish resistance. Hexavalent chromium, 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 hexavalent chromium, because of lower operating costs and fewer environmental concerns. However, trivalent chromium is more sensitive to contamination than hexavalent chromium, and does not provide the full range of coating thicknesses that hexavalent chromium provides.

6.1.2   Chromic Acid Anodizing

Chromic acid anodizing is commonly used on aluminum aircraft parts which 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 A/ft^2. The chromic acid anodizing process produces PM emissions made up entirely of chromic acid mist.

6.1.3   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 simply for aesthetics. The coating material used in thermal metal spraying may originally be in the form of a powder, rod, or wire which is heated and deposited in a molten or semi-molten condition onto the part being treated. Emissions of concern from thermal metal spraying are particulate matter (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 which combusts spray gas such as oxygen 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.

6.2 NESHAP Applicability

The use of HAPs as coating material for corrosion control processes has given rise to several National Emission Standards for Hazardous Air Pollutants (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 area 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 is in compliance with the standards outlined in these sections.

6.3 Emission Factors

Emissions from electroplating operations are dependent on the metal used in the process. Emission factors have been developed for chromium electroplating processes and are presented in Table 6-1. If the electroplating shop performs electroplating operations using metals other than chromium, the appropriate emission factors should be selected from chapter 12.20 of AP-42.

Unlike the emission factors for chromium electroplating, the emission factors for chromic acid anodizing operations are in units of $lb/10^3hr\text{-}ft^2$. This is because the emission factors are dependent on the tank surface area. The emission factors for chromic acid anodizing are listed in Table 6-2.

In 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, emission factors for thermal metal spraying using nickel and chromium have been developed for each of the more common application methods. These emission factors are in units of lb HAP/lb coating sprayed and are provided in Table 6-3. Note that an emission factor for hexavalent chromium is given, and not for total chromium. Other common materials applied using thermal metal spraying includes cadmium, lead, and manganese; however, emission factors are not known to have been developed for these metals.

Table 6-1. Chromium and PM Emission Factors for Chromium Electroplating

Process	Control Type[1]	Emission Factors (lb/10^3 A-hr)		
		Chromium	PM_{10}[2]	$PM_{2.5}$[2]
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

1. 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.

2. Original source lists emission factors for total PM. Assumption is that total PM = PM_{10} = $PM_{2.5}$.

Table 6-2. Chromium and PM Emission Factors for Chromic Acid Anodizing

Control Type[1]	Emission Factor (lb/10^3 hr-ft^2)		
	Chromium	PM$_{10}$[2]	PM$_{2.5}$[2]
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

1. 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.

2. Original source lists emission factors for PM. Assumption is that PM = PM$_{10}$ = PM$_{2.5}$.

Table 6-3. 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

"---" – Indicates No Data Available

6.4   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 hexavalent

chromium. 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, which 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 which are often employed. Fume suppressants may be subdivided into two categories; those which suppress surface misting and 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. Any change in the process for thermal metal spraying could potentially reduce the amount of emissions, but may not be feasible. Most likely the majority of any emission reduction 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.

6.5   Emissions Calculation

Algorithms and Emission Factors (EFs) used by the Air Force are generally from AP-42; however, EFs for Air Force-unique sources have been developed by the Air Force. The only algorithms and EFs authorized for use in estimating Air Force emissions are those maintained within the Air Program Information Management System (APIMS).

6.5.1   Electroplating

To calculate emissions from hard and decorative chromium electroplating operations, the total annual energy input (A-hr) is multiplied by the appropriate emission factor, as shown in Equation 6-1.

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

Equation 6-1

Where,

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)
EF_{Pol}	=	Emission factor (lb/10^3A-hr)

A detailed control volume depicting emissions from electroplating is provided in Figure 6-2.
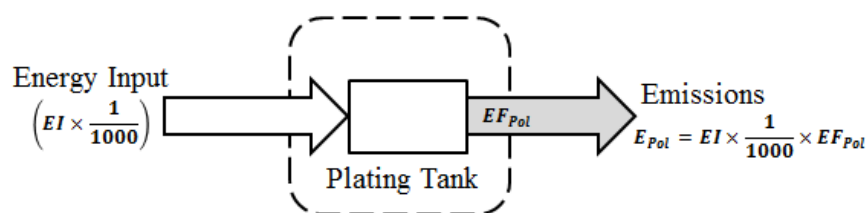
Figure 6-2. Electroplating Control Volume

6.5.2 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 are then multiplied by the appropriate emission factor, as shown in Equation 6-2.

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

Equation 6-2

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 6-3.
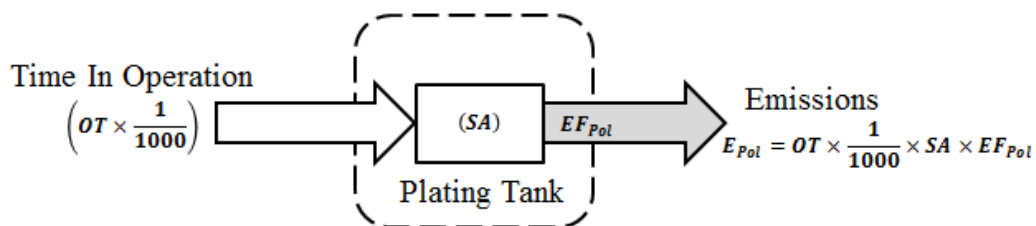
Figure 6-3. Chromic Acid Anodizing Control Volume

6.5.3 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 employs the use of emission factors for emissions calculations. The two methods are described below.

6.5.3.1 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 associated with each process. Transfer efficiency refers to the fraction of coating solids which adhere to the part surface. Overspray refers to those solids which are applied that 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 estimations 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, but if this information is unavailable a conservative assumption of 0% fallout may be made. Calculation is performed as follows:

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

Equation 6-3

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 6-4.
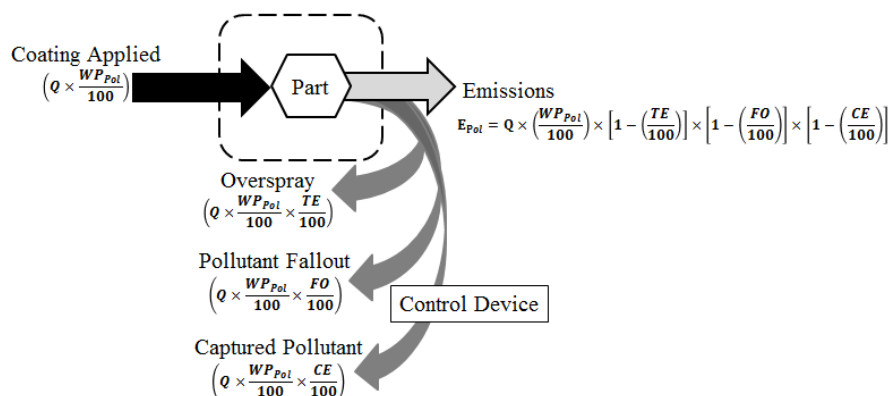
Figure 6-4. Thermal Metal Spraying Control Volume – Mass Balance Method

Note that if the fallout fraction is unknown, but the quantity of overspray recovered is known, then Equation 6-3 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 6-4

Where,

$\mathbf{Q_S}$ = Quantity of coating applied (lb/yr)

$\mathbf{Q_R}$ = 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 HAP may be determined using Equation 6-5.

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

Equation 6-5

Where,

$\mathbf{WP_{HAP}}$ = Weight percent of the specific HAP in the coating (%)

$\mathbf{MW_{HAP}}$ = Molecular weight of HAP in the coating compound (g)

$\mathbf{MW_{Cmpd}}$ = Molecular weight of the HAP containing compound (g)

$\mathbf{WP_{Cmpd}}$ = Weight percent of the HAP containing compound in the coating (%)

6.5.3.2 Emission Factor Method

The emission factor 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 emission factors, the particulate matter (PM) emission factors for thermal spraying have not been developed directly for total PM, but rather, for speciation of HAPs within PM. Emission factors have been calculated to determine chromium, hexavalent chromium, and nickel emissions and are provided in Table 6-3. Emissions calculation using the emission factor 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 6-6

Where,

EF_{Pol} = Pollutant emission factor (lb/lb)

A more detailed control volume for thermal spraying using emission factors is given in Figure 6-5.
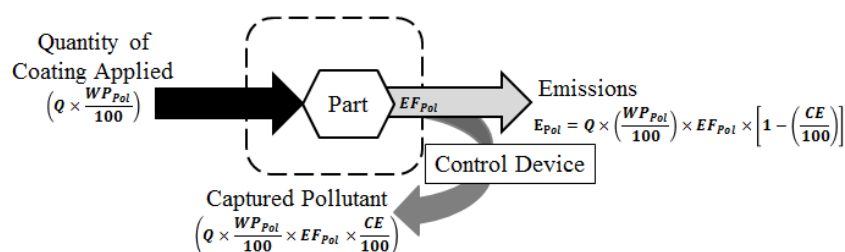
Figure 6-5. Thermal Metal Spraying Control Volume - Speciated Inorganic HAP Emission Factor Method

6.6 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 or EESOH-MIS. Information may also be obtained from the product literature (e.g. SDS, container label, and technical specification sheets). If necessary, Bioenvironmental Engineering 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, 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, so the manufacturer may need to know this information regarding the typical pieces being treated in order 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 so desired, a conservative emission calculation is possible by assuming this value to be equal to zero.

6.7 Example Problems

6.7.1 Problem #1 (Electroplating and Chromic Acid Anodizing)

Anytown AFB 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. Emission factors for electroplating and chromic acid anodizing may be found in Table 6-1 and Table 6-2 respectively. For shop A, the emission factor is **6.00E-03lb/10^3 A-hr** and for shop B, the emission factor is **9.14E-03lb/10^3 hr-ft^2**.

Step 2 – Calculate chromium emissions for shop A. Using the data given in the problem statement, the emission factors recorded in Step 1, and Equation 6-1, the chromium emissions are calculated as follows:

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

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

Step 3 - Determine the chromium emissions from Shop B. Using the data given in the problem statement, the emission factors recorded in Step 1, and Equation 6-2, the chromium emissions are calculated as follows:

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

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

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

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

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

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

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

Anytown AFB is interested in determining the amount of hexavalent chromium 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 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% chromium oxide (Cr_2O_3) by weight. Assuming that the HEPA filter has an efficiency of 99%, calculate the amount of hexavalent chromium emitted the previous year.

Step 1 – 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 6-5 as follows:

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

$$WP_{Cr} = \frac{(52 \times 2)\frac{g}{mol}}{[(52 \times 2) + (16 \times 3)]\frac{g}{mol}} \times 95\%$$

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

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

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

Step 3 – Calculate Cr^{+6} emissions. Using the control efficiency and the quantity of the coating applied as given in the problem statement, plus the emission factors recorded in step 3, the emissions of hexavalent chromium for each booth may be calculated using Equation 6-6.

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

For Booth #1:

For Powder A:

$$E_{Cr^{+6}} = 25\frac{lb}{yr} \times \left(\frac{25\%}{100\%}\right) \times 0.018\frac{lb\ Cr^{+6}}{lb\ Cr} \times \left[1 - \left(\frac{99\%}{100\%}\right)\right]$$

$$E_{Cr^{+6}} = 25\frac{lb}{yr} \times 0.25 \times 0.018\frac{lb\ Cr^{+6}}{lb\ Cr} \times [1 - (0.99)]$$

$$E_{Cr^{+6}} = 25\frac{lb}{yr} \times 0.25 \times 0.018\frac{lb\ Cr^{+6}}{lb\ Cr} \times [0.01]$$

$$\boldsymbol{E_{Cr^{+6}} = 6.25\frac{lb}{yr} \times 0.018\frac{lb\ Cr^{+6}}{lb\ Cr} \times [0.01] = 1.13E - 03\frac{lb}{yr}}$$

For Powder B:

$$E_{Cr^{+6}} = 15\frac{lb}{yr} \times \left(\frac{65\%}{100\%}\right) \times 0.018\frac{lb\ Cr^{+6}}{lb\ Cr} \times \left[1 - \left(\frac{99\%}{100\%}\right)\right]$$

$$E_{Cr^{+6}} = 15\frac{lb}{yr} \times \left(\frac{65\%}{100\%}\right) \times 0.018\frac{lb\ Cr^{+6}}{lb\ Cr} \times [1 - (0.99)]$$

$$E_{Cr^{+6}} = 15\frac{lb}{yr} \times 0.65 \times 0.018\frac{lb\ Cr^{+6}}{lb\ Cr} \times [0.01]$$

$$\boldsymbol{E_{Cr^{+6}} = 9.75\frac{lb}{yr} \times 0.018\frac{lb\ Cr^{+6}}{lb\ Cr} \times [0.01] = 1.76E - 03\frac{lb}{yr}}$$

For Booth #2:

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

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

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

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

Step 4 – **Calculate total Cr^{+6} emissions.** The total emissions are the sum of the Cr^{+6} from each coating in both booths.

$$E_{Cr^{+6}} = (0.00113 + 0.00176 + 0.000465)\frac{lb}{yr}$$

$$\boxed{\boldsymbol{E_{Cr^{+6}} = 3.36E - 03}\frac{lb}{yr}}$$

6.8 Resources

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

7 DRY CLEANING (CLN)

> ➢ *Point Source*

7.1 Introduction

Most Air Force Base 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, some installations perform dry cleaning on-base. At these locations, the emissions from the dry cleaning process must be included in an AEI.

Dry cleaning involves the cleaning of fabrics (e.g., garments, draperies, leather goods) with a variety of different solvents. As the industry has evolved, so has the process, and alternative 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 (e.g., perchloroethylene).

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, so their use is limited to transfer machines where the solvent concentration in vapors does not build to high levels. Additionally, the use of liquid CO_2 is becoming more popular as it is recycled from industrial and manufacturing processes. While there are new technologies emerging, the most common type of solvent is a synthetic, halogenated hydrocarbon known as perchloroethylene.

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/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 Air Force installation**. In the dry-to-dry process, both washing and drying take place in one machine. This machine may either be vented or vent-less, and emissions occur only during loading and unloading.

The dry cleaning industry can be divided into three sectors: coin-operated facilities, commercial operations, and industrial cleaners. Coin-operated dry cleaning units are self-service machines that are usually found in Laundromats. Coin operated units usually have a capacity of 8 to 25

pounds of clothes per load. Commercial dry cleaners are typically independent small businesses that offer dry cleaning services to the public. Most commercial dry cleaning units are dry-to-dry and have an average capacity of 35 pounds, with a range of 15 to 97 pounds per load. Businesses which provide uniforms and/or clothing rentals which result in soiled fabrics often have industrial cleaners that use dry cleaning solvents. The average capacity of industrial dry cleaners is 140 pounds per load for dry-to-dry units and 250 pounds per load for transfer units.

Due to the increase in air quality regulations and the high cost of synthetic halogenated solvents, most dry cleaning machines are equipped with control devices that capture/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, which is required under the EPA's 2008 Final Rule for all sources.

The two primary types of control devices used on dry cleaning machines are refrigerated condensers and carbon adsorbers. After separating out the water, the solvent captured by a refrigerated condenser is placed back into the pure solvent supply tank. In order to recover/reclaim the solvent collected by a carbon adsorber, it must be desorbed off the carbon adsorption material (usually accomplished using steam). Desorbed solvent and water are then condensed and separated. Reclaiming solvent captured via carbon adsorption can be accomplished either on- or off-site. If done on-site, the solvent is placed back into the pure solvent supply tank. Control devices of this nature are required to be installed in all new dry cleaning machines. NESHAP and the 2008 Final Rule requirements for dry cleaning require leak detection and seal inspection programs, monitoring and reporting programs, and some form of control device, such as the use of refrigerated condensers or carbon adsorbers. **Dry cleaning facilities and equipment are considered point sources** and a simple control diagram for these operations is given in Figure 7-1.
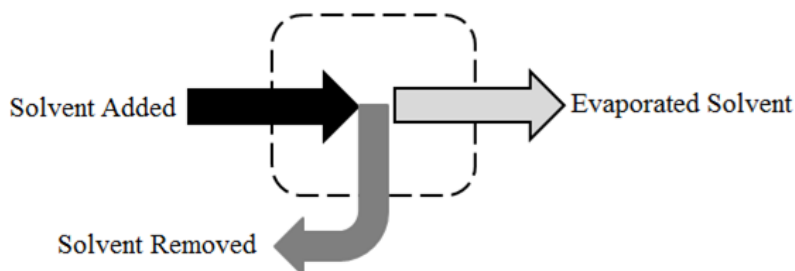
Figure 7-1. Simplified Control Volume for Emissions from Dry Cleaning

7.2   NSPS and NESHAP Applicability

The EPA has established New Source Performance Standards (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 cartridge installed at a petroleum dry cleaning plant after this date must be a cartridge filter.   Additional 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, dry cleaning facilities that use perchloroethylene 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 and operation of dry cleaning machines which use perchloroethylene.   Note that this standard also states that each dry cleaning facility 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 is in compliance with the standards outlined in this NESHAP, refer to 40 CFR 63 subpart M.

7.3   Emission Factors

Chapter 4, Section 1, of AP-42 provides emission factors from dry cleaning processes. However, the emission factors 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, calculation of emissions from dry cleaning should be performed using a mass balance approach rather than an emission factor approach. This calculation method is described in Section 7.4.

7.4   Emissions Calculation

Algorithms and Emission Factors (EFs) used by the Air Force are generally from AP-42; however, EFs for Air Force-unique sources have been developed by the Air Force. The only algorithms and EFs authorized for use in estimating Air Force emissions are those maintained within the Air Program Information Management System (APIMS).   The primary method of calculating emissions from dry cleaning is to use a mass balance approach. Emissions calculations using a mass balance approach are performed as follows:

$$\mathbf{E_{Solvent}} = [(\mathbf{V_{FS}} - \mathbf{V_{WS}}) - \mathbf{V_{CS}}] \times \mathbf{D}$$

Equation 7-1

Where,

$E_{Solvent}$ = Annual emissions of solvent (lb/yr)

V_{FS} = Volume of fresh solvent added to the dry cleaning process (gal/yr)

V_{WS} = Volume of waste solvent removed from the process (gal/yr)

D = Density of solvent (lb/gal)

V_{CS} = Volume of solvent which is captured via carbon adsorption and <u>not</u> reintroduced back into the process (gal/yr) (Note: May be a VOC or HAP depending on the solvent used)

If captured solvent is <u>not</u> recovered (desorbed) on-site and reintroduced into the process, then the quantity captured by the carbon adsorber must also be subtracted from the total amount of fresh solvent added to the process (i.e., V_{CS} is the total volume of solvent captured by the carbon adsorber). A more detailed diagram of the emissions resulting from dry cleaning is given in Figure 7-2.
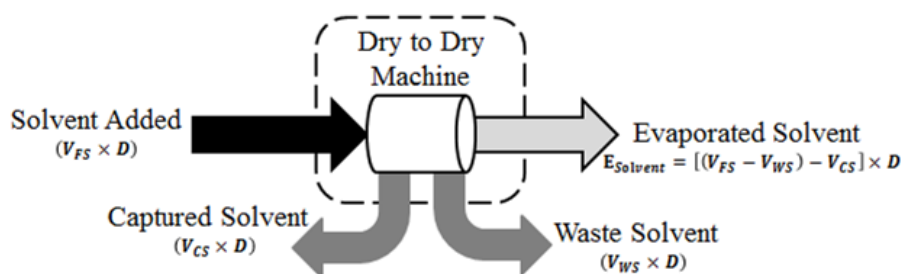
Figure 7-2. Detailed Control Volume for Emissions from Dry Cleaning

7.5 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, though that information 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.

7.6 Example Problem

A dry cleaning facility has a single dry-to-dry machine that uses perchloroethylene (PERC). A total of 250 gal of fresh perchloroethylene 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 perchloroethylene was captured by the carbon adsorption material during

the year and shipped off-site for reclamation. Calculate the perchloroethylene emissions using the mass balance method described above. [Note: Density of perchloroethylene is **13.5 lb/gal**]

Step 1 – Use the data above to calculate emissions from dry cleaning processes. The problem states that the volume of PERC added (V_{FS}) was 250gal, the amount removed (V_{WS}) was 200gal, and the volume recovered (V_{CS}) was 25gal. Use this data and Equation 7-1 to determine total emissions.

$$E_{Solvent} = [(V_{FS} - V_{WS}) - V_{CS}] \times D$$

$$E_{PERC} = \left[\left(250\frac{gal}{yr} - 200\frac{gal}{yr}\right) - 25\frac{gal}{yr}\right] \times 13.5\frac{lb}{gal}$$

$$E_{PERC} = \left[\left(50\frac{gal}{yr}\right) - 25\frac{gal}{yr}\right] \times 13.5\frac{lb}{gal}$$

$$E_{PERC} = \left[25\frac{\cancel{gal}}{yr}\right] \times 13.5\frac{lb}{\cancel{gal}}$$

$$\boxed{E_{PERC} = 337.5\ \frac{lb}{yr}}$$

7.7   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

8   ELECTRONIC TRANSMISSIONS (ELEC)

ONLY FOR MANDATORY GHG REPORTING IF REQUIRED TO REPORT
  ➢ *Fugitive Source*

8.1   Introduction

Air Force 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 in order to prevent electrical discharges and arcing from occurring and 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 is the most common gas used to insulate equipment. Electric power facilities constitute over 80% of SF_6 used in the United States, and currently there are no viable alternatives to SF_6 over significant distances. Other gases, such as perfluorocarbons, are sometimes used either pure or mixed with SF_6 to decrease the cost of using pure SF_6. Selected global warming potentials (GWPs) of common gases used in electric power facilities are given in Table 8-1.

Table 8-1. Selected Global Warming Potentials of Common Dielectric Gases

Pollutant	GWP
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% emitted into the atmosphere. **Note that this chapter only applies to Air Force**

installations with mandatory GHG reporting facilities. A graphic representation of the emissions from electronic transmission is provided in Figure 8-1.
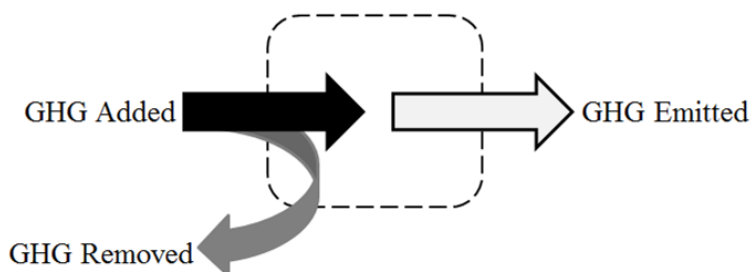
Figure 8-1. Simplified Electronic Transmission Control Volume

8.2   Greenhouse Gas Mandatory Reporting Rule

The EPA has established mandatory greenhouse gas reporting requirements for owners and operators of facilities that directly emit greenhouse gases into the atmosphere. According to 40 CFR 98.2, any facility which operates electrical transmission and distribution equipment using SF_6 and PFC with a total nameplate capacity exceeding 17,820 pounds is 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:

- Nameplate capacity of equipment containing SF_6 and each PFC.
- Transmission miles.
- Distribution miles.
- Pounds of SF_6 and PFC stored in containers and <u>not</u> 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 ±2lbs and periodically calibrated per manufacturer specifications. To verify that the facility is in compliance with the reporting requirements stipulated by the EPA, refer to 40 CFR 98 subpart DD for additional information.

8.3 Emissions Calculation

Greenhouse gas emissions from electronic transmission and distribution are performed using a mass balance approach. Emissions calculations require the net difference in nameplate capacity to be known and can be found by subtracting the nameplate capacity of any retiring equipment from the nameplate capacity of new equipment added to inventory. Note that the nameplate capacity is specific for each particular gas.

$$NC_D = NC_N - NC_R$$

Equation 8-1

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 8-2

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 greenhouse gas using electronic transmission and distribution equipment is provided in Figure 8-2.
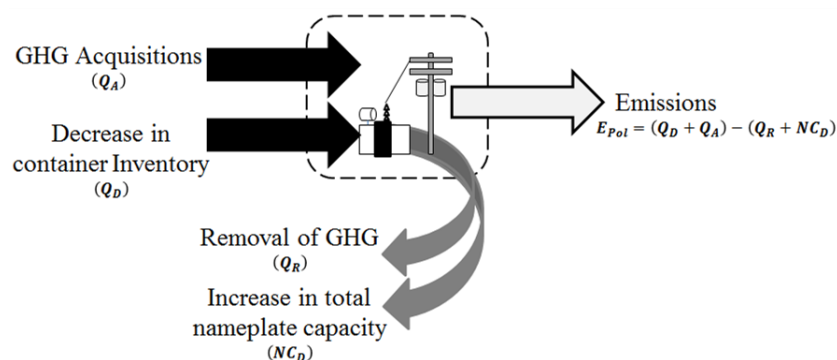
Figure 8-2. Electronic Transmission Control Volume

The emissions of greenhouse gases in 100-year CO_2e are then calculated by multiplying the annual emissions of the pollutant from Equation 8-2 by their respective GWP from Table 8-1, 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 8-3

Where,

E_{GHG} = Annual GHG emissions in CO_2e (lb/yr)

E_{Pol} = Annual emissions of either SF_6 or PFCs (lb/yr)

GWP_{Pol} = 100-year GWP of selected GHG in CO_2e. This is provided in Table 8-1.

8.4 Information Resources

All information required for calculating emissions from electronic transmission facilities, including nameplate capacity, volume of gas in storage, volume of gas acquired, volume of gas disposed, and if applicable, any gas mixtures, can be obtained through base Civil Engineering. GWPs of applicable GHGs can be found in 40 CFR 98 Subpart A.

8.5 Example Problem

Anytown AFB is mandated to calculate greenhouse gas emissions from the electric power facility on site. Base Civil Engineering was contacted, and reports the total nameplate capacity 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 greenhouse gas emissions from the operation of electrical transmission equipment for this facility.

Step 1 - 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 nameplate capacity increased to **11,800 lb** from **11,500 lbs**. Also, according to Table 8-1, the GWP of SF_6 is **22,800**.

Step 2 - Calculate the net increase in total nameplate capacity. Using the data recorded in Step 1 and Equation 8-1, the net increase in total nameplate capacity is calculated as follows:

$$NC_D = NC_N - NC_R$$

$$\mathbf{NC_D} = 11{,}800 \frac{lb}{yr} - 11{,}500 \frac{lb}{yr} = \mathbf{300 \frac{lb}{yr}}$$

Step 3 - Calculate the annual emissions of SF_6. Using the data given in Step 1 and Equation 8-2, the annual emissions of SF_6 are calculated as follows:

$$E_{Pol} = (Q_D + Q_A) - (Q_R + NC_D)$$

$$E_{SF_6} = \left(50 \frac{lb}{yr} + 460 \frac{lb}{yr}\right) - \left(40 \frac{lb}{yr} + 300 \frac{lb}{yr}\right)$$

$$\mathbf{E_{SF_6}} = \left(510 \frac{lb}{yr}\right) - \left(340 \frac{lb}{yr}\right) = \mathbf{170 \frac{lb}{yr}}$$

Step 4 - 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 8-3 as follows:

$$E(CO_2e)_{GHG} = \sum_{i=1}^{n}\left(E_{Pol_i} \times GWP_{Pol_i} + \cdots + E_{Pol_n} \times GWP_{Pol_n}\right)$$

$$E(CO_2e)_{GHG} = 170 \frac{lb}{yr} \times 22800$$

$$\boxed{\mathbf{E(CO_2e)_{GHG}} = \mathbf{3{,}876{,}000 \frac{lb}{yr}}}$$

8.6 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

9   EQUIPMENT LEAKS (SPRL) – NOT A STATIONARY SOURCE

➢ *Fugitive Source* – Do Not Calculate

9.1   Introduction

Most Air Force installations have fuel transfer systems consisting of pumps, pipelines, fill stands, hydrants, loading and unloading racks, etc. Over time, various components, such as valves, pump seals, connectors, flanges, compressor seals, and pressure relief valves, may develop leaks. These leaks result in the fugitive emissions of VOCs and HAPs.

Previous source guides outlined the calculation of emissions from equipment leaks using the quantity of system components and their respective emission factor. However, the issues with this method include the fact that the emission factors developed for equipment leaks were developed for marketing terminals used in the petroleum industry (according to AP-42 chapter 5.2), which is not appropriate for most facilities found at Air Force installations. Additionally, several processes which may have equipment leaks calculate emissions using a mass balance approach. This approach means that leaks are already accounted for when calculating emissions for the process. **For these reasons, calculating emissions from equipment leaks is not recommended and therefore, not provided in this document.**

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10 ETHYLENE OXIDE STERILIZERS (STER)

➢ *Point Source*

10.1 Introduction

Ethylene Oxide (EtO) is commonly used in the sterilization of medical equipment and surgical materials. Approximately 1,900 hospitals have EtO sterilization chambers on property, though bulk sterilization may occur at contracted sterilization facilities. Many hospitals/clinics on Air Force 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 oxygen, water, and electricity, and energizes it to form ozone within the sterilizer. The ozone is then converted back into oxygen and water vapor by the end of the sterilization cycle, and is therefore not a significant source of ozone emissions and is not addressed in this section or any other place within this document.

EtO sterilization is ideal for heat and moisture sensitive equipment. However, EtO is highly flammable in the presence of as little as 3% 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 which 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% EtO or a gas mixture (10% EtO with 90% CO_2, 10% EtO with 90% HCFC, etc.). Often, EtO sterilizers are operated in a closed loop system, which typically results in zero emissions.

EtO is both a volatile organic compound (VOC) and a hazardous air pollutant (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 which 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 (e.g., 10% EtO with 90% CO_2, 10% EtO with 90% HCFC, etc.), 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 10-1.
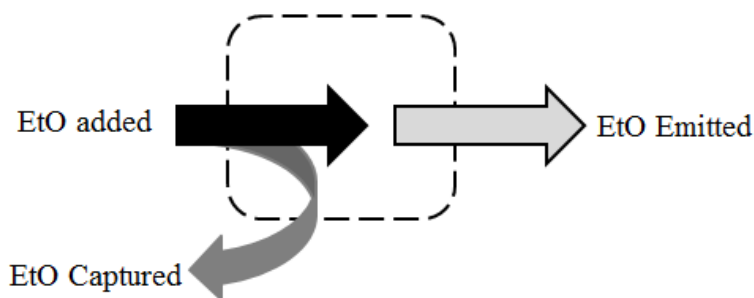
Figure 10-1. Simplified Control Volume for Emissions from EtO Sterilizers

10.2 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 for demonstrating compliance with this requirement. For additional information, consult 40 CFR 63 subpart WWWWW to verify that all facilities using EtO sterilizers are in compliance with this NESHAP. Additionally 40 CFR 63 subpart O, *Ethylene Oxide Emissions Standards for Sterilization Facilities,* outlines the standards for ethylene oxide emissions for sterilization facilities. These standards are applicable to all sources using 1 ton in sterilization or fumigation operations but does 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 over 1 ton must achieve at least 99% reduction in emissions from each sterilization chamber vent. Refer to 40 CFR 63 subpart O for more information.

10.3 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.

10.4 Emissions Calculation

Algorithms and Emission Factors (EFs) used by the Air Force are generally from AP-42; however, EFs for Air Force-unique sources have been developed by the Air Force. The only algorithms and EFs authorized for use in estimating Air Force emissions are those maintained within the Air Program Information Management System (APIMS). 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:

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

Equation 10-1

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 10-2.
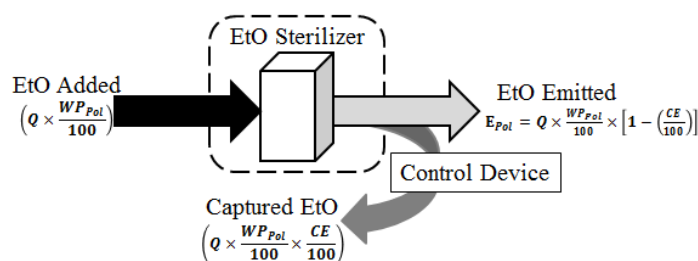
Figure 10-2. EtO Sterilizers Control Volume

10.5 Information Resources

Hospitals and/or clinics which 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.

10.6 Example Problem

The base hospital has a vacuum chamber sterilizer for sterilizing heat sensitive medical equipment. The only type of sterilant used in this sterilizer is a gas mixture containing 10% EtO and 90% 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.

Step 1 – **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 10-1.

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

For EtO:

$$E_{EtO} = 235 \frac{lb}{yr} \times \frac{10\%}{100\%} \times \left[1 - \left(\frac{0\%}{100\%}\right)\right]$$

$$E_{EtO} = 235 \frac{lb}{yr} \times \frac{10\cancel{\%}}{100\cancel{\%}} \times [1]$$

$$E_{EtO} = 235 \frac{lb}{yr} \times 0.10 \times [1]$$

$$\boxed{E_{EtO} = 23.5 \frac{lb}{yr}}$$

For CO$_2$:

$$E_{CO_2} = 235 \frac{lb}{yr} \times \frac{90\%}{100\%} \times \left[1 - \left(\frac{0\%}{100\%}\right)\right]$$

$$E_{CO_2} = 235 \frac{lb}{yr} \times \frac{90\cancel{\%}}{100\cancel{\%}} \times [1]$$

$$E_{CO_2} = 235 \frac{lb}{yr} \times 0.90 \times [1]$$

$$\boxed{E_{CO_2} = 211.5 \frac{lb}{yr}}$$

10.7 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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11 EXTERNAL COMBUSTION (ECOM)

➢ *Point Source*

11.1 Introduction

External combustion (ECOM) sources include furnaces and boilers. Furnaces heat an area by warming air while boilers utilize water which may also produce enough steam to generate electricity. Larger, stationary external combustion engines are located at the base heat/power plant. As with any combustion source, emissions from external combustion units include criteria pollutants, HAPs, and greenhouse gases (GHG). 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 and HAPs**. A basic control volume outlining the input of air and fuel and output of emissions is graphically represented in Figure 11-1.
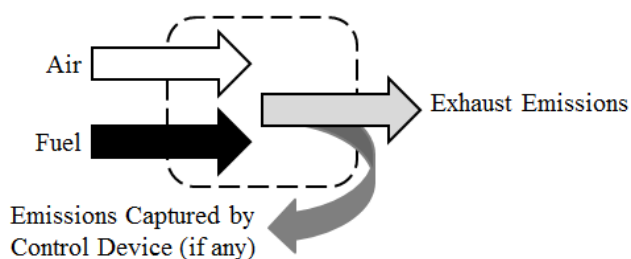
Figure 11-1. Simplified Control Volume for Emissions from External Combustion

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 which 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 which 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 steady state but are few in number compared to

industrial boilers. Industrial boilers are generally not as large as utility boilers and they may be subdivided into heavy industrial and light industrial. 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 these two 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 11-1.

Table 11-1. Boiler Types and Sizes

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

SOURCE: Chapter 7-"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 broken down further into heavy and light.

11.2 NSPS and NESHAP Applicability

It should be noted that, though this chapter does define and provide emission factors for utility boilers, at this time, the Air Force does not have any utility boilers at any installations. Though several New Source Performance Standards (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 which are currently in use at Air Force installations. These sections detail the PM, NO_X, and SO_X emission limits for those units with a heat input greater than 100MMBtu/hr. These values may be used to verify the accuracy of emission factors which may need to be calculated based on the fuel sulfur content or ash content. Additional information regarding these emission limits and the facilities which 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 which have been enacted which 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 conform to these requirements.

11.3 Greenhouse Gas Mandatory Reporting Rule

The EPA has established mandatory greenhouse gas reporting requirements for owners and operators of facilities that directly emit greenhouse gases into the atmosphere. According to 40 CFR 98.2, any facility operating stationary fuel combustion sources whose aggregate maximum rated heat input capacity is 30 MMBtu/hr and emits 25,000 metric tons of CO_2e or more per year in combined emissions from all stationary fuel combustion sources is subject to the reporting rules outlined in 40 CFR 98 subpart C. 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 greenhouse gas reporting requirements.

11.4 Emission Factors

For 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 oxygen concentration. NO_X emissions may be reduced by either flue gas recirculation (FGR) or low NO_X burners. Flue gas recirculation 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 oxygen 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. Boilers which employ flue gas recirculation (FGR), low NO_X burners (LNB), or staged combustors (SC) will reduce NO_X emissions. Similarly, since the formation of thermal NO_X is oxygen and temperature dependent, using low excess air (LEA), over-fire air, or reduced air preheat (RAP) 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 ammonia (NH_3) or urea at a specific temperature range into the combustion flue gases. The ammonia or urea reacts

with the nitrogen oxides to form molecular nitrogen (N_2), oxygen (O_2), and water (H_2O). SCR is similar to SNCR in that ammonia 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 resulting in increased VOC, CO, and PM emissions. Sometimes the addition of low NO_X burners 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 sulfur oxides 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%.

External combustion results in the formation of greenhouse gases. The most common greenhouse gases are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). A well maintained system will convert almost all of the 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 which operate with poor combustion efficiency produce considerably less N_2O and CH_4 compared to CO_2.

The following emission factors are presented in a lb 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 11-2. **Note that in the following sections, the tables do not provide emission factors for those boilers classified as "residential". If calculating emissions from residential boilers is required, use those emission factors for boilers smaller than 10 MMBtu/hr.**

Table 11-2. Typical Fuel Heating Values

Fuel Type	Heating Value (Btu/unit fuel)
CNG	$1.026E\text{-}03$ MMBtu/ft^3
Fuel Oil - No. 6	$1.50E\text{-}01$ MMBtu/gal
Fuel Oil - No. 5	$1.40E\text{-}01$ MMBtu/gal
Fuel Oil - Distillate/Diesel	$1.38E\text{-}01$ 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
LPG	$9.20E\text{-}02$ MMBtu/gal
Waste Oil	$1.38E\text{-}01$ MMBtu/gal
Landfill Gas	$4.85E\text{-}04$ MMBtu/ft^3
Digester Gas[1]	$4.85E\text{-}04$ 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 A-General Provision," U.S. Environmental Protection Agency

1. Values provided in source document for landfill gas used for digester gas.

11.4.1 Natural Gas

Natural gas is used mainly for industrial process, steam and heat production, for residential and commercial space heating, and for 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 100MMBtu/hr are generally field erected. The field erected units may be either wall-fired or tangential-fired and usually have multiple burners with several NO$_X$ control options. Conversely, package units are constructed off site and are generally smaller due to shipping constraints. These units typically have heat input levels less than 100MMBtu/hr, are always wall-fired with one or more individual burners, and are limited in the NO$_X$ control options. Criteria pollutant and HAP emission factors are provided in Table 11-3 and Table 11-4 respectively. Note that the tables do not provide emission factors for furnaces. This is due to the fact that the weighted average of boilers compared to furnaces justifies the removal of these emission factors from this guide. Refer to section 1.4 of AP-42 for information regarding the emission factors for furnaces if needed.

Table 11-3. Criteria Pollutant Emission Factors for Natural Gas-Fired ECOM Units

Firing Configuration [SCC]	Control Type[1]	Emission Factors (lb/10^6ft^3)							
		NO_X	CO	SO_X	Pb	VOC	PM_{10}[2]	$PM_{2.5}$[2]	GHG[3]
>100MMBtu Wall Fired [1-01-006-01, 1-02-006-01, 1-03-006-01]									
Pre-NSPS[4]	Uncontrolled	280	84	0.6	5.00E-04	5.5	7.6	7.6	120,713.1
Post-NSPS[4]	Uncontrolled	190	84	0.6	5.00E-04	5.5	7.6	7.6	120,713.1
Wall Fired	LNB	140	84	0.6	5.00E-04	5.5	7.6	7.6	120,248.2
Wall Fired	FGR	100	84	0.6	5.00E-04	5.5	7.6	7.6	120,713.1
<100MMBtu Wall Fired [1-01-006-02, 1-02-006-02, 1-02-006-03[5], 1-03-006-02, 1-03-006-03]									
Wall Fired	Uncontrolled	100	84	0.6	5.00E-04	5.5	7.6	7.6	120,713.1
Wall Fired	LNB	50	84	0.6	5.00E-04	5.5	7.6	7.6	120,248.2
Wall Fired	LNB/FGR	32	84	0.6	5.00E-04	5.5	7.6	7.6	120,248.2
All Sizes Tangential Fired [1-01-006-04, 1-02-006-04[5]]									
Tangential Fired	Uncontrolled	170	24	0.6	5.00E-04	5.5	7.6	7.6	120,713.1
Tangential Fired	FGR	76	98	0.6	5.00E-04	5.5	7.6	7.6	120,713.1

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

1. Control types include: low NO_X burners (LNB) and flue gas recirculation (FGR).

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

3. Greenhouse gas emissions are the total of CO_2, N_2O, and CH_4 emission factors multiplied by their GWP. The GWP for CO_2, CH_4, and N_2O are 1, 25, and 298 respectively.

4. New Source Performance Standards (NSPS) defined in 40 CFR 60 Subparts D and Db. Post NSPS units are boilers >250 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.

5. 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 SCC 1-02-006-03, no emission factor provided for Pb or controlled NO_X.

Table 11-4. HAP Emission Factors for Natural Gas-Fired ECOM Units

HAP	Emission Factors lb/10^{6}ft^3			
	Boilers>100MMBtu/hr [1-01-006-01, 1-02-006-01, 1-03-006-01]	Boilers 10-100MMBtu/hr [1-01-006-02, 1-02-006-02, 1-02-006-03$^{(1)}$, 1-03-006-02, 1-03-006-03]	Boilers <10MMBtu/hr	All Sizes Tangential [1-01-006-04, 1-02-006-04$^{(1)}$]
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	1.20E-06	1.20E-06	1.20E-06	1.20E-06
Benzo(a)pyrene	1.20E-06	1.20E-06	1.20E-06	1.20E-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	1.20E-06	1.20E-06	1.20E-06	1.20E-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	7.50E-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
PAHs	4.00E-04	4.00E-04	4.00E-04	---
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," Mohave Desert Air Quality Management District (MDAQMD), 2013

1. HAP emission factors were not provided in the source document for this SCC; however, it is assumed that the emission factors provided apply to this SCC.

"---" Indicates No Data Available.

11.4.2 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. Emission factors for fuel oil-fired ECOM units for criteria pollutants and speciated HAPs are provided in Table 11-5 and Table 11-6 respectively. Note that the tables do not provide emission factors for furnaces. This is due to the fact that the weighted average of boilers compared to furnaces justifies the removal of these emission factors from this guide. Refer to section 1.3 of AP-42 for information regarding the emission factors for furnaces if needed.

Emissions from external combustion 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 employed on the equipment, the boiler's firing configuration, and the level of equipment maintenance. Boilers which 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 is 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 through the use of a flame retention device or through recirculation which 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. ESPs work by charging the suspended particles and collecting them through electrostatic attraction. New ESPs may reduce PM emissions by as much as 90%.

Table 11-5. Criteria Pollutant Emission Factors Fuel Oil-Fired ECOM Units

Fuel Oil	Firing Configuration [SCC]	Uncontrolled and [Controlled] Emission Factors lb/10³ gal							
		NO_x[1]	CO	SO_x[2]	Pb	VOC[3]	PM_{10}[1,2]	$PM_{2.5}$[1,2]	GHG[4]
		Utility Boilers							
No. 6 Fuel Oil	Normal Firing [1-01-004-01] / Tangential Firing [1-01-004-04]	47 / 32 [40 / 26] - LNB	5	162.7{S}	1.51E-03	7.60E-01	6.61{S}+2.18 [4.70E-02{S}+1.55E-02] - ESP [5.60E-01{S}+1.85E-01] - SCB	4.82{S}+1.59 [3.14E-02{S}+1.04E-02] - ESP [5.38E-01{S}+1.78E-01] - SCB	25,000.0
No. 5 Fuel Oil	Normal Firing [1-01-004-05] / Tangential Firing [1-01-004-06]	47 / 32	5	162.7{S}	2.40E-03[6] / 4.98E-03[5]	7.60E-01	7.08 [5.04E-02] - ESP [6.00E-01] - SCB	5.16 [3.36E-02] - ESP [5.76E-01] - SCB	22,571.8
No. 4 Fuel Oil[11]	Normal Firing [1-01-005-04] / Tangential Firing [1-01-005-05]	47 / 32	5	155.7{S}	3.49E-03[5]	7.60E-01	4.96 [3.53E-02] - ESP [4.20E-01] - SCB	3.61 [2.35E-02] - ESP [4.03E-01] - SCB	24,218.0
		Industrial Boilers							
No. 6 Fuel Oil	[1-02-004-01]	47 [40] - LNB	5	162.7{S}	4.49E-03[10]	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	25,018.0
	[1-02-004-02, 1-02-004-03]	47	5	159{S}	4.49E-03[10]	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	25,018.0
No. 5 Fuel Oil	[1-02-004-04]	47	5	162.7{S}	4.49E-03[13]	2.80E-01	8.60 [1.90] - MCL	5.60 [4.00E-01] - MCL	22,589.8
Residual	[1-02-004-05][6]	55	5	158.6{S}	4.49E-03[13]	2.80E-01	7.90{S}+2.77	6.90{S}+2.42[7]	24,919.0
No. 4 Fuel Oil[11]	[1-02-005-04]	47	5	155.7{S}	8.30E-03[12]	2.00E-01	6.02	3.92	24,212.3
Distillate	[1-02-005-01]	24	5	7.1[8]	1.24E-03[9]	2.00E-01	1.00	2.50E-01	22,580.2
	[1-02-005-02, 1-02-005-03]	20	5	7.1[8]	8.30E-03[8]	2.00E-01	1.00	2.50E-01	22,557.1
	[1-02-005-05][6]	20	5	143.6{S}	1.10E-02[5]	2.00E-01	1.00[6]	9.91E-01[7]	22,377.2
		Commercial/Institutional Boilers							
No. 6 Fuel Oil	[1-03-004-01]	47	5	162.7{S}	4.49E-03[13]	1.13	5.79{S}+1.91	2.15{S}+0.71	25,004.9
	[1-03-004-02, 1-03-004-03]	55	5	159{S}	4.49E-03[13]	1.13	5.79{S}+1.91	2.15{S}+0.71	24,906.0
No. 5 Fuel Oil	[1-03-004-04]	55	5	159{S}	4.49E-03[13]	1.13	6.20	2.30	22,576.7
No. 4 Fuel Oil[11]	[1-03-005-04]	20	5	152{S}	8.30E-03[12]	3.40E-01	1.08	0.83	24,216.4
Distillate	[1-03-005-01]	24	5	147.7{S}	1.24E-03[9]	3.40E-01	1.08	0.83	22,584.3
	[1-03-005-02, 1-03-005-03]	20	5	144{S}	1.10E-02[5]	3.40E-01	1.08	0.83	22,359.8

Notes for Table 11-5 on the following page

Notes for Table 11-5:

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.

1. Control devices include: low NO_X burner (LNB), flue gas recirculation (FGR), electrostatic precipitators (ESP), scrubbers (SCB), and multi-cyclones (MCL).

2. 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.

3. Source document provides an emission factor for NMTOC. VOC assumed to be equal to NMTOC.

4. SOURCE: "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 98-Mandatory Greenhouse Gas Reporting, Subpart C-Mandatory Greenhouse Gas Reporting," U.S. Environmental Protection Agency. Greenhouse gas emissions are the total of the CO_2, CH_4, and N_2O emissions and converted to equivalent CO_2 (CO2e). CO2e calculated by multiplying each gas by its global warming potential (GWP). The GWP for CO_2, CH_4, and N_2O are 1, 25, and 298 respectively. Emission factors for greenhouse gases from AP-42 were used where given, with missing emission factors selected from Tables C-1 and C-4 from 40 CFR 98.

5. This value calculated using CARB speciation data. PM total value taken from AP42 and multiplied by .0005 for utility boilers burning residual oil or .0055 for boilers burning distillate oil. No. 4 fuel oil considered residual for utility boilers and distillate for industrial and commercial boilers.

6. 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.

7. Source provided PM_{10} data only. $PM_{2.5}$ estimated using fractions as given by 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.

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

9. An average heat value of 138MMBtu/1000gal used for unit conversion.

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

11. No. 4 oil for utility boilers assumed to be residual.

12. Emission factor for industrial boilers burning distillate fuel used as a surrogate.

13. Emission factor for Industrial boilers burning no. 6 fuel oil used as a surrogate.

Table 11-6. HAP Emission Factors for Fuel Oil-Fired ECOM Units

HAP	Emission Factors (lb/10^3 gal)					
	Residual Fuel Oils and No. 4 Fuel Oil Blends					Distillate Fuel Oil
	Utility Boilers (No. 6 Fuel Oil)[1]	Industrial Boilers (No. 6 and No. 5 Fuel Oil)[2]	Industrial Boilers (No. 4 Fuel Oil)[3]	Commercial Boilers (No. 6 and No. 5 Fuel Oil)[4]	Commercial Boilers (No. 4 Fuel Oil)[3]	All Types[5]
Acenaphthene	2.11E-05	2.30E-05	3.31E-05	2.06E-04	5.63E-05	2.11E-04
Acenaphthylene	2.53E-07	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	1.22E-06	2.32E-05	3.75E-06	2.08E-04	6.38E-06	2.39E-05
Antimony	5.25E-03	1.09E-03	---[6]	1.09E-03[7]	---[6]	---
Arsenic	1.32E-03	5.89E-04	1.60E-03[6]	5.89E-04[7]	1.60E-03[6]	1.60E-03
Benzo(a)anthracene	4.01E-06	2.24E-05	2.12E-06	2.01E-04	3.60E-06	1.35E-05
Benzene	2.14E-04	3.32E-02	6.91E-04	2.98E-01	1.17E-03	4.40E-03
Benzo(b,k)fluoranthene	1.48E-06	1.60E-06	2.32E-07	1.44E-05	3.95E-07	1.48E-06
Benzo(g,h,i)perylene	2.26E-06	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	2.78E-05	4.20E-04	---[6]	4.20E-04[7]	---[6]	---
1,3-Butadiene	---	6.17E-03	2.32E-03	5.54E-02	3.95E-03	1.48E-02
Cadmium	3.98E-04	3.43E-03	1.50E-03[6]	3.43E-03[7]	1.50E-03[6]	1.50E-03
Chlorobenzene	---	---	3.14E-05	---	5.34E-05	2.00E-04
Chloroform	---	4.96E-03	---	4.45E-02	---	---
Chromium	8.45E-04	1.64E-03	6.00E-04[6]	1.64E-03[7]	6.00E-04[6]	6.00E-04
Chromium VI	2.48E-04	3.50E-04	1.00E-04[6]	3.50E-04[7]	1.00E-04[6]	1.00E-04
Chrysene	2.38E-06	2.56E-05	2.01E-06	2.30E-04	3.42E-06	1.28E-05
Cobalt	6.02E-03	2.24E-03	---[6]	2.24E-03[7]	---[6]	---
Dibenzo(a,h)anthracene	1.67E-06	2.28E-05	1.02E-06	2.05E-04	1.73E-06	6.49E-06
Ethylbenzene	6.36E-05	1.42E-03	3.14E-05	1.27E-02	5.34E-05	2.00E-04
Fluoranthene	4.84E-06	2.78E-05	5.21E-06	2.49E-04	8.86E-06	3.32E-05
Fluorene	4.47E-06	3.18E-05	1.84E-05	2.85E-04	3.12E-05	1.17E-04
Formaldehyde	3.30E-02	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	2.14E-06	2.25E-05	1.04E-06	2.02E-04	1.77E-06	6.64E-06
Lead	---[8]	4.49E-03	8.30E-03	4.49E-03[7]	8.30E-03	---[8]
Manganese	3.00E-03	4.38E-02	3.10E-03[6]	4.38E-02[7]	3.10E-03[6]	3.10E-03
Mercury	1.13E-04	1.93E-04	2.00E-03[6]	1.93E-04[7]	2.00E-03[6]	2.00E-03
2-Methylnaphthalene	---	---	2.20E-05	---	3.74E-05	1.40E-04
Naphthalene	1.13E-03	4.95E-03	8.32E-04	4.44E-02	1.41E-03	5.30E-03
Nickel	8.45E-02	1.30E-01	3.90E-03[6]	1.30E-01[7]	3.90E-03[6]	3.90E-03
Perylene	---	---	4.25E-06	---	7.23E-06	2.71E-05
Phenanthrene	1.05E-05	4.38E-05	5.84E-05	3.93E-04	9.93E-05	3.72E-04
Phosphorous	9.46E-03	2.86E-02	---[6]	2.86E-02[7]	---[6]	---
Pyrene	4.25E-06	2.35E-05	6.41E-06	2.11E-04	1.09E-05	4.08E-05
Selenium	6.83E-04	3.23E-03	2.20E-03[6]	3.23E-03[7]	2.20E-03[6]	2.20E-03
2,3,7,8-Tetrachlorodibenzo-p-dioxin	---	6.33E-10	---	5.68E-09	---	---
Toluene	6.20E-03	7.30E-03	6.91E-04	6.55E-02	1.17E-03	4.40E-03
1,1,1-Trichloroethane	2.36E-04	---	3.71E-05	---	6.30E-05	2.36E-04
Xylenes	1.09E-04	9.28E-03	2.51E-04	8.33E-02	4.27E-04	1.60E-03

Notes for Table 11-6 on the next page.

Notes for Table 11-6:

1. 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. Though source only lists the emission factors for SCC's 1-01-004-01 and 1-01-004-04, these emission factors are assumed to apply to all utility boilers burning residual fuel oil which include the following SCC's: 1-01-004-05/06 and 1-01-005-04/05.

2. SOURCE (Unless otherwise stated): "CATEF - California Air Toxics Emission Factors," California Environmental Protection Agency, 1996. Source lists emission factors for SCC's 1-02-004-01/02/03 only.

3. SOURCE: Values are estimates which were calculated by first determining the ratio of HAP to TOC as provided for Distillate firing boilers. This ratio was multiplied by the 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.

4. SOURCE: Values are estimates which were calculated by first determining the ratio of HAP to TOC 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 SCC's: 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.

5. SOURCE: "Emissions Inventory Program, Emission Factors for Boilers," Mohave Desert Air Quality Management District (MDAQMD), 2013. Though the source only lists SCC's 1-02-005-01/02/03 and 1-03-005-01/02/03, these emission factors are assumed to also apply to the following SCC's: 1-02-005-05, 1-05-001-05, and 1-05-002-05.

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

7. Industrial boiler emission factor for this HAP used as a surrogate.

8. Refer to Table 11-5 for emission factor specific to SCC.

"---" Indicates No Data Available

11.4.3 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 oxygen 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 which is fluidized by an upward flow of air.

Stoker-fired systems account for the vast majority of 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 which minimizes the carryover of solids to the combustion chamber. CFBs, however, employ high fluidization velocities to maintain a continuous, high-volume recycle rate which 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% of total NO_X from coal combustion.

11.4.3.1   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, and increased volatile matter than bituminous coal and may be used as an alternative fuel in some boilers originally designed to burn bituminous coals. Emission factors for external combustion units burning bituminous and subbituminous coals are provided in Table 11-7.

There are a variety of control devices available for external combustion units which 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, low NO_X burners (LNB), SNCR, SCR, multiple cyclones, ESP, or the 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 another section of this chapter). In the absence of control efficiency data, several emission factors have been calculated for a variety of control devices, particularly for particulate matter.

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, but Table 11-8 provides emission factors for speciated HAPs from external combustion units burning bituminous and subbituminous coal. Note that AP-42 provides emission factors 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 emission factors provided here.

Table 11-7. Criteria Pollutant Emission Factors for Bituminous/Subbituminous Coal-Fired ECOM Units

Coal Type	Firing Configuration [SCC]	Emission Factors lb/ton							
		NO$_X$ [Controlled][1]	CO	SO$_X$[2]	Pb [Controlled]	VOC[3]	PM$_{10}$ [Controlled][1,2]	PM$_{2.5}$ [Controlled][1,2]	GHG[4]
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 [(6)]	0.04	2.6{A} 1.3{A} [MCL] 0.042{A} [ESP]	1.48{A} 0.86{A} [MCL] 0.022{A} [ESP]	5151.9
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]	5136.7
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]	5153.8
Bituminous	Spreader Stoker [1-01-002-04, 1-02-002-04, 1-03-002-09]	11	5	38{S}	1.26E-02 [(6)]	0.05	13.2 12 [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]	5140.2
Bituminous	Overfeed Stoker [1-01-002-05, 1-02-002-05, 1-03-002-07]	7.5	6	38{S}	1.26E-02 [(6)]	0.05	6.0 5.0 [MCL]	2.2 3.8 [MCL]	5140.2
Bituminous	PC, Wet Bottom, Tangentially Fired [1-01-002-11]	14	0.5	38{S}	(6)	0.04(7)	2.6{A}(7)	1.48{A}(7)	5168.1
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}	(6) [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]	5151.6
Bituminous	PC, Dry Bottom, Cell Burner Fired [1-01-002-15]	31	0.5	38{S}	(6)	0.06(8)	2.3{A}(8)	0.6{A}(8)	5168.1
Bituminous	FBC, Bubbling Bed [1-01-002-17, 1-02-002-17, 1-03-002-17]	15.2	18	(5)	(6)	0.05	12.4(9)	4.65(10)	6171.3
Bituminous	FBC, Circulating Bed [1-01-002-18, 1-02-002-18, 1-03-002-18]	5	18	(5)	(6) [4.20E-04]	0.05	12.4(9)	4.65(10)	6171.3
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 [(6)]	0.04	2.6{A}(7)	1.48{A}(7)	3720.4
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}(8)	0.6{A}(8)	3705.3
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}(11)	0.11{A}(11)	3722.4
Subbituminous	Spreader Stoker [1-01-002-24, 1-02-002-24, 1-03-002-24]	8.8	5	35{S}	8.75E-03 [(6)]	0.05	13.2(12)	4.6(12)	3708.8
Subbituminous	Overfeed Stoker [1-01-002-25, 1-02-002-25, 1-03-002-25]	7.5	6	35{S}	8.75E-03 [(6)]	0.05	6.0(13)	2.2(13)	3708.8
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}	(6) [4.20E-04]	0.06	2.3{A}(14)	0.6{A}(14)	3720.2
Subbituminous	PC, Dry Bottom, Cell Burner Fired [1-01-002-35]	14	0.5	35{S}	(6)	0.06(8)	2.3{A}(8)	0.6{A}(8)	3723.9
Bituminous	Underfeed Stoker [1-02-002-06]	9.5	11	31{S}	(6)	1.3	6.2	3.8	5158.7
Subbituminous	Underfeed Stoker [1-03-002-08]	9.5	11	31{S}	(6)	1.3	6.2	3.8	3727.3
Bituminous	Hand-fed Units [1-03-002-14]	9.1	275	31{S}	(6)	10	6.2(15)	3.8(15)	5263.7

Notes for Table 11-7 are provided on the following page.

Notes for Table 11-7:

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.

1. 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).

2. 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. 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.

3. Source document provides an emission factor for TNMOC. TNMOC is assumed to be equal to VOC.

4. GHG emission factors are the sum of CO_2, CH_4, and N_2O multiplied by their respective global warming potentials (GWP) and given in equivalent CO_2 (CO_2e). The GWP for CO_2, CH_4, and N_2O are 1, 25, and 298 respectively. CO_2 emission factors come from Table C-1 of: 40 CFR 98.

5. Sulfur emission factors for 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.

6. AP-42 does not provide an emission factor for lead for these SCC's, 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. PM is the emission factor for total PM (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.

7. Value provided is a surrogate. This value from SCC 1-01-002-01.

8. Value provided is a surrogate. This value from SCC 1-01-002-02.

9. Per AP-42, spreader stoker with multiple cyclones and reinjection used as a surrogate.

10. 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.

11. SCC 1-01-002-03 used as a surrogate for this value.

12. SCC 1-01-002-04 used as a surrogate for this value.

13. SCC 1-01-002-05 used as a surrogate for this value.

14. SCC 1-01-002-12 used as a surrogate for this value.

15. SCC 1-02-002-06 used as a surrogate for this value.

Table 11-8. HAP Emission Factors for Bituminous/Subbituminous Coal-Fired ECOM Units-CONTROLLED

HAP	Emission Factors (lb/ton)				
	Dry Bottom, Cyclone Furnace, and FBC-Circulating Bed Boilers[1,2]	Wet Bottom Boilers[3,4]	Spreader and Overfeed Stoker and FBC-Bubbling Bed Boilers[3,5]	Underfeed Boilers[3,6]	Hand-fed Boilers[3,7]
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[8]	1.80E-05	$9.20\text{E-}07*HV*(C/A*PM)^{0.63}$	$9.20\text{E-}07*HV*(C/A*PM)^{0.63}$	$9.20\text{E-}07*HV*(C/A*PM)^{0.63}$	$9.20\text{E-}07*HV*(C/A*PM)^{0.63}$
Arsenic[8]	4.10E-04	$3.10\text{E-}06*HV*(C/A*PM)^{0.85}$	$3.10\text{E-}06*HV*(C/A*PM)^{0.85}$	$3.10\text{E-}06*HV*(C/A*PM)^{0.85}$	$3.10\text{E-}06*HV*(C/A*PM)^{0.85}$
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[8]	2.10E-05	$1.20\text{E-}06*HV*(C/A*PM)^{1.1}$	$1.20\text{E-}06*HV*(C/A*PM)^{1.1}$	$1.20\text{E-}06*HV*(C/A*PM)^{1.1}$	$1.20\text{E-}06*HV*(C/A*PM)^{1.1}$
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[8]	5.10E-05	$3.30\text{E-}06*HV*(C/A*PM)^{0.5}$	$3.30\text{E-}06*HV*(C/A*PM)^{0.5}$	$3.30\text{E-}06*HV*(C/A*PM)^{0.5}$	$3.30\text{E-}06*HV*(C/A*PM)^{0.5}$
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[8]	2.60E-04	$3.70\text{E-}06*HV*(C/A*PM)^{0.58}$	$3.70\text{E-}06*HV*(C/A*PM)^{0.58}$	$3.70\text{E-}06*HV*(C/A*PM)^{0.58}$	$3.70\text{E-}06*HV*(C/A*PM)^{0.58}$
Chromium VI[8]	7.90E-05	---	---	---	---
Chrysene	1.00E-07	4.54E-07	5.67E-07	1.47E-05	1.13E-04
Cobalt[8]	1.00E-04	$1.70\text{E-}06*HV*(C/A*PM)^{0.69}$	$1.70\text{E-}06*HV*(C/A*PM)^{0.69}$	$1.70\text{E-}06*HV*(C/A*PM)^{0.69}$	$1.70\text{E-}06*HV*(C/A*PM)^{0.69}$
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[9]	1.20E+00	1.20E+00	1.20E+00	1.20E+00	1.20E+00
Hydrogen Fluoride[9]	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[8]	(10)	$3.40\text{E-}06*HV*(C/A*PM)^{0.80}$	$3.40\text{E-}06*HV*(C/A*PM)^{0.80}$	$3.40\text{E-}06*HV*(C/A*PM)^{0.80}$	$3.40\text{E-}06*HV*(C/A*PM)^{0.80}$
Manganese[8]	4.90E-04	$3.80\text{E-}06*HV*(C/A*PM)^{0.60}$	$3.80\text{E-}06*HV*(C/A*PM)^{0.60}$	$3.80\text{E-}06*HV*(C/A*PM)^{0.60}$	$3.80\text{E-}06*HV*(C/A*PM)^{0.60}$
Mercury[8]	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 11-8. HAP Emission Factors for Bituminous/Subbituminous Coal-Fired ECOM Units - CONTROLLED (cont.)

HAP	Emission Factors (lb/ton)				
	Dry Bottom, Cyclone Furnace, and FBC-Circulating Bed Boilers[1,2]	Wet Bottom Boilers[3,4]	Spreader and Overfeed Stoker and FBC-Bubbling Bed Boilers[3,5]	Underfeed Boilers[3,6]	Hand-fed Boilers[3,7]
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[8]	2.80E-04	$4.40E\text{-}06*HV*(C/A*PM)^{0.48}$	$4.40E\text{-}06*HV*(C/A*PM)^{0.48}$	$4.40E\text{-}06*HV*(C/A*PM)^{0.48}$	$4.40E\text{-}06*HV*(C/A*PM)^{0.48}$
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[8]	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

1. 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.
2. Apply to SCC's: 1-01-002-02/22, 1-02-002-02/22, 1-03-002-06/22, 1-01-002-15/35, 1-01-002-12/26, 1-02-002-12/26, 1-03-002-16/26, 1-01-002-18, 1-02-002-18, 1-03-002-18, 1-01-002-03/23, 1-02-002-03/23, and 1-03-002-03/23. Refer to note 9.
3. SOURCE: These emission factors were calculated using the ratio of the HAP to HAP totals (minus the metals) as given in AP-42. This ratio was then multiplied by the 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.
4. Applies to SCC's: 1-01-002-01/21, 1-02-002-01/21, 1-03-002-05/21, and 1-01-002-11. Refer to note 9.
5. Apply to SCC's: 1-01-002-04/24, 1-02-002-04/24, 1-03-002-09/24, 1-01-002-05/25, 1-02-002-005/25, 1-03-002-07/25, 1-01-002-17, 1-02-002-17, 1-03-002-17.
6. Emission Factors apply to the following SCC's: 1-02-002-06 and 1-03-002-08.
7. Emission Factors apply to SCC 1-03-002-14.
8. 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 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.
9. Source document does not provide an emission factor for the following SCC's: 1-01-002-11/15/35.
10. Refer to Table 11-8 for SCC-specific emission factors.
"---" Indicates No Data Available.

11.4.3.2   Anthracite Coal

Anthracite is the highest ranking coal with more fixed carbon and less volatile matter than the other three coal types. Anthracite currently accounts for only a small portion of the total quantity of coal combusted in the United States and emission factors are given in Table 11-9. Speciated HAP data for Anthracite coal-fired units are provided in Table 11-10. Since several of these emission factors are calculated or from surrogate sources, site-specific data should be used whenever possible.

Table 11-9. Criteria Pollutant Emission Factors for Anthracite Coal-Fired ECOM Units

Firing Configuration [SCC]	Emission Factors lb/ton							
	NO_X	CO	SO_X[1]	Pb	VOC	PM_{10} [Controlled][2]	$PM_{2.5}$ [Controlled][2]	GHG[3]
Pulverized Coal Boilers [1-01-001-01, 1-02-001-01, 1-03-001-01]	18.0	0.6[4]	39{S}	8.90E-03[4]	0.07[4]	2.3{A} 1.10{A} [MCL] 0.013{A} [BGH]	0.6{A} 0.48{A} [MCL] 0.006{A} [BGH]	5777.1
Stoker-fired Boilers [1-01-001-02, 1-02-001-04, 1-03-001-02]	9.0	0.6	39{S}	8.90E-03	0.3[6]	4.8[4]	1.8[5]	5721.6
Hand-fired [1-02-001-07, 1-03-001-03]	3.0[4]	90[4]	39{S}[4]	8.90E-03[4]	10	5.2[4]	1.95[5]	5777.1
FBC [1-02-001-17]	1.8[4]	0.3[4]	2.9[4]	---	---	---	---	5777.1

SOURCE (Unless otherwise stated): 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.

1. Several SO_X Emission Factors based on the sulfur content of the coal. S= weight percent sulfur. For example, if the coal sulfur content is 3.4%, S=3.4.

2. Control types include: Multiple Cyclone (MCL) and Baghouse (BGH).

3. The emission factors are presented in CO_2 equivalents (CO_2e), by multiplying the emissions from each greenhouse gas by their global warming potentials (GWP). The GWP for CO_2 is 1, for CH_4 is 25, and for N_2O is 298. Emission factors not found in AP-42 were taken from Tables C-1 and C-2 of 40 CFR 98.

4. 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. Calculations made using the ratio of $PM_{2.5}$ to PM_{10} as provided by "Emissions Inventory Program, Emission Factors for Boilers," Mohave Desert Air Quality Management District (MDAQMD), 2013.

5. Source provides an emission factor value for TOC, which is used here as a conservative value for VOC.

6. VOC emission factor may be estimated using the upper range of the emission factors for the speciated organic HAPs given in Table 1.2-5 of AP-42. This value is 0.002 lb/ton.

"---" Indicates No Data Available

Table 11-10. HAP Emission Factors for Anthracite Coal-Fired ECOM Units

| HAP | Emission Factors lb/ton[1] | | | |
	Pulverized Coal Boilers [1-01-001-01, 1-02-001-01, 1-03-001-01][2]	Stoker-fired Boilers [1-01-001-02, 1-02-001-04, 1-03-001-02][2]	Hand-fired [1-02-001-07, 1-03-001-03][2]	FBC [1-02-001-17]
Acenaphthene	1.26E-03	5.42E-03	1.81E-01	---
Acenaphthylene	4.94E-03	2.12E-02	7.06E-01	---
Anthracene	1.44E-03	6.16E-03	2.05E-01	---
Arsenic[3]	1.90E-04	1.90E-04	1.90E-04	1.90E-04
Benzo(a)anthracene	4.08E-03	1.75E-02	5.83E-01	---
Benzo(k)fluoranthene	1.44E-03	6.16E-03	2.05E-01	---
Benzo(g,h,i)perylene	3.16E-04	1.36E-03	4.52E-02	---
Benzo(a)pyrene	3.05E-04	1.31E-03	4.35E-02	---
Benzo(e)pyrene	3.56E-04	1.53E-03	5.09E-02	---
Beryllium[3]	3.10E-04	3.10E-04	3.10E-04	3.10E-04
Biphenyl	5.84E-03	2.50E-02[(1)]	8.34E-01	---
Cadmium[3]	7.10E-05	7.10E-05	7.10E-05	7.10E-05
Chromium[3]	2.80E-02	2.80E-02	2.80E-02	2.80E-02
Chrysene	4.77E-03	2.05E-02	6.82E-01	---
Coronene	2.24E-04	9.61E-04	3.20E-02	---
Fluoranthene	9.77E-03	4.19E-02	1.40E+00	---
Fluorene	1.44E-03	6.16E-03	2.05E-01	---
Indeno(123-cd)perylene	3.97E-04	1.70E-03	5.67E-02	---
Lead[3]	8.90E-03	8.90E-03	8.90E-03	---
Manganese[3]	3.60E-03	3.60E-03	3.60E-03	3.60E-03
Mercury[3]	1.30E-04	1.30E-04	1.30E-04	1.30E-04
Naphthalene	1.26E-02	1.30E-01[(1)]	1.81E+00	---
Nickel[3]	2.60E-02	2.60E-02	2.60E-02	2.60E-02
Perylene	6.90E-05	2.96E-04	9.86E-03	---
Phenanthrene	1.38E-02	6.80E-03[(1)]	1.97E+00	---
Pyrene	6.90E-03	2.96E-02	9.86E-01	---
Selenium[3]	1.30E-03	1.30E-03	1.30E-03	1.30E-03

1. SOURCE (Unless otherwise stated): 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.
2. SOURCE (Unless otherwise stated): Emission factors for organic compounds were calculated using the ratio of the HAP to the total organic compound for residential space heaters as given by AP-42. This ratio was multiplied by the total TOC as given by AP-42 for stoker-fired boilers, or by total VOC as given "Uncontrolled Emission Factor Listing for Criteria Air Pollutants" for hand-fired and pulverized coal boilers. Only use in the absence of available data.
3. SOURCE: The stoker-fired boiler emission factor is used as a surrogate for these values. This is for the emission factors for the metals only and should only be used in the absence of available data.

"---" Indicates No Data Available.

11.4.3.3   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 U.S. has two regions with extensive lignite deposits centered in North Dakota and Texas. Lignite is mainly used for steam/electric production in power plants. The emission factors for the criteria pollutants from lignite coal combustion are given in Table 11-11. Speciated HAP emission factors for lignite coal-fired ECOM units are given in Table 11-12.

Table 11-11. Criteria Pollutant Emission Factors for Lignite Coal-Fired ECOM Units

Firing Configuration [SCC]	Emission Factors lb/ton							
	NO_X [Controlled][1]	CO	SO_X[2]	Pb [Controlled]	VOC[3]	PM_{10}[2]	$PM_{2.5}$[2]	GHG[4]
PC, Dry Bottom, Wall Fired, Pre-NSPS / Post NSPS [1-01-003-01]	13 / 6.3 4.6 [OFA and LNB]	0.25 0.48 [OFA and LNB]	30{S}	(7) [4.20E-04]	0.04	1.82{A} 0.70{A} [MCL]	0.52{A} 0.28{A} [MCL]	3084.9
PC, Dry Bottom, Tangential Fired, Pre-NSPS / Post NSPS [1-01-003-02]	7.1 / (5)	0.6(6) / 0.1	30{S}	(7) [4.20E-04]	0.04	2.3{A} 0.88{A} [MCL]	0.66{A} 0.36{A} [MCL]	3084.9
Cyclone [1-01-003-03]	15	0.6(6)	30{S}	(7) [4.20E-04]	0.07	---	---	3084.9
Overfeed Stoker [1-01-003-04]	6(6)	6(6)	30{S}	(7) [(7)]	0.03	---	---	3084.9
Spreader Stoker [1-01-003-06]	5.8	5(6)	30{S}	(7) [(7)]	0.03	1.6{A} 0.66{A} [MCL]	0.56{A} 0.42{A} [MCL]	3084.9
FBC [1-01-003-17, 1-01-003-18]	3.6	0.15 (SCC 1-01-003-18 only)	10{S}	(7) [4.20E-04] (SCC 1-01-003-18 only)	0.03	---	---	3815.0

SOURCE (Unless otherwise stated): 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.

1. Controls types include: over fire air (OFA), low NO_X burners (LNB), and multiple cyclones (MCL).
2. SO_X Emission Factors based on the sulfur content of the coal. S= weight percent sulfur. For example, if the coal sulfur content is 3.4%, S=3.4.
3. Source gives emission factor for TNMOC which is used here as a conservative estimate of VOC.
4. Greenhouse gas emission factors have been converted into units of CO_2 equivalents (CO_2e) by multiplying each greenhouse gas by their global warming potential (GWP). The GWP for CO_2 is 1, for CH_4 is 25, and for N_2O is 298. Any emission factor not found in AP-42 was taken from Tables C-1 and C-2 of 40 CFR 98.
5. Emission factor for post NSPS for boilers >250MMBtu/hr constructed after August 17, 1971 is 6.8 lb/ton. For those boilers constructed after September 18, 1978, the emission factor is 6.0 lb/ton.
6. 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.
7. Emission factor may be calculated as follows: $Pb\ EF = 4.83E - 05 \times \left(\frac{C}{A} \times PM\right)^{0.80}$. In the equation, C is the concentration of the metal in the coal 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. PM is the total PM emitted in lb/MMBtu. For unit conversion, the heating value of 14.21MMBtu/ton was used.

"---" Indicates No Data Available.

Table 11-12. HAP Emission Factors for Lignite Coal-Fired ECOM Units

HAP	Emission Factors lb/ton		HAP	Emission Factors lb/ton	
	Pulverized Coal, Cyclone, and FBC - Circulating Bed Boilers[1]	Spreader Stoker, Overfeed, and FBC - Bubbling Bed Boilers[2]		Pulverized Coal, Cyclone, and FBC - Circulating Bed Boilers[1]	Spreader Stoker, Overfeed, and FBC - Bubbling Bed Boilers[2]
Acenaphthene	5.10E-07[3]	1.74E-06	Ethylene Dibromide	1.20E-06	4.08E-06
Acenaphthylene	2.50E-07[3]	8.51E-07	Ethylene Dichloride	4.00E-05	1.36E-04
Acetaldehyde	5.70E-04	1.94E-03	Fluoranthene	7.10E-07[3]	2.42E-06
Acetophenone	1.50E-05	5.10E-05	Fluorene	9.10E-07[3]	3.10E-06
Acrolein	2.90E-04	9.87E-04	Formaldehyde	2.40E-04	8.17E-04
Anthracene	2.10E-07[3]	7.15E-07	Hexane	6.70E-05	2.28E-04
Antimony[4]	1.80E-05	$1.31E-05*(C/A*PM)^{0.63}$	Hydrogen Chloride	1.20E+00	1.20E+00
Arsenic[4]	4.10E-04	$4.41E-05*(C/A*PM)^{0.85}$	Hydrogen Fluoride	1.50E-01	1.50E-01
Benzo(a)anthracene	8.00E-08[3]	2.72E-07	Indeno(1,2,3-cd)pyrene	6.10E-08[3]	2.08E-07
Benzene	1.30E-03	4.42E-03	Isophorone	5.80E-04	1.97E-03
Benzo(b,j,k)fluoranthene	1.10E-07[3]	3.74E-07	Lead[4]	4.20E-04	$4.83E-05*(C/A*PM)^{0.80}$
Benzo(g,h,i)perylene	2.70E-08[3]	9.19E-08	Manganese[4]	4.90E-04	$5.40E-05*(C/A*PM)^{0.60}$
Benzo(a)pyrene	3.80E-08[3]	1.29E-07	Mercury	8.30E-05	---
Benzyl Chloride	7.00E-04	2.38E-03	Methyl Bromide	1.60E-04	5.44E-04
Beryllium[4]	2.10E-05	$1.71E-05*(C/A*PM)^{1.1}$	Methyl Chloride	5.30E-04	1.80E-03
Biphenyl	1.70E-06[3]	5.78E-06	5-Methyl Chrysene	2.20E-08[3]	7.49E-08
Bis(2-ethylhexyl)phthalate	7.30E-05	2.48E-04	Methyl Hydrazine	1.70E-04	5.78E-04
Bromoform	3.90E-05	1.33E-04	Methyl Methacrylate	2.00E-05	6.80E-05
Cadmium[4]	5.10E-05	$4.69E-05*(C/A*PM)^{0.5}$	Methyl Tert-butyl Ether	3.50E-05	1.19E-04
Carbon Disulfide	1.30E-04	4.42E-04	Methylene Chloride	2.90E-04	9.87E-04
2-Chloroacetophenone	7.00E-06	2.38E-05	Naphthalene	1.30E-05[3]	4.42E-05
Chlorobenzene	2.20E-05	7.49E-05	Nickel[4]	2.80E-04	$6.25E-05*(C/A*PM)^{0.48}$
Chloroform	5.90E-05	2.01E-04	Phenanthrene	2.70E-06[3]	9.19E-06
Chromium[4]	2.60E-04	$5.26E-05*(C/A*PM)^{0.58}$	Phenol	1.60E-05	5.44E-05
Chromium VI	7.90E-05	---	Propionaldehyde	3.80E-04	1.29E-03
Chrysene	1.00E-07[3]	3.40E-07	Pyrene	3.30E-07[3]	1.12E-06
Cobalt[4]	1.00E-04	$2.42E-05*(C/A*PM)^{0.69}$	Selenium	1.30E-03	---
Cumene	5.30E-06	1.80E-05	Styrene	2.50E-05	8.51E-05
Cyanide	2.50E-03	8.51E-03	Tetrachloroethylene	4.30E-05	1.46E-04
Dimethyl Sulfate	4.80E-05	1.63E-04	Toluene	2.40E-04	8.17E-04
2,4-Dinitrotoluene	2.80E-07	9.53E-07	1,1,1-Trichloroethane	2.00E-05	6.80E-05
Ethyl Benzene	9.40E-05	3.20E-04	Xylenes	3.70E-05	1.26E-04
Ethyl Chloride	4.20E-05	1.43E-04	Vinyl Acetate	7.60E-06	2.59E-05

SOURCE (Unless otherwise stated 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. This source states that the emission factors apply to boilers that have some type of control device installed including wet limestone scrubbers, electrostatic precipitators, fabric filters, or any combination of each.

1. These emission factors apply to the following SCC's: 1-01-003-01, 1-01-003-02, 1-01-003-03, 1-01-003-18, 1-02-003-01, 1-02-003-02, 1-02-003-03, 1-03-003-05, and 1-03-003-06.

2. These emission factors were calculated by taking the ratio of each HAP to total HAPS (Minus metals) as given by AP-42. This ratio was multiplied by the TNMOC emission factor to estimate each HAP for the following SCC's: 1-01-003-04, 1-01-003-06, and 1-01-003-17. These values assumed to apply to industrial and commercial boilers though TNMOC not provided. Applicable SCC's include: 1-02-003-04, 1-02-003-06, 1-03-003-07, and 1-03-003-09.

3. This emission factor does not apply to SCC 1-01-003-18. In the absence of available data, use the emission factor for SCC 1-01-003-17 as a surrogate.

4. Emission factors for metals may be calculated if the properties of the lignite are known using the equations provided in Table 1.7-12 of AP-42. In these equations, C=the concentration of the metal in the coal in parts per million weight (ppmwt). A=the weight fraction of ash in the coal. For example, 10% ash is 0.1 ash fraction. PM is the site-specific emission factor for total particulate matter in units of lb/MMBtu. A heating value of 14.21 MMBtu/ton was used for unit conversion.

"---" Indicates No Data Available.

11.4.4 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, 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. Again, NO_X emissions are a combination of thermal NO_X and fuel NO_X. Controls of NO_X emissions include FGR and low NO_X burners, but LPG has a higher NO_X forming potential than natural gas. The LPG criteria pollutant EFs are provided in Table 11-13, while the emission factor data for speciated HAPs is provided in Table 11-14.

Table 11-13. Criteria Pollutant Emission Factors for LPG-Fired ECOM Units

Primary Gas [SCC]	Emission Factors lb/10^3 gal							
	NO_X	CO	SO_X[1]	Pb	VOC[2]	PM_{10}[(3)]	$PM_{2.5}$[(3)]	GHG[4]
Utility Boilers[5]								
Butane [1-01-010-01]	21	3.6	0.095{S}	---	0.26	0.6	0.6	14765.3
Propane [1-01-010-02]	19	3.2	0.095{S}	---	0.25	0.6	0.6	12663.9
Industrial Boilers								
Butane [1-02-010-01]	15	8.4	0.016	5.10E-05[(6)]	1.1	0.8	0.8	14573.2
Propane [1-02-010-02]	13	7.5	0.018	4.58E-05[(6)]	1.0	0.7	0.7	12773.2
Commercial Boilers								
Butane [1-03-010-01]	15	8.4	0.016	5.10E-05[(6)]	1.1	0.8	0.8	14573.2
Propane [1-03-010-02]	13	7.5	0.018	4.58E-05[(6)]	1.0	0.7	0.7	12773.2

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.

1. SO_X emission factors based on sulfur content expressed in $gr/100ft^3$ 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," Mohave Desert Air Quality Management District (MDAQMD), 2013.
2. AP-42 provides an emission factor for TOC. This value used here as a conservative estimate of VOC.
3. AP-42 provides an emission factor for total PM. This value used assumed to be equal to PM_{10} and $PM_{2.5}$.
4. Greenhouse gas (GHG) emission factors are the emissions of CO_2, CH_4, and N_2O and are presented in equivalent CO_2. Each gas was multiplied by their global warming potential (GWP) and summed to estimate this emission factor. The GWP for CO_2, CH_4, and N_2O is 1, 25, and 298 respectively. For utility boilers, greenhouse gas emission factors were calculated using the default emission factors and heating values as given in Table C-1 and C-2 of 40 CFR 98.
5. 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.
6. SOURCE: "Emissions Inventory Program, Emission Factors for Boilers," Mohave Desert Air Quality Management District (MDAQMD), 2013.

"---" Indicates No Data Available.

Table 11-14. HAP Emission Factors for Liquefied Petroleum Gas (LPG)-Fired ECOM Units

HAP	Emission Factors lb/10³ gal					
	Butane			Propane		
	Utility [SCC] [1-01-010-01][1]	Industrial [SCC] [1-02-010-01]	Commercial [SCC] [1-03-010-01]	Utility [SCC] [1-01-010-02][1]	Industrial [SCC] [1-02-010-02]	Commercial [SCC] [1-03-010-02]
Acenaphthene	4.83E-06	1.84E-07	1.84E-07	4.65E-06	1.65E-07	1.65E-07
Acenaphthylene	4.83E-06	1.84E-07	1.84E-07	4.65E-06	1.65E-07	1.65E-07
Acetaldehyde	2.42E-03	9.18E-05	3.16E-04	2.32E-03	8.24E-05	2.84E-04
Acrolein	2.15E-03	8.16E-05	2.75E-04	2.06E-03	7.32E-05	2.47E-04
Anthracene	6.44E-06	2.45E-07	2.45E-07	6.19E-06	2.20E-07	2.20E-07
Arsenic	---	2.04E-05	2.04E-05	---	1.83E-05	1.83E-05
Benzene	4.56E-03	1.73E-04	5.92E-04	4.39E-03	1.56E-04	5.31E-04
Benzo(a)anthracene	4.83E-06	1.84E-07	1.84E-07	4.65E-06	1.65E-07	1.65E-07
Benzo(a)pyrene	4.29E-06	1.63E-07	1.63E-07	4.13E-06	1.46E-07	1.46E-07
Benzo(b)fluoranthene	4.83E-06	1.84E-07	1.84E-07	4.65E-06	1.65E-07	1.65E-07
Benzo(g,h,I)perylene	4.29E-06	1.63E-07	1.63E-07	4.13E-06	1.46E-07	1.46E-07
Benzo(k)fluoranthene	4.83E-06	1.84E-07	1.84E-07	4.65E-06	1.65E-07	1.65E-07
Beryllium	---	1.22E-06	1.22E-06	---	1.10E-06	1.10E-06
Cadmium	---	1.12E-04	1.12E-04	---	1.01E-04	1.01E-04
Chromium	---	1.43E-04	1.43E-04	---	1.28E-04	1.28E-04
Chrysene	4.83E-06	1.84E-07	1.84E-07	4.65E-06	1.65E-07	1.65E-07
Cobalt	---	8.57E-06	8.57E-06	---	7.69E-06	7.69E-06
Dibenzo(a,h)anthracene	4.29E-06	1.63E-07	1.63E-07	4.13E-06	1.46E-07	1.46E-07
Dichlorobenzene	3.22E-03	1.22E-04	1.22E-04	3.10E-03	1.10E-04	1.10E-04
7,12-Dimethylbenz(a)anthracene	4.29E-05	1.63E-06	1.63E-06	4.13E-05	1.46E-06	1.46E-06
Ethylbenzene	5.37E-03	2.04E-04	7.04E-04	5.16E-03	1.83E-04	6.31E-04
Fluoranthene	8.05E-06	3.06E-07	3.06E-07	7.74E-06	2.75E-07	2.75E-07
Fluorene	7.52E-06	2.86E-07	2.86E-07	7.23E-06	2.56E-07	2.56E-07
Formaldehyde	2.01E-01	7.65E-03	7.65E-03	1.94E-01	6.86E-03	6.86E-03
Hexane	3.49E-03	1.33E-04	4.69E-04	3.36E-03	1.19E-04	4.21E-04
Indeno(1,2,3-cd)pyrene	4.83E-06	1.84E-07	1.84E-07	4.65E-06	1.65E-07	1.65E-07
Lead	---	5.10E-05	5.10E-05	---	4.58E-05	4.58E-05
Manganese	---	3.88E-05	3.88E-05	---	3.48E-05	3.48E-05
Mercury	---	2.65E-05	2.65E-05	---	2.38E-05	2.38E-05
3-Methylchloranthrene	4.83E-06	1.84E-07	1.84E-07	4.65E-06	1.65E-07	1.65E-07
Naphthalene	8.05E-04	3.06E-05	3.06E-05	7.74E-04	2.75E-05	2.75E-05
Nickel	---	2.14E-04	2.14E-04	---	1.92E-04	1.92E-04
Phenanthrene	4.56E-05	1.73E-06	1.73E-06	4.39E-05	1.56E-06	1.56E-06
Pyrene	1.34E-05	5.10E-07	5.10E-07	1.29E-05	4.58E-07	4.58E-07
Selenium	---	2.45E-06	2.45E-06	---	2.20E-06	2.20E-06
Toluene	2.09E-02	7.96E-04	2.70E-03	2.01E-02	7.14E-04	2.42E-03
Xylenes	1.56E-02	5.92E-04	2.01E-03	1.50E-02	5.31E-04	1.80E-03

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

1. SOURCE: These values calculated using the ratio of each HAP to the total HAPs (minus metals) as provided by the "Emissions Inventory Program, Emission Factors for Boilers," Mohave Desert Air Quality Management District (MDAQMD), 2013. This ratio was multiplied by the total VOC as given by 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 for a conservative estimate.

"---" Indicates No Data Available

11.4.5 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). 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 emission factors for waste oil-fired ECOM units are given in Table 11-15 and HAP EFs are provided in Table 11-16.

Table 11-15. Criteria Pollutant Emission Factors for Waste Oil-Fired ECOM Units

Source Category [SCC]	Emission Factors lb/10^3 gal							
	NO_X	CO	SO_X[1]	Pb[2]	VOC[3]	PM_{10}[4]	$PM_{2.5}$[4]	GHG[5]
Boilers [1-01-013-02[6], 1-02-013-02[6], 1-03-013-02]	19	5.0	147{S}	55{L}[7]	1.0[8]	51{A}	51{A}	22077.2

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.

1. SO_X emission factors based on weight % sulfur in the fuel. For example if sulfur content is 3.4%, then S=3.4.

2. Pb emission factors based on weight % lead in the fuel. For example, if the lead content of the waste oil is 5%, then L=5.

3. AP-42 provides an emission factor for TOC. This value used here as a conservative estimate of VOC.

4. 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 $PM_{2.5}$.

5. Greenhouse gas (GHG) emission factors are the emissions of CO_2, CH_4, and N_2O and are presented in equivalent CO_2. Each gas was multiplied by their global warming potential (GWP) and summed to estimate this emission factor. The GWP's for CO_2, CH_4, and N_2O are 1, 25, and 298 respectively. The EF for CH_4 and N_2O from 40 CFR 98.

6. 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.

7. 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 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.

8. Value not given in the source document for SCC 1-02-013-02, but it is assumed to be 1.0 lb/10^3gal.

Table 11-16. HAP Emission Factors for Waste Oil-Fired ECOM Units

HAP	Emission Factors lb/10^3 gal Small Boilers[1]
Arsenic	1.10E-01
Cadmium	9.30E-03
Chromium	2.00E-02
Cobalt	2.10E-04
Lead	55{L}[2]
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.

1. Though the source document only stated SCC 1-03-013-02, these emission factors are assumed to apply to the following SCC's as well: 1-01-013-02 and 1-02-013-02

2. Pb 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.

11.4.6 Landfill and Digester Gas

Digester gas is formed as organic matter breaks down in the absence of oxygen. It is composed primarily of methane and carbon dioxide 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 methane to carbon dioxide 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 emission factors for enclosed flares are given in Table 11-17. Similarly, the emission factors for HAPs for enclosed flares that combust digester gas are provided in Table 11-8. **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 Transitory Guide for information regarding landfill gas and its associated emission factors.**

Table 11-17. Criteria Pollutant Emission Factors for Digester Gas Flares (Enclosed)

Fuel	Emission Factors (lb/10^6ft^3)						
	NO$_X$	CO	SO$_X$	VOC[1]	PM$_{10}$	PM$_{2.5}$[2]	GHG[3]
Digester Gas	48.0	1.8	2.0	12.1	12.0	12.0	55961.6

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

1. Source document provided emission factor for ROG, which is assumed to be equal to VOC.

2. 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.

3. GHG emission factors taken from Tables C-1 and C-2 of 40 CFR 98 for landfill gas. They are presented in terms of equivalent CO$_2$ (CO$_2$e) by summing the product of the emission factors and the respective global warming potential (GWP) for each gas. The GWP for CO$_2$, CH$_4$, and N$_2$O are 1, 25, and 298 respectively.

Table 11-18. HAP Emission Factors for Digester Gas Flares (Enclosed)

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

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

11.4.7 VOC Speciation

At Air Force installations, external combustion sources are some of the biggest contributors to emissions of criteria pollutants. When conducting an air emissions inventory (AEI) or making major source determinations, the emissions from external combustion sources, such as boilers, may be made more difficult 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. Emission factors 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), and several air quality management districts which have independently developed their own set of emission factors. Since there is so much variety in the condition of the boiler and its configuration, any emission factors are estimates of emissions only and should be used only in the absence of actual measured data.

Provided in the following tables are several VOCs and HAPs which have been measured from several boilers using a variety of fuels and firing configurations. The following tables provide the weight percent of speciated VOCs and several HAPs. Since there are few sources of

emission factors available, those used in this document were assumed to be representative of all boilers. The weight percent of individual pollutants was calculated (and are presented in Table 11-9) using the total VOCs as shown:

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

Equation 11-1

Where,

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

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

Equation 11-2

Where,

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

Table 11-19. Speciated VOC Weight Percent for Boilers

Compound Name	HAP[1]	Natural Gas[2]	Fuel Oil		Coal[4]		LPG[2]
			Residual[3]	Distillate[2]	Bituminous, Subbituminous, and Lignite	Anthracite	
Acenaphthene	X	0.00%	0.02%	0.02%	0.01%	1.97%	0.00%
Acenaphthylene	X	0.00%	0.02%	0.01%	0.00%	7.70%	0.00%
Acetaldehyde	X	0.04%	2.30%	26.29%	8.97%	---	0.03%
Acetophenone	X	---	---	---	0.24%	---	---
Acrolein	X	0.03%	2.64%	26.29%	4.56%	---	0.03%
Anthanthrene		---	---	---	---	0.05%	---
Anthracene	X	0.00%	0.01%	0.00%	0.00%	2.24%	0.00%
Benzaldehyde		0.23%	3.11%	---	---	---	0.24%
Benzene	X	1.61%	16.69%	0.33%	20.46%	---	0.06%
Benzo(a)anthracene	X	0.00%	0.01%	0.00%	0.00%	6.36%	0.00%
Benzo(b,j,k)fluoranthene	X	0.00%	0.00%	0.00%	0.00%	2.24%	0.00%
Benzo(g,h,i)perylene	X	0.00%	0.01%	0.00%	0.00%	0.49%	0.00%
Benzo(a)pyrene	X	0.00%	---	0.00%	0.00%	0.47%	0.00%
Benzo(e)pyrene	X	---	0.00%	0.00%	---	0.56%	---
Benzyl Chloride	X	---	---	---	11.02%	---	---
Biphenyl	X	---	---	---	0.03%	---	---
Bis(2-ethylhexyl)phthalate	X	---	---	---	1.15%	---	---
Bromoform	X	---	---	---	0.61%	---	---
1,3-Butadiene	X	---	4.64%	1.11%	---	---	---
Butane		29.79%	---	---	---	---	31.29%
Carbon Disulfide	X	---	---	---	2.05%	---	---
2-Chloroacetophenone	X	---	---	---	0.11%	---	---
Chlorobenzene	X	---	---	0.02%	0.35%	---	---
Chloroform	X	---	3.73%	---	0.93%	---	---
2-Chloronaphthalene		---	0.00%	0.00%	---	---	---
Chrysene	X	0.00%	0.01%	0.00%	0.00%	7.43%	0.00%
Coronene	X	---	---	---	---	0.35%	---
Cumene	X	---	---	---	0.08%	---	---
Dibenzo(a,h)anthracene	X	0.00%	0.01%	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%	0.81%	0.02%	1.48%	---	0.07%

Table 11-19. Speciated VOC Weight Percent for Boilers (cont.)

| Compound Name | HAP[1] | Natural Gas[2] | Fuel Oil | | Coal[4] | | LPG[2] |
			Residual[3]	Distillate[2]	Bituminous, Subbituminous, and Lignite	Anthracite	
Ethyl Chloride	X	---	---	---	0.66%	---	---
Ethylene Dibromide	X	---	---	---	0.02%	---	---
Ethylene Dichloride	X	---	---	---	0.63%	---	---
Fluoranthene	X	0.00%	0.01%	0.00%	0.01%	15.23%	0.00%
Fluorene	X	0.00%	0.02%	0.01%	0.01%	2.24%	0.00%
Formaldehyde	X	0.86%	35.98%	26.29%	3.78%	---	1.12%
Hexane	X	0.43%	---	0.26%	1.05%	---	0.04%
Hydrogen Chloride	X	---	---	13.97%	---	---	---
Indeno(1,2,3-cd)pyrene	X	0.00%	0.01%	0.00%	0.00%	0.62%	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%	0.06%	0.01%	---	---	0.00%
Naphthalene	X	0.01%	2.88%	0.40%	0.20%	19.70%	0.00%
PAH	X	0.01%	---	3.74%	---	---	0.01%
Pentane		36.88%	---	---	---	---	38.74%
Perylene	X	---	0.00%	0.00%	---	0.11%	---
Phenanthrene	X	0.00%	0.02%	0.03%	0.04%	21.49%	0.00%
Phenol	X	---	---	---	0.25%	---	---
Propane		22.69%	---	---	---	---	23.84%
Propionaldehyde	X	---	---	---	5.98%	---	---
Propylene		6.03%	16.47%	0.75%	---	---	4.06%
Pyrene	X	0.00%	0.01%	0.00%	0.01%	10.75%	0.00%
Styrene	X	---	---	---	0.39%	---	---
Toluene	X	1.03%	5.28%	0.33%	3.78%	---	0.26%
Total Dioxins/Furans	X	---	0.00%	0.00%	0.00%	---	---
Vinyl Acetate	X	---	---	---	0.12%	---	---
Xylenes	X	0.25%	5.25%	0.12%	0.58%	---	0.19%

1. An "X" indicates that pollutant is a HAP
2. SOURCE: "Emissions Inventory Program, Emission Factors for Boilers," Mohave Desert Air Quality Management District (MDAQMD), 2013
3. SOURCE: "CATEF - California Air Toxics Emission Factors," California Environmental Protection Agency, 1996
4. 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%.

"---" Indicates No Data Available

11.5 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. At this time, the average control efficiencies of most control devices have not been determined; rather, a set of emission factors 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 emission factor should be selected when calculating emissions.

11.6 Emissions Calculation

Algorithms and Emission Factors (EFs) used by the Air Force are generally from AP-42; however, EFs for Air Force-unique sources have been developed by the Air Force. The only algorithms and EFs authorized for use in estimating Air Force emissions are those maintained within the Air Program Information Management System (APIMS). If a combustion source is controlled but a controlled emission factor is not available, the emissions can still be estimated by using the uncontrolled emission factor and the efficiency of the control device, if known. If the operation has a pollution control device for which an emission factor 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:

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

Equation 11-3

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 11-2.
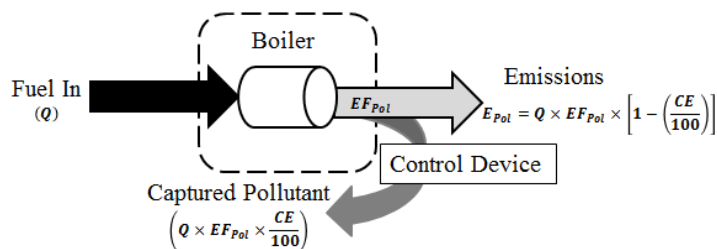
Figure 11-2. External Combustion Control Volume

11.7 Information Resources

Civil Engineering is usually responsible for operating/maintaining external combustion units on base and should be contacted to obtain the information required to calculate emissions (e.g., type and size of combustor, type 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 %, 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.

11.8 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%. Approximately 18,200 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 emission factor for NO_X, SO_X, and VOC for a commercial boiler using distillate oil as provided in Table 11-5. For SCC 1-02-005-02, the NO_X, SO_X, and VOC emission factors 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 emission factors 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:

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

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Step 3 - Calculate the NOx emissions. Since NO_X is the only pollutant of concern whose emissions are controlled, it is calculated using Equation 11-3, the emission factor as found in Step 1, and the stated control efficiency of 60%.

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

$$E_{NO_X} \ = \ 18.2 \frac{10^3 gal}{yr} \times \left[1 - \left(\frac{60\%}{100\%}\right)\right] \times 20 \frac{lb}{10^3 gal}$$

$$E_{NO_X} \ = \ 18.2 \frac{10^3 gal}{yr} \times [1 - (0.6)] \times 20 \frac{lb}{10^3 gal}$$

$$E_{NO_X} \ = \ 18.2 \frac{\cancel{10^3 gal}}{yr} \times [0.4] \times 20 \frac{lb}{\cancel{10^3 gal}}$$

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

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 emission factors from Step 1, the fuel consumed from Step 2, and a control efficiency of "0" for both pollutants.

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

For VOC emissions:

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

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

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

For SO_X emissions:

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

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

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

11.9 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

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-Mandatory Greenhouse Gas Reporting," U.S. Environmental Protection Agency

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Lutz 2001, Lutz, James D.; McMahon, James E.; Logee, Terrence; "Technical Support Document: Energy Efficiency Standards for Consumer Products: Residential Water Heaters," United States Department of Energy, January 2001.

MDAQMD 2013, "Emissions Inventory Program, Emission Factors for Boilers," Mohave Desert Air Quality Management District (MDAQMD), 2013

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

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 Air Force fire fighters is accomplished at the DoD Louis F. Garfield Fire Training Academy located at Goodfellow AFB, TX. However, a few other Air Force installations have smaller scale fire fighter training facilities which are used for periodic refresher trainings. The training performed at Goodfellow and the other Air Force installations is performed in live fire training pits which usually include a mock-up metal structure, such as an aircraft, vehicle, or building.

The 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. Emission indices for these pollutants are dependent upon the type of fuel burned and are estimated based on measured emissions from the uncontrolled burning of each fuel. 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.
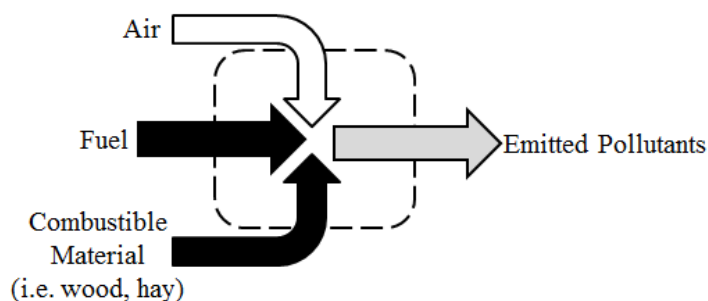
Figure 12-1. Simplified Control Volume for Emissions from Fire Fighter Training

12.2 Emission Factors

Emission factors for fire fighter training are dependent on the type of fuel used and material burned. Emission factors from the combustion of the fuel have been calculated and originally provided by *Air Quality Procedures for Civilian Airports and Air Force Bases* in appendix H. The emission factors for the most common fuels used are provided in Table 12-1.

Table 12-1. Criteria and HAP Emission Factors for Burned Fuel During Fire Fighter Training

Fuel	Emission Factors (lb/10³gal)							
	NO_X	CO	SO_X	VOC	PM_{10}	$PM_{2.5}$[1]	GHG[2]	Formaldehyde
Propane	55.7	15.4	0.02[3]	24.0[4]	9.5[5]	9.5	12663.9	0.7
JP-8	10.0	296.1	6.8[3]	584.5[4]	193.9[5]	193.9	21569.9	7.0
Tekflame[6]	3.7	68.3	0.04	49.6	33.3	33.3	21569.9	---

SOURCE (unless otherwise stated): "Emissions Testing of Fire Fighter Training Facility Final Technical Report," Environmental Quality Management (EQM), 1998.

1. $PM_{2.5}$ is conservatively assumed to equal PM_{10}.
2. GHG emission factor is the sum of CO_2, N_2O, and CH_4 emissions multiplied by their respective global warming potentials (GWP). The GWP of CO_2, CH_4, and N_2O are 1, 25, and 298 respectively. The emission factors for CO_2, CH_4, and N_2O were provided by 40 CFR 98 Tables C-1 and C-2. JP-8 emission factors were used as a surrogate for Tekflame.
3. SOURCE: "Air Quality Procedures for Civilian Airports and Air Force Bases," U.S. Department of Transportation, FAA Office of Environment and Energy (AEE), April 1997.
4. Source provides THC emission factor. This is used as a conservative estimate of VOC.
5. Source provides PM emission factor. A conservative assumption of PM = PM_{10} = $PM_{2.5}$ was made.
6. SOURCE: Kenney, Michael, et al, "Aviation Emissions and Air Quality Handbook, Version 3." Federal Aviation Administration (FAA), 2014.

"---" Indicates no data available

Total emissions from fire fighter training also include those emissions from the material that is being burned. A separate set of emission factors 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. Emission factors for these items are given in section 2.5 of AP-42 regarding the open burning of agricultural materials. These emission factors are provided in Table 12-2.

Table 12-2. Criteria Pollutant Emission Factors for Burned Materials During Fire Fighter Training

Material	Emission Factors (lb/ton)					
	NO_X	CO	VOC[1]	PM_{10}[2]	$PM_{2.5}$[2]	GHG[3]
Hay[4]	4.0	139.0	17.0	32.0	32.0	2297.1
Wood Pallets[5]	4.0	140.0	19.0	17.0	17.0	3798.6

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.

1. Source provides TOC emission factor. This is used as a conservative estimate of VOC.
2. Source provides total particulate emission factor. A conservative assumption of PM = PM_{10} = $PM_{2.5}$ was made.
3. This value is the sum of the products of CO_2, CH_4, and N_2O and their respective global warming potentials (GWP). The GWP of CO_2 is 1, CH_4 is 25, and N_2O is 298. CH_4 emission factor taken directly from source document, while CO_2 and N_2O emission factors taken directly from 40 CFR 98 Tables C-1 and C-2.
4. Emission factors are assumed to be head fire burning.
5. "Unspecified" forest residues used to select emission factors.

For enhanced accuracy, if agricultural materials are used and their composition and mass is known, then the appropriate emission factor may be selected. Emission factors for the burning of various agricultural products are given in sections 2.5 and 13.1 of AP-42.

12.3 Emissions Calculation

Algorithms and Emission Factors (EFs) used by the Air Force are generally from AP-42; however, EFs for Air Force-unique sources have been developed by the Air Force. The only algorithms and EFs authorized for use in estimating Air Force emissions are those maintained within the Air Program Information Management System (APIMS). Generally, emissions from fire fighter training operations using propane and/or JP-8 fuel 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.
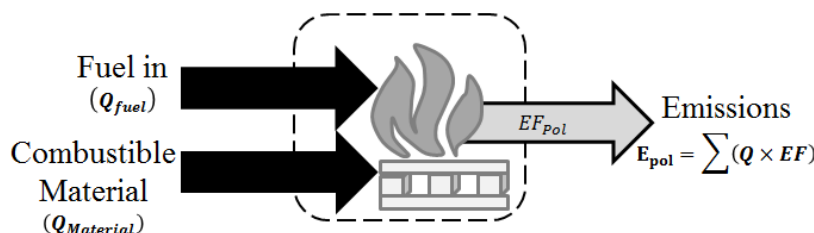
Figure 12-2. Fire Fighter Training Control Volume

12.4 Information Resources

The quantity of fuel and material burned is available from the Aircraft Rescue and Firefighting (ARFF) 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 pallets were also burned throughout the year. Calculate the emission of CO, SO$_X$, and PM$_{10}$ for the year.

Step 1 - Select and record emission factors. Table 12-1 provides the emission factors for the fuel. For propane, the CO, SO$_X$, and PM$_{10}$ **are 15.40, 0.02, and 9.50 lb/10^3 gal** respectively. For JP-8, the emission factors for CO, SO$_X$, and PM$_{10}$ are **296.10, 6.80, and 193.90 lb/10^3 gal** respectively. Table 12-2 provides the emission factors for the hay and pallets that were burned. SO$_X$ emissions are typically a function of the sulfur content of fuel used, therefore SO$_X$ emission factors are not given in Table 12-2. For hay, the CO and PM$_{10}$ emission factors are **139 and 32 lb/ton** respectively. For the wood pallets, the CO and PM$_{10}$ emission factors are **140 and 17 lb/ton** respectively.

Step 2 – Convert the fuel and material quantity into the appropriate units. The fuel emission factors are in units of lb/10^{3}gal while the material emission factors are in units of lb/ton, so for accurate calculations, the quantities must be converted into the correct units as follows:

For Fuels:

$$Q_{Propane} = \frac{24{,}000\frac{gal}{yr}}{1{,}000\frac{gal}{10^3 gal}} = \mathbf{24}\,\frac{10^3\,gal}{yr}$$

$$Q_{JP-8} = \frac{800\frac{gal}{yr}}{1{,}000\frac{gal}{10^3 gal}} = \mathbf{0.8}\,\frac{10^3\,gal}{yr}$$

For Material:

$$Q_{Hay} = \frac{8{,}500\frac{lb}{yr}}{2{,}000\frac{lb}{ton}} = \mathbf{4.25}\,\frac{ton}{yr}$$

$$Q_{Pallets} = \frac{4{,}500\frac{lb}{yr}}{2{,}000\frac{lb}{ton}} = \mathbf{2.25}\,\frac{ton}{yr}$$

Step 3 – Calculate emissions for each pollutant. Use the emission factors recorded in Step 1 and Equation 12-1 as follows:

$$E_{Pol} = Q \times EF_{Pol}$$

For Propane:

$$E_{CO} = 24\frac{10^3 gal}{yr} \times 15.40\frac{lb}{10^3 gal} = \textbf{369.60}\frac{lb}{yr}$$

$$E_{SO_X} = 24\frac{10^3 gal}{yr} \times 0.02\frac{lb}{10^3 gal} = \textbf{0.48}\frac{lb}{yr}$$

$$E_{PM_{10}} = 24\frac{10^3 gal}{yr} \times 9.50\frac{lb}{10^3 gal} = \textbf{228.00}\frac{lb}{yr}$$

For JP-8:

$$E_{CO} = 0.8\frac{10^3 gal}{yr} \times 296.10\frac{lb}{10^3 gal} = \textbf{236.88}\frac{lb}{yr}$$

$$E_{SO_X} = 0.8\frac{10^3 gal}{yr} \times 6.80\frac{lb}{10^3 gal} = \textbf{5.44}\frac{lb}{yr}$$

$$E_{PM_{10}} = 0.8\frac{10^3 gal}{yr} \times 193.90\frac{lb}{10^3 gal} = \textbf{155.12}\frac{lb}{yr}$$

For Hay:

$$E_{CO} = 4.25\frac{ton}{yr} \times 139\frac{lb}{ton} = \textbf{590.75}\frac{lb}{yr}$$

$$E_{PM_{10}} = 4.25\frac{ton}{yr} \times 32\frac{lb}{ton} = \textbf{136.00}\frac{lb}{yr}$$

For Wood Pallets:

$$E_{CO} = 2.25\frac{ton}{yr} \times 140\frac{lb}{ton} = \textbf{315.00}\frac{lb}{yr}$$

$$E_{PM_{10}} = 2.25\frac{ton}{yr} \times 17\frac{lb}{ton} = \textbf{38.25}\frac{lb}{yr}$$

Step 4 - Calculate the total emissions. Add the emissions from the fuels and material burned as shown:

For CO:

$$E_{CO} = 369.60\frac{lb}{yr} + 236.88\frac{lb}{yr} + 590.75\frac{lb}{yr} + 315.00\frac{lb}{yr}$$

$$\boxed{E_{CO} = \textbf{1512.23}\ \frac{lb}{yr}}$$

For SO$_X$:

$$E_{SO_x} = 0.48 \frac{lb}{yr} + 5.44 \frac{lb}{yr}$$

$$\boxed{E_{SO_x} = 5.92 \ \frac{lb}{yr}}$$

For PM$_{10}$:

$$E_{PM_{10}} = 228.00 \frac{lb}{yr} + 155.12 \frac{lb}{yr} + 136.00 \frac{lb}{yr} + 38.25 \frac{lb}{yr}$$

$$\boxed{E_{PM_{10}} = 557.37 \ \frac{lb}{yr}}$$

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

AEE 1997, "Air Quality Procedures for Civilian Airports and Air Force Bases," U.S. Department of Transportation, FAA Office of Environment and Energy (AEE), April 1997

EQM 1998, "Emissions Testing of Fire Fighter Training Facility Final Technical Report," Environmental Quality Management (EQM), 1998

FAA 2014, Kenney, Michael, et al, "Aviation Emissions and Air Quality Handbook, Version 3." Federal Aviation Administration (FAA), 2014

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 FUEL CELL MAINTENANCE AND TESTING (CELL, FCT) – NOT A STATIONARY SOURCE

 ➢ *Neither Point nor Stationary Source*

Air Force policy does not consider this a stationary source of emissions. However, if the regulator insists this category be included as a stationary source, contact the Air Force air quality Subject Matter Expert (SME) for permission to calculate these emissions

13.1 Introduction

Air Force 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 until the cell may be entered. 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.** This is because the emissions from the removal of fuel cells into bowsers and the subsequent purging of the fuel vapors in the fuel tank result in minimal release of VOC emissions. The air drying of the explosion suppression foam resulted in more significant emissions; however, T.O 1-1-3 dictates that suppression foam that has been removed must be sealed, which prevents the release of evaporated VOCs into the atmosphere. 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 Air Force air quality Subject Matter Expert 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 oxygen 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 clingage.
- The fuel cell is ventilated and continuously monitored to verify that the oxygen 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 that essentially come 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 Loading" section of this document. Emissions from the evaporation of the fuel from the removed foam is assumed to be negligible due to the strict requirements that all removed foam must be immediately sealed to prevent fuel vaporization. This leaves the purging and ventilation of the fuel cell as the only source of emissions from fuel cell maintenance and testing.

13.2 Emissions Calculation

Algorithms and Emission Factors (EFs) used by the Air Force are generally from AP-42; however, EFs for Air Force-unique sources have been developed by the Air Force. The only algorithms and EFs authorized for use in estimating Air Force emissions are those maintained within the Air Program Information Management System (APIMS).

13.2.1 VOC Emissions Calculations

Estimating emissions from fuel cell maintenance and testing may be tricky since it is difficult to estimate the vapor concentration of the fuel in the fuel cell. Also, it is difficult to estimate the amount of clingage that remains after removing the fuel from the fuel cell. 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 twice the fuel cell volume as shown:

$$E_{VOC} = 2 \times C_{VOC} \times 0.13368 \times \sum_{i}^{n}(V_i \times N_i)$$

Equation 13-1

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, the typical vapor pressures and vapor molecular weight are provided in Table 13-1. These values may be used to calculate C_{VOC} as shown:

$$C_{VOC} = \frac{M_V \times P_{VA}}{R \times T_{LA}}$$

Equation 13-2

Where,

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.**

Table 13-1. JP-8 Vapor Pressure and Vapor Molecular Weight

Petroleum Liquid	Vapor Molecular Weight (lb/lb-Mol)	True Vapor Pressure (psia)						
		40°F	50°F	60°F	70°F	80°F	90°F	100°F
JP-8/Jet A	130	1.58E-02	2.19E-02	3.01E-02	4.08E-02	5.48E-02	7.27E-02	9.54E-02

SOURCE: "JP-8 Volatility Study," Southwest Research Institute (SWRI), March 2001. Vapor pressures calculated using the composite data calculation, an average flash point temperature of 118.238°F, and atmospheric pressure of 760mmHg. These values assumed to be representative of Jet A fuel.

13.2.2 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 13-2. HAP emissions from fuel cell maintenance and testing are calculated as follows:

$$E_{HAP} = E_{VOC} \times \frac{WP_{HAP}}{100}$$

Equation 13-3

Where,

E_{HAP} = Annual emissions of speciated HAP (lb/yr)
WP_{HAP} = Weight percent of the speciated HAP in JP-8 (%)
100 = Factor for converting from a percent to a fraction (%)

Table 13-2. Average Vapor Weight Percent of HAPs in JP-8/Jet A Fuel

Compound	Typical Wt. % In JP-8/Jet A
Benzene	3.38E-02
Cumene (Isopropylbenzene)	1.81E-01
Ethylbenzene	1.59E-01
Fluorene	3.44E-03
Isooctane (2,2,4-Trimethyl Pentane)	1.23E-03
Naphthalene	2.68E-01
Phenylbenzene (1,1'-biphenyl)	6.78E-02
Pyrene	1.00E-05
Toluene	2.19E-01
Xylenes (mixed isomers)	1.19E-02

SOURCE: Mayfield, Howard T., "JP-8 Composition and Variability," Armstrong Laboratory, Environics Directorate, Environmental Research Division, May 1996. These values assumed to be representative of Jet A.

13.3 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.

13.4 Example Problem

The base fuels maintenance shop performs maintenance on C-17 aircraft fuel cells. 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.

Step 1 – **Convert the temperature into the correct units.** To calculate the initial VOC concentration, the temperature must be converted to units of °R as shown:

$$°R = 60 + 470 = \mathbf{530°R}$$

Step 2 – **Select and record the vapor molecular weight and vapor pressure**. These values are provided in Table 13-1. 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**.

Step 3 – Calculate the vapor saturation concentration. Using the temperature from Step 1, the parameters recorded in Step 2, and Equation 13-2, the saturation concentration is calculated as shown:

$$C_{VOC} = \frac{M_V \times P_{VA}}{R \times T_{LA}}$$

$$\boldsymbol{C_{VOC}} = \frac{130\left(\frac{lb}{lb-mol}\right) \times 0.0301(psia)}{10.732\left(\frac{psia\ ft^3}{°R\ lb-mol}\right) \times 530(°R)} = \boldsymbol{0.0006879\frac{lb}{ft^3}}$$

Step 4 – 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 13-1:

$$E_{VOC} = 2 \times C_{VOC} \times 0.13368 \times \sum_{i}^{n}(V_i \times N_i)$$

$$E_{VOC} = 2 \times 0.0006879\frac{lb}{ft^3} \times 0.13368\frac{ft^3}{gal} \times \left[\left(5{,}637\frac{gal}{unit} \times 43\frac{units}{yr}\right) + \left(7{,}857\frac{gal}{unit} \times 49\frac{units}{yr}\right)\right]$$

$$E_{VOC} = 2 \times 0.0006879\frac{lb}{ft^3} \times 0.13368\frac{ft^3}{gal} \times \left[\left(242391\frac{gal}{yr}\right) + \left(384993\frac{gal}{yr}\right)\right]$$

$$E_{VOC} = 2 \times 0.0006879\frac{lb}{ft^3} \times 0.13368\frac{ft^3}{gal} \times \left[627384\frac{gal}{yr}\right]$$

$$\boxed{\boldsymbol{E_{VOC} = 115.39\frac{lb}{yr}}}$$

Step 5 – Select and record the weight percent of xylenes in the vapor. This value is given in Table 13-2 as **1.19E-02%.**

Step 6 – 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 13-3:

$$E_{HAP} = E_{VOC} \times \frac{WP_{HAP}}{100}$$

$$E_{Xylenes} = 115.39\frac{lb}{yr} \times \frac{0.0119\%}{100\%}$$

$$E_{Xylenes} = 115.39\frac{lb}{yr} \times 0.000119$$

$$\boxed{\boldsymbol{E_{Xylenes} = 0.014\frac{lb}{yr}}}$$

13.5 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

14 FUEL DISPENSING (FDSP)

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

Air Force policy does not consider fuel dispensing to on-road vehicles a stationary source of emissions. However, if the regulator insists this category be included as a stationary source, contact the Air Force 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

14.1 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/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: 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 changed in order to classify the emission sources more accurately and reduce instances of duplicate reporting. **Emissions from loading fuel into tanks, including the loading of storage tanks at fuel service stations and the loading of large tanks which service stationary internal combustion engines are stationary sources whose emissions are accounted for in the "Storage Tanks" section of this document. Emissions from the loading of smaller tanks, which are those with a diameter less than 3 feet and length less than 5 feet, are described in the "Fuel Transfer" section of this document.** Conversely, since emissions from fueling mobile equipment are the result of displaced vapors from the fuel tank of a mobile source, **the refueling of vehicles is regarded as a mobile source and is addressed in the Mobile Guide.** Section 5.2.2.3 of AP-42 states that air emissions from motor vehicle refueling are incorporated in the MOBILE model; therefore these emissions are already accounted for in the on-road vehicle emission factors. Refer to the mobile guide for the calculation of emissions from dispensing fuel to aircraft and non-road engines.

The remaining fuel dispensing activity that results in emissions is the evaporation of spilled fuel. In an effort to simplify the guide, **the method for determining these emissions is described under the "Fuel Transfer" section of this document**.

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15 FUEL SPILLS (SPRL) – NOT A STATIONARY SOURCE

➢ *Fugitive Source*
➢ *Transitory Source*

Air Force policy does not consider this a stationary source of emissions. However, if the regulator insists this category be included as a stationary source, contact the Air Force air quality Subject Matter Expert (SME) for permission/guidance on emissions calculations

15.1 Introduction

Significant fuel spills are not common occurrences at any Air Force 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. The Comprehensive Environmental Response Compensation and Liability Act (CERCLA) and the Emergency Planning and Community Right-to-Know Act (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 Toxic Release Inventory (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 is being moved to a supplemental document, known as the "Transitory Guide, which describes those stationary emission sources which are considered non-traditional operations. For guidance in calculating emissions for fuel spills, refer to the Air Force Transitory Guide.

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16 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.

Air Force policy does not consider the dispensing of fuel into vehicles a stationary source of emissions. However, if the regulator insists this category be included as a stationary source, subtract those emissions calculated in the Mobile AEI and add them under this source to avoid duplicate reporting

16.1 Introduction

Fuel transfer activities involve the transfer of liquid fuel from bulk storage to outlets such as fuel service stations or smaller tanks such as those used to fuel nonroad engines, ground support equipment, or mobile and stationary generators. **Emissions from the filling of larger storage tanks, which are those with a diameter larger than 3 feet and a length greater than 5 feet, are calculated in the "Storage Tanks" section of this document. 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 described in the Mobile Guide.**

At Air Force installations, fuel is transferred from large storage tanks into tanker trucks at fuel loading docks. The tanker trucks may then distribute fuel to aircraft, tanks at fuel dispensing centers, non-road or stationary equipment, or smaller Petroleum, Oil, and Lubricant (POL) tanks. Loading losses occur as a tank is filled with liquid fuel and are the primary source of evaporative emissions. They occur as organic vapors in "empty" cargo tanks are displaced to the atmosphere as the liquid is loaded into the tanks. These vapors are a composite of: vapors formed in the empty tank by evaporation of residual product from previous loads, vapors transferred to the tank in vapor balance systems as product is being unloaded, and vapors generated in the tank as the new product is being loaded. **The vapor emissions are fugitive in nature and include both VOCs and HAPs**. This is depicted in a simple control volume in Figure 16-1. Vapor emissions that are lost during transferring of fuel from source to source depend on multiple factors that include loading method, vapor capturing unit efficiency, and fuel type.
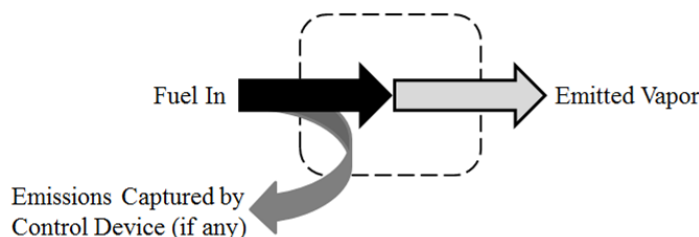
Figure 16-1. Simple Control Volume for Emissions from Fuel Transfer

The loading method used in fuel transfer has a significant effect on the amount of vapor emissions released 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 that is released into the atmosphere. 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 16-2.
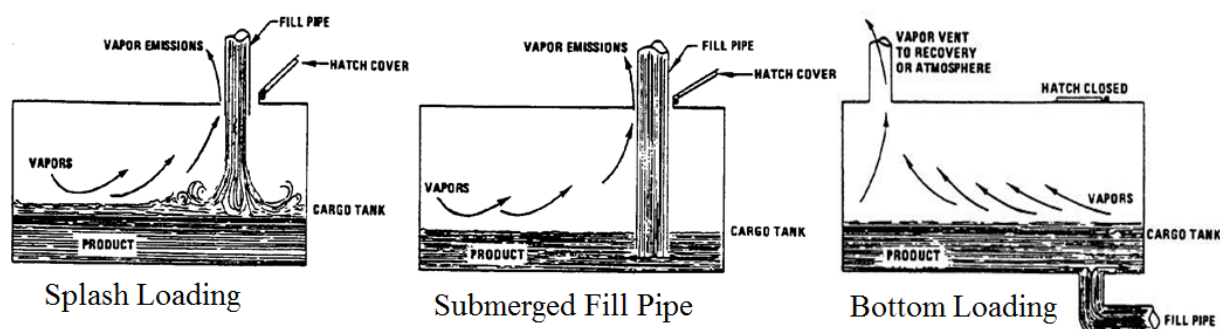
Figure 16-2. Splash Loading, Submerged Fill Pipe, and Bottom Loading Methods

The structure of equipment and vapor recovery systems can help reduce vapor losses throughout fuel transportation. Control efficiencies for the recovery units range from 90 to over 99 percent; however, only 70 to 90 percent of the displaced vapors reach the control device, due to leakage from both the tank truck and collection system.

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, each with different vapor pressures, and there are multiple destinations for fuels on base which may make it more difficult to gather data or determine what emissions are classified as mobile or stationary. In an effort to simplify how each base should calculate fuel transfer emissions, a diagram of the typical transfer methods and destinations of fuel on base is provided in Figure 16-3.
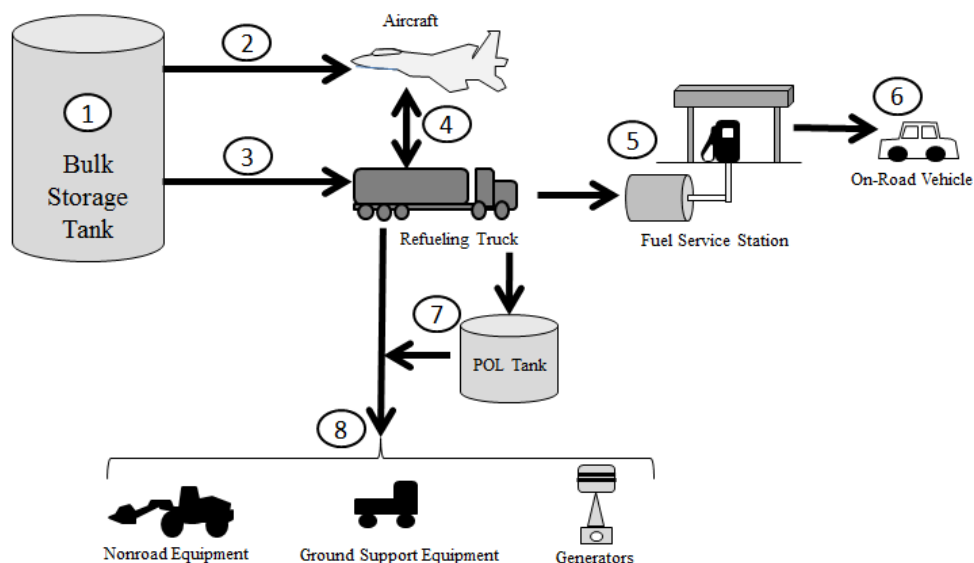
Figure 16-3. Typical On-Base Fuel Transfer Activities and Destinations.

Figure 16-3 shows the typical fuel transfer stages a fuel may go through at an Air Force installation. The fuel is *loaded by* and *loaded into* several pieces of equipment, each of which results in some form of emissions. Depending on the classification (mobile vs. stationary) of these pieces of equipment, determines whether or not the emissions are regarded as mobile or stationary. At any point on this figure, there may be significant fuel spills that result in emissions as the fuel evaporates. These are uncommon occurrences and the emissions are addressed in the Transitory Guide. The stages listed in Figure 16-3 may be described as follows:

1. This point in the figure describes emissions from the evaporation of fuel in a storage tank which are known as "breathing losses." These emissions are regarded as **stationary** and are calculated using the EPA's TANKS modeling program as described in the "Storage Tanks" section of this document.

2. This point in the figure describes the loading of fuel **from a stationary source** (storage tank via a hydrant system) **into a mobile source** (aircraft). The **stationary emissions** are the "working losses" from the storage tank. These emissions are calculated by the EPA's TANKS modeling program as described in the "Storage Tanks" section of this document. The **mobile emissions** from aircraft refueling are generated from the **displaced vapor** in the aircraft fuel tanks. The mobile emissions should be reported in the mobile AEI and may be calculated as directed by the Mobile Guide.

3. This point in the figure describes the loading of fuel **from a stationary source** (Storage tank) **into a mobile source** (refueling truck). The **stationary emissions** are the "working losses" from the storage tank. These emissions are calculated by the EPA's TANKS

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modeling program as described in the "Storage Tanks" section of this document. The **mobile emissions** from loading fuel into refueling trucks are generated from the **displaced vapor** in the truck. The mobile emissions should be reported in the mobile AEI and may be calculated as directed by the Mobile Guide.

4. This point in the figure describes the fueling and defueling of aircraft via a refueling truck. Both pieces of equipment are **mobile** and all emissions generated from these activities (which come from **displaced vapors** in the refueling truck or aircraft fuel tanks) should be reported in the mobile AEI and calculated as directed by the Mobile Guide.

5. This point in the figure describes the loading of fuel **from a mobile source** (refueling truck) **into** a **stationary source** (storage tank) at a fuel dispensing location. Likely, the **only mobile emissions** from the fueling of the tank via the refueling truck are from any **significant fuel spills**. These emissions are addressed in the Transitory Guide. The **stationary emissions** include **breathing and working losses** from the storage tanks. These emissions are calculated by the EPA's TANKS modeling program as described in the "Storage Tanks" section of this document.

6. This point in the figure describes the loading of fuel **from a stationary source** (fuel dispensing facility) **into a mobile source** (vehicle). The **stationary emissions** are the result of the evaporation of **spilled fuel** and are calculated below. The mobile emissions are generated from the **displaced vapor** in the vehicle fuel tanks. The displaced vapor emissions should be included in a Mobile AEI and are already calculated by the MOBILE6 model used to determine on-road vehicle emissions.

7. This point in the figure describes the loading of fuel **from a mobile source** (refueling truck) **into** a **stationary source** (storage tank). Likely, the **only mobile emissions** from the fueling of the tank via the refueling truck are from any **significant fuel spills**. These emissions are addressed in the Transitory Guide. 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 3 feet and minimum length of 5 feet, these emissions are calculated by the EPA's TANKS modeling program as described in the "Storage Tanks" section of this document.

8. This point in the figure describes the loading of fuel **from either a stationary** (storage tank) **or mobile source** (refueling truck) **into a stationary** (stationary ICOM) **or mobile source** (nonroad equipment – NRDE or Ground Support Equipment – GSE). The **mobile/stationary emissions from the fuel loading outlet** (refueling truck or storage tank) at this point are likely to only be the result of any **significant fuel spills**. These emissions are addressed in the Transitory Guide. The **mobile/stationary emissions from**

the fuel loading inlet (NRDE, GSE, and stationary ICOM) are generated from the **displaced vapor** in the fuel tanks. Emissions are similarly calculated for each as described below and in the Mobile guide. Care should be taken to ensure that emissions are reported in the correct mobile or stationary AEI to avoid duplicate reporting.

16.2 NSPS and NESHAP Applicability

40 CFR 60 subpart XX describes the standards of performance for bulk gasoline terminals and applies to all loading racks that deliver gasoline to fuel trucks. According to this section, any facility whose construction or modification commenced after December 17, 1980 is required to have a vapor collection system to collect the total organic compound 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 which are required of the bulk gasoline terminals, there are also National Emission Standards for Hazardous Air Pollutants (NESHAPs) promulgated in 40 CFR 63 subparts R and BBBBBB. Subpart R applies to facilities which are deemed as major sources. This section outlines the standards for loading racks and alternative means of emission limitation. Subpart BBBBBB applies to minor source gasoline distribution bulk terminals and outlines the national emission limitations and management practices including requiring monthly leak inspections and requiring submerged fill for all tanks with a capacity of 250+ gallons.

16.3 Emission Factors

The loading loss is the primary source of evaporative emissions from the loading of fuel tanks. These losses are the result of organic vapors within a tank which are displaced to the atmosphere as the tank is loaded with fuel. Calculation of these emissions requires the use of a saturation factor. The saturation factor refers to the ratio of the saturated value of the expelled vapor to the unsaturated value. These values vary based on the method of fuel loading. A tank that is filled with only one fuel, or fuels with similar characteristics, is said to be practicing "dedicated normal service." When loading vapors are returned back to the loading terminal after the fuel is unloaded to a storage tank, it is known as "dedicated vapor balance". Section 5.2 of AP-42 provides the saturation factors which are given in Table 16-1.

The vapor emissions resulting from fuel transfer are a function of the vapor pressure of the fuel. The vapor pressure 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 16-2.

Table 16-1. 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.

Table 16-2. Vapor Pressures for Various Fuels

Petroleum Liquid	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[1]	50	1.80	2.30	2.80	3.40	4.00	4.80	5.70
Gas RVP 6	69	1.90	2.37	2.93	3.60	4.38	5.29	6.35
Gas RVP 7	68	2.30	2.90	3.50	4.30	5.20	6.20	7.40
Gas RVP 7.8	68	2.59	3.21	3.94	4.79	5.79	6.96	8.30
Gas RVP 8	68	2.67	3.30	4.04	4.92	5.94	7.13	8.50
Gas RVP 8.3	68	2.79	3.44	4.22	5.13	6.19	7.42	8.83
Gas RVP 9	67	3.06	3.77	4.61	5.59	6.74	8.06	9.58
Gas RVP 10	66	3.40	4.20	5.20	6.20	7.40	8.80	10.50
Gas RVP 11	65	3.87	4.75	5.77	6.96	8.34	9.92	11.74
Gas RVP 11.5	65	4.09	5.00	6.07	7.31	8.75	10.41	12.29
Gas RVP 12	64	4.29	5.24	6.36	7.65	9.15	10.86	12.82
Gas RVP 13	62	4.70	5.70	6.90	8.30	9.90	11.70	13.80
Gas RVP 13.5	62	4.93	6.01	7.26	8.71	10.38	12.29	14.46
Gas RVP 15	60	5.58	6.77	8.16	9.77	11.61	13.71	16.09
Diesel	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[2]	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.

1. 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.
2. SOURCE: "JP-8 Volatility Study," Southwest Research Institute (SWRI), 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 the average provided by "Petroleum Quality Information System Fuels Data (2005)," Defense Logistics Agency (DLA), Defense Energy Support Center, Technology and Standardization Division, 2006.

Table 16-3. 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[1]

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.

1. 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 16-4. Typical Fuel Transfer Control Efficiencies

Control Techniques		Control Efficiency (%)
Flares[1]	Compounds ≤ 3 Carbon atoms	99.0
	Other Organic Compounds	98.0
Thermal Oxidizers[2]		99.0
Carbon Systems[3]		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>.

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

2. 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.

3. Must have an alarm system that will prevent break through.

16.4 Emissions Calculation

Algorithms and emission factors (EFs) used by the Air Force are generally from AP-42; however, EFs for Air Force-unique sources have been developed by the Air Force. The only algorithms and EFs authorized for use in estimating Air Force emissions are those maintained within the Air Program Information Management System (APIMS).

Emissions of concern from fuel transfer are VOCs and HAPs. VOC emissions from fuel transfer operations are calculated by taking the product of the loading loss and total fuel transferred into the tank for the year. The total HAPs emitted are calculated by using the weight percent HAPs in the fuel and multiplying by the total VOCs emitted.

The total VOC emissions from fuel transfer/dispensing is the sum of the emissions from vapor displacement and spills, if any, and is shown in Equation 16-1.

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

Equation 16-1

Where,

 E(Total)voc   = Total annual VOCs emitted from fuel transfer/dispensing 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)

16.4.1 VOC Emissions Calculations from Vapor Displacement

VOC emissions due to 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 16-2

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 16-1.
 P   = True vapor pressure of fuel (psia). This is provided in Table 16-2.
 M   = Vapor molecular weight of the fuel (lb/lb-mol). This is provided in Table 16-2.
 T   = Temperature of bulk liquid loaded (°R).
 Cap = Capture efficiency of the loading terminal (%). This is provided in Table 16-3.
 CE   = Efficiency of the control device (%). This is provided in Table 16-4.
 100 = Factor for converting a percent to a fraction (%).

A detailed control volume for fuel loading activities is provided in Figure 16-4.
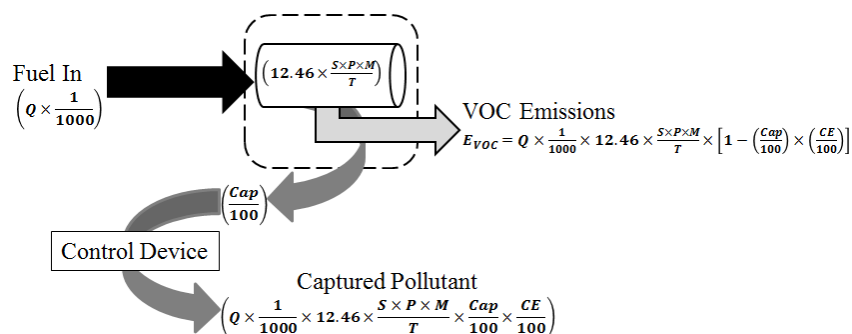
Figure 16-4. Fuel Transfer Control Volume

16.4.2 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, <u>not</u> the significant spills which may occur periodically that may be reported to base Environmental Management or the Hazardous Materials Response Team. Emissions resulting from fuel spills of this magnitude are calculated using the methodology as described in the "Spills and Releases" section of the Transitory Guide.

Emissions from smaller-scale fuel spills, such as those at fuel service stations, have been studied to determine a representative Spillage Factor (SF) 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. For this reason, the rate of evaporation for diesel is much less than gasoline, but the same spillage factor may be used, though this value 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 are estimated as follows:

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

Equation 16-3

Where,

$\quad$ **SF** $\quad$ = Spillage factor. The typical value is 0.7 (lb/10^3 gal)

16.4.3 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 Air Force installations. In the absence of available data, Table 16-5 provides the typical weight percent of individual HAPs found in several fuels used at Air Force installations.

Table 16-5. HAP Speciation of Fuels Commonly Used at Air Force Installations

Compound	Typical Wt. %		
	In Diesel	In Gasoline	In JP-8/Jet A[1]
Anthracene	2.82E-03[2]	---	---
Benzene	8.00E-04	1.80E+00	3.38E-02
1,3-Butadiene	---	2.00E-04[2]	---
Cumene (Isopropylbenzene)	---	5.00E-01	1.81E-01
Dibenzofuran	1.64E-02[2]	---	---
Ethylbenzene	1.30E-02	1.40E+00	1.59E-01
Fluorene	2.94E-02[2]	---	3.44E-03
Hexane	1.00E-04	1.00E+00	---
Isooctane (2,2,4-Trimethyl Pentane)	---	4.00E+00	1.23E-03
Naphthalene	3.39E-01[2]	1.74E-01[2]	2.68E-01
Phenanthrene	3.22E-02[2]	---	---
Phenylbenzene (1,1'-biphenyl)	---	---	6.78E-02
Pyrene	3.62E-02[2]	---	1.00E-05
Toluene	3.20E-02	7.00E+00	2.19E-01
Xylenes (mixed isomers)	2.90E-01	7.00E+00	1.19E-02

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

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

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

"---" Indicates 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 16-4

Where,

ㅤㅤ**E$_{HAP}$**ㅤㅤ= HAP emitted due to fuel transfer activities (lb/yr)
ㅤㅤ**E$_{VOC}$**ㅤㅤ= Total VOCs emitted due to fuel transfer activities (lb/yr).
ㅤㅤ**WP$_{HAP}$**ㅤ= Weight percent HAP in the fuel (%)
ㅤㅤ**100**ㅤㅤㅤ= Factor converting weight percent to weight fraction (%)

16.5 Information Resources

The gasoline terminal supervisor should be contacted for information regarding fuel transfer including 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 base Civil Engineering or the applicable manufacturer will need to be contacted to obtain the control efficiency of the vapor recovery unit.

16.6 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 and a vapor recovery system with 95% 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°F (520° R). Calculate the annual VOC emissions and benzene emissions associated with fuel transfer operations on base.

Step 1 – Record the saturation factor, vapor pressures, vapor molecular weights, and capture efficiencies. Based on the loading method employed, the saturation factor is **1.00** (from Table 16-1). Since the fuel used was JP-8, the vapor pressure at 60°F and vapor molecular weight may be found in Table 16-2. The vapor pressure and molecular weight are **0.0301 psia** and **130lb/lb-mol** respectively. The tanker trucks are not required to pass an annual leak test which means that, according to Table 16-3, the capture efficiency of the vapor recovery system is **70.0%**.

Step 2 – Calculate VOC emissions. Using Equation 16-2, the data provided in the problem statement, the data collected in Step 1 above, and assuming no spillage, this is accomplished as follows:

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

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

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

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

$$E_{VOC} = 4,450 \frac{10^3 gal}{yr} \times 12.46 \frac{°R \ lb-mol}{psia \ 10^3 gal} \times \frac{1.00 \times 0.0301 \ psia \times 130 \frac{lb}{lb-mol}}{520°R} \times \{0.335\}$$

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

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

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

Step 3 – Calculate the total benzene emissions. Using the total VOCs emitted as calculated in Step 2, the weight percent of benzene in JP-8 as given by Table 16-5, and Equation 16-4, the total benzene emissions are calculated as follows:

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

$$E_{Benzene} = 139.8 \frac{lb}{yr} \times \left(\frac{0.0338\%}{100\%}\right)$$

$$E_{Benzene} = 139.8 \frac{lb}{yr} \times 0.000338$$

$$\boxed{E_{Benzene} = 4.73E - 02 \frac{lb}{yr}}$$

16.7 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

SWRI 2001, "JP-8 Volatility Study," Southwest Research Institute (SWRI), March 2001

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

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17 CONSTRUCTION (CNST) – NOT A STATIONARY SOURCE

- ➢ *Point Source* – Mobile Equipment
- ➢ *Fugitive Source* – Construction Activity
- ➢ *Transitory Source* – All Operations

Air Force policy does not consider this a stationary source of emissions. However, if the regulator insists this category be included as a stationary source, contact the Air Force air quality Subject Matter Expert (SME) for permission/guidance on emissions calculations

17.1 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 greenhouse gases. 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-locating 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 the Air Force Transitory Guide.**

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18 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

18.1 Introduction

Hot Mix Asphalt (HMA) paving operations on Air Force installations are typically associated with large-scale paving operations. Although uncommon and generally short-term, HMA has the potential to be a substantial contributor to air emissions during a particular year. The primary source of emissions includes fugitive and ducted 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 an Air Force installation are temporary and non-routine in nature. **For this reason, this section is being moved to a supplemental document that describes those emission sources that are considered non-traditional operations. For guidance in calculating the fugitive emissions from asphalt pavement, refer to the Air Force Transitory Guide. 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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19 INCINERATORS (INCN)

➢ *Point Source*

19.1 Introduction

There are several types of incinerators likely found on Air Force Installations including classified waste incinerators, medical waste incinerators, and air curtain incinerators. Other incinerators, such as municipal solid waste incinerators, which are used to burn garbage and other household waste, and sewage sludge incinerators, can potentially be large sources of air emissions, but are not typically found at Air Force Installations. These types of refuse are typically shipped off-site for incineration and are therefore not addressed in this document. 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. Rather, information regarding air curtain incinerators may be found in the Air Force Transitory Guide. **Both 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 19-1.
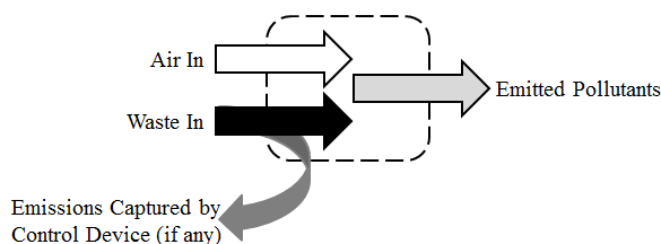
Figure 19-1. Simplified Control Volume for Emissions from Incinerator Use

19.1.1 Classified Waste Incinerators

Many Air Force installations use a classified waste incinerator as a means of disposing of classified information. This information is typically in the form of paper documents, plastic (microfiche) sheets, or computer tapes/discs. The EPA has not developed emission factors specific to classified waste incinerators. For emissions estimation purposes, "industrial/commercial" incinerator emission factors may be used as surrogate emission factors for classified waste incinerators. Classified waste incinerators may be further subdivided based on if they are of multiple chamber or single chamber design.

19.1.2 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. A study performed by the EPA in 1993 reported that a vast majority (>95%) of medical waste incinerators were of the controlled-air type, a small percentage (<2%) were of the excess-air type, and very few (<1%) were of the rotary kiln type. However, since the time of the study the number of medical waste incinerators has decreased from over 2,300 in 1996 to about 57 in 2009. These percentages may not be representative of the technologies in use today, though it is assumed that the majority of the remaining incinerators are of the controlled-air type.

19.1.2.1   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 is begun 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 oxygen, 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 allowed to cool down and the ash removed so the incinerator may be used again. Continuous-duty incinerators can be operated continuously for an indefinite period of time; 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.

19.1.2.2   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 which would make continuous operation possible. Consequently, the incinerator must be shut down at routine intervals (e.g., daily) for ash removal.

19.1.2.3   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 Air Force installations. For more information regarding rotary-kiln incinerators, refer to section 2.3 of AP-42.

19.1.3 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 the combustion efficiency. Emission factors 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. Emission factors for air curtain incinerators, therefore, may be found in the Transitory Guide.**

19.2 NSPS and NESHAP Applicability

Increased scrutiny regarding the air pollution created by incinerators has led to development of strict regulations. There are several new source performance standards (NSPS) required by the EPA applicable to incinerators. Any steam-generating unit, which includes solid waste incinerators with a heat recovery steam-generating unit, has standards in the 40 CFR 60 subpart Db, *Standards of Performance for Industrial, Commercial, Institutional Steam Generating Units*, which outline the emission standards based on size of the steam-generating unit and year of construction, modification, or reconstruction. The 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*, which provides the operator training, waste management, and inspection guidelines for each medical waste incinerator constructed or modified in the stated time period. 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*, which outlines the emission limits and compliance testing requirements for those incinerators constructed within the stated time period.

It should be noted that, while not covered in this document, 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 of 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 national emission standards for hazardous air pollutants (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 is in compliance with these standards.

19.3 Control Techniques

There are several types of control devices available to minimize the amount of emitted pollutants into the atmosphere. These controls are commonly used for particulate emissions control and are

often used in conjunction with each other. Common controls include electrostatic precipitators, in-duct sorbent injections, spray dryers, and fabric filters. Electrostatic precipitators work by applying an electric charge to the 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 which reacts with the acidic gas in the exhaust stream to form salts. These salts are then removed by a particulate control device. Spray dryers are 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 control device.

19.4 Emission Factors

Emission factors have not been developed directly for incinerators which 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, emission factors applicable to "industrial/commercial" incinerators which burn refuse other than municipal waste should be used for emission calculations. These emission factors are listed in the tables of section 2.1 of AP-42 and are also provided in Table 19-1, and are based on whether the incinerator is a single or multiple chamber design.

Table 19-1. Criteria Pollutant Emission Factors for Classified Waste Incinerators

Combustor Type	Emission Factors (lb/ton)						
	NOx	CO	SOx	VOC[1]	PM$_{10}$[2]	PM$_{2.5}$[2]	GHG[3]
Single Chamber	2.0	20.0	2.5	15.0	4.5	3.0	2034.6
Multiple Chamber	3.0	10.0	2.5	3.0	2.1	1.4	2034.6

SOURCE: 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.

1. Emission factors based on values provided for total organic compounds in source document.

2. Source document provided emissions for total 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.

3. Greenhouse gas emission factors are based on heating values and emission factors for CO_2, CH_4, and N_2O listed in 40 CFR 98 Tables C1 and C2 for municipal solid waste incinerators. Emission factor presented in equivalent CO_2 (CO_2e) by adding the product of each emission factor and the global warming potential for each gas. The global warming potentials for CO_2, CH_4, and N_2O are 1, 25, and 298 respectively.

Emission factors are provided for medical waste incinerators with common control devices seen on Air Force 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 emission factors developed by

AP-42 may be used for emission calculations. These emission factors are given in section 2.3 of AP-42 and also provided here in Table 19-2.

In addition to the criteria pollutant emission factors, AP-42 provides speciated HAP emission factors resulting from medical waste incineration. Again, it is preferable to use on-site test data if possible.   Note that HAP emission factors have not been developed for classified waste incinerators, so it may be necessary to select surrogate emission factors to estimate these emissions. Review chapter 2 of AP-42 for guidance as needed. The speciated HAP emission factors for medical waste incinerators are provided in Table 19-3.

Table 19-2. Criteria Pollutant Emission Factors for Medical Waste Incinerators

Pollutant	Uncontrolled (lb/ton)	Control Device Emission Factors (lb/ton)[1]								
		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[2]	2.17E+00	---	3.75E-01	8.45E-01	2.09E+00	2.57E-02	3.83E-01	7.14E-01	2.42E-02[3]	---
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[4]	2.99E-01	---	---	6.86E-02	1.40E-01	1.40E-01	4.71E-02	---	---	---
PM_{10}[5]	3.04E+00	6.54E-01	1.16E-01	---	2.09E+00	1.06E+00	---	---	1.93E+00	---
$PM_{2.5}$[5]	2.02E+00	2.45E-02	4.35E-03	---	7.83E-02	4.00E-02	---	---	7.24E-02	---
GHG[6]	2.03E+03	---	---	---	---	---	---	---	---	---

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.

1. Control devices include – WS – wet scrubber, FF – fabric filter, DSI – dry sorbent injection, CI – carbon injection, and ESP – electrostatic precipitator.
2. Provided in source document as SO_2.
3. This value is the sum of SO_2 and SO_3 as provided in the source document.
4. Emission factors based on values provided for total organic compounds in source document.
5. PM values based on fraction cumulative mass percentages for size distribution of total particulate matter data.
6. Greenhouse gas emission factors are based on heating values and emission factors for CO_2, CH_4, and N_2O listed in 40 CFR 98 Tables C1 and C2 for municipal solid waste incinerators. Emission factor presented in equivalent CO_2 (CO_2e) by adding the product of each emission factor and the global warming potential for each gas. The global warming potentials for CO_2, CH_4, and N_2O are 1, 25, and 298 respectively.

"---" – Indicates No Data Available. If needed, a conservative estimate may be made using the uncontrolled emission factors as surrogate emission factors.

Table 19-3. Speciated HAP Emission Factors for Medical Waste Incinerators

Pollutant	Uncontrolled (lb/ton)	Control Device Emission Factors (lb/ton)[1]								
		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	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.

1.   Control devices include – WS – wet scrubber, FF – fabric filter, DSI – dry sorbent injection, CI – carbon injection, and ESP – electrostatic precipitator.

"---" – Indicates No Data Available. If needed, a conservative estimate may be made using the uncontrolled emission factors as surrogate emission factors.

19.5 Emissions Calculation

Algorithms and emission factors (EFs) used by the Air Force are generally from AP-42; however, EFs for Air Force-unique sources have been developed by the Air Force. The only algorithms and EFs authorized for use in estimating Air Force emissions are those maintained within the Air Program Information Management System (APIMS).

Pollutant emissions from incinerator use are estimated by taking the product of the mass of waste burned and the appropriate emission factor for each pollutant. If estimating emissions from waste incineration in the presence of a control device, use the emission factor developed for that particular control device. As an alternative, or if an emission factor for that particular control device has not been developed, then it will be necessary to multiply the mass of waste burned and the uncontrolled emission factor by the efficiency of the control device. This calculation is described in Equation 19-1 below.

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

Equation 19-1

Where,

E_{Pol}	=	Emissions of a particular pollutant (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 19-2.
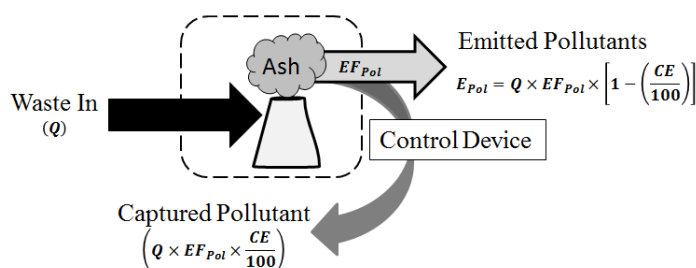
Figure 19-2. Incinerator Use Control Volume

19.6 Information Resources

Medical waste incinerators are typically operated by the base hospital/clinic. The hospital (or clinic) facility manager should be contacted for specific information (e.g., type of incinerator,

quantity of waste combusted) regarding the calculation of emissions. 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.

19.7 Example Problem

Anytown AFB 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%, 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:

$$Q = \frac{11,500 \frac{lb}{yr}}{2,000 \frac{lb}{ton}} = \mathbf{5.75} \; \frac{ton}{yr}$$

Step 2 – **Select and record the appropriate emission factor.** The emission factors for classified waste incinerators are provided in Table 19-1. For a multiple chamber incinerator, the PM_{10} emission factor is given as **2.1lb/ton.**

Step 3 – **Calculate emissions.** Using the total amount of waste incinerated, the emission factor recorded in Step 2, the control device efficiency, and Equation 19-1, PM_{10} emissions are calculated as follows:

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

$$E_{PM_{10}} = 5.75 \; \frac{ton}{yr} \times 2.1 \frac{lb}{ton} \times \left[1 - \left(\frac{97\%}{100\%}\right)\right]$$

$$E_{PM_{10}} = 5.75 \frac{ton}{yr} \times 2.1 \frac{lb}{ton} \times [1 - 0.97]$$

$$E_{PM_{10}} = 5.75 \; \frac{\cancel{ton}}{yr} \times 2.1 \frac{lb}{\cancel{ton}} \times [0.03]$$

$$\boxed{E_{PM_{10}} = \mathbf{0.36} \frac{lb}{yr}}$$

19.8 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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20 LANDFILLS (LAND)

> *Fugitive Source*
> *(Potential) Point Source* – If Gas Collection System Used

20.1 Introduction

A landfill is a defined area of land, used explicitly to deposit wastes. While only a few Air Force installations have active landfills (i.e., wastes currently being deposited) on their property, many installations have closed (i.e., wastes no longer being deposited) landfills on their property. **Both active and closed landfills serve as fugitive (and potentially point) sources of VOCs, HAPs, greenhouse gases (GHG), and particulate matter.**

There are a variety of different wastes which may be deposited in landfills, including municipal solid waste (MSW), construction and demolition wastes, commercial and industrial organic wastes, agricultural wastes, etc. All landfills which contain any organic wastes will generate and release gaseous emissions. According to AP-42, these emissions contain approximately 55% by volume CH_4, 40% CO_2, 5% N_2 (an inert gas), and trace amounts of non-methane organic compounds (NMOCs). Landfills are known to be the third largest human generated source of methane in the United States.

Most landfills are equipped with some form of active or passive gas collection systems and control devices. Active collection systems employ the use of mechanical blowers or compressors to generate a pressure gradient in order to extract the landfill gases. 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 internal combustion (IC) engine, while passive collection systems will vent the gases directly to the atmosphere without the use of any control device. Air Force 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 20-1.
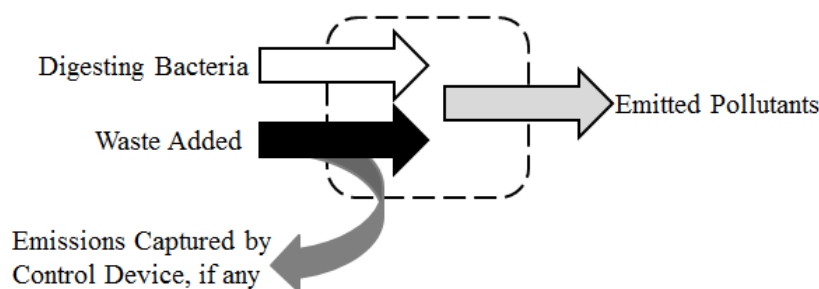
Figure 20-1. Simplified Control Volume for Emissions from Landfills

In general, a three step process is followed when depositing waste into an active landfill. The waste is spread, compacted, and then covered with a layer of soil. The covering of the waste is typically performed using heavy equipment (e.g., bulldozers, graders) and results in the generation of fugitive dust emissions. 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. **However, while estimating fugitive dust emissions at landfills is described below, both on-road and non-road equipment exhaust emissions are considered mobile in nature and are addressed in the Mobile Source Emissions Guide.**

Municipal solid waste (MSW) landfills primarily receive household wastes, but may additionally receive wastes such as 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). The regulations outlined there describe the 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 both active landfills and for a period of 30 years after landfill closure. Details regarding these requirements are given in 40 CFR 258.

The waste deposited into a designated Construction and Demolition (C&D) landfill may vary widely in size and composition. There are three main factors that influence the characteristics of this type of waste: the original structure type (e.g., building, road, bridge), the original structure size (e.g., low-rise, high-rise), and the activity being performed (e.g., construction, renovation, repair, demolition). For example, some wastes may be generated as a result of asphalt paving operations, residential building demolition, or industrial building construction.

According to an EPA report, approximately one-fourth to one-third of C&D wastes are wood products. Other main components include asphalt, drywall, and masonry. Minor components may consist of metals, plastics, shingles, and insulation. Although a specific landfill may contain most of these components, C&D landfills are often designated for one type of C&D waste. If the composition of the waste is known, then more accurate emissions may be calculated.

20.2 NSPS and NESHAP Applicability

Several New Source Performance Standards (NSPS) have been developed to aid in the reduction of pollution from active and closed landfills. Emissions 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, 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 non-methane organic compound (NMOC) emission rate of at least 50 megagrams per year must have control devices installed to monitor and control the amount of NMOC released to the atmosphere. 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 national emission standards for hazardous air pollutants (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 as well as 40 CFR 63 subpart AAAA.

20.3 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 equivalent CO_2 (CO_2e) is subject to the greenhouse gas (GHG) reporting rules as outlined in 40 CFR 98. CH_4 generation from landfills and destruction as a result of 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 municipal solid waste 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, <u>and</u> 3) An annual report was not required under any requirement in 40 CFR 98 subpart HH in any reporting year prior to 2013.**

20.4 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 methane to carbon dioxide, which has a significantly lower global warming potential. Typical control efficiencies of common control devices are provided in Table 20-1.

The disadvantage of combustion control is that the combustion of landfill gas may lead to nitrogen oxides (NO_X), sulfur oxides (SO_X), carbon monoxide (CO), and particulate matter. 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. Phosphoric acid fuel cell (PAFC) is an example of an energy recovery technology. This system 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 carbon dioxide and methane using a number of 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 through the use of flares.

Table 20-1. 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[1]	99.6	87-99+
	Non-Halogenated Species	99.8	67-99+
Flare[2] (SCC 5-01-004-10, 5-03-006-01)	NMOC	99.2	90-99+
	Halogenated Species[1]	98.0	91-99+
	Non-Halogenated Species	99.7	38-99+
Gas Turbine	NMOC	94.4	90-99+
	Halogenated Species[1]	99.7	98-99+
	Non-Halogenated Species	98.2	97-99+
IC Engine	NMOC	97.2	94-99+
	Halogenated Species[1]	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.

1. 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 HCl.

2. 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.

20.5 Emission Factors

VOC, HAP, and GHG emissions are calculated using the LandGEM model, so the use of emission factors 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 emission factors. Fugitive dust emission factors at landfills are also a function of the soil moisture and silt content. Emission factor equations are provided in Section 11.9 of AP-42. Using the geometric average for silt and moisture content and average grader speed, the emission factor equations were simplified and are provided in Table 20-2. For enhanced accuracy, refer to Table 11.9-1 of AP-42 and use on-site moisture content, silt content, or average grader speed to calculate more accurate emission factors.

Table 20-2. Fugitive Dust Emission Factors at Active Landfills

Operation	Emission Factors[1]		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.

1. Particulate 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.

20.6 Emissions Calculation

Algorithms and Emission Factors (EFs) used by the Air Force are generally from AP-42; however, EFs for Air Force-unique sources have been developed by the Air Force. The only algorithms and EFs authorized for use in estimating Air Force emissions are those maintained within the Air Program Information Management System (APIMS).

20.6.1 Uncontrolled Emissions

The Landfill Gas Emissions Model (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, including CH_4, CO_2, NMOCs, and individual air pollutants from landfills. 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 as a result 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 emissions inventory table for a user-specified year.

20.6.2 Controlled Emissions

The LandGEM model does not directly calculate emissions from landfills that have emissions 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. Emissions of CO_2 and other combustion products from the control device must then be considered. **Air emissions resulting from the combustion of landfill gases are calculated using the methods described in the "external combustion" section of this document.** 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:

$$E(Cont.)_{Pol} = E(Uncont.)_{Pol} \times \left[1 - \left(\frac{Cap}{100}\right) \times \left(\frac{CE}{100}\right)\right]$$

Equation 20-1

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 20-2.
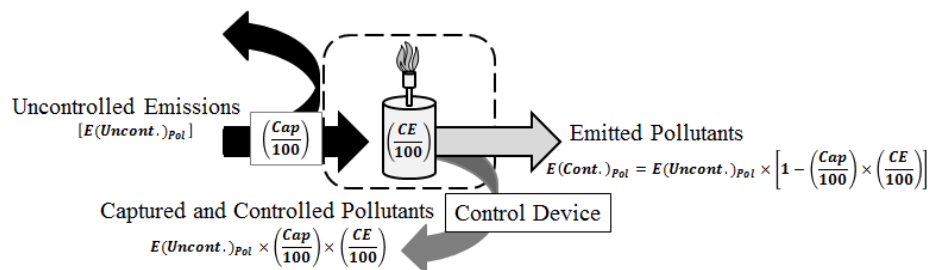
Figure 20-2. Landfill Control Volume – Controlled Emissions

20.6.3 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 emission factors provided in Table 20-2, fugitive dust emissions are calculated as follows:

$$E_{Pol} = [EF(Bulldozing)_{Pol} \times OT] + [EF(Grading)_{Pol} \times VMT]$$

Equation 20-2

Where,

E_{Pol}	=	Annual emissions of pollutant (lb/yr)
$EF(Bulldozing)_{Pol}$	=	Bulldozing emission factor (lb/hr). This is provided in Table 20-2.
OT	=	Annual bulldozing operating time (hr/yr)
$EF(Grading)_{Pol}$	=	Grading emission factor (lb/VMT). This is provided in Table 20-2.
VMT	=	Annual miles traveled by grader (miles/yr)

20.7 Information Resources

Base Civil Engineering is typically responsible for operating and maintaining on-base landfills, and should be contacted to obtain specific landfill information. Base weather may be contacted to determine the annual average rainfall received by the base. The average rainfall 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 Civil Engineering.

20.8 Example Problem

Anytown AFB 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 Civil Engineering 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 located in an area which receives an average of 36 inches of rain per year. The average temperature of the landfill gas is estimated to be 50°F (10° C). Calculate the annual emission rate of total NMOC (considered the same as VOC) and of 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*. If the landfill is currently open, LandGEM can also calculate the estimated closure year as long as the two fields below the **Landfill Closure Year** are completed.

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

Under section 3: SELECT GAS/POLLUTANTS, change **Gas/Pollutant #3** to *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. 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 air emission inventory 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 megagrams per year (Mg/year) and standard tons per year (short tons/year). The appropriate data column can be copied to another spreadsheet and combined with similar calculations for other landfills at an installation to summarize the installation's landfill emissions for the inventory year. The objective of this problem is to determine the 2014 annual emissions from the landfill for NMOC and dichloromethane. Scroll down to the Results section of the REPORT tab and find the column labeled Xylenes – HAP/VOC and NMOC. Find 2014 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 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 further calculations require the units to be in lb/yr. Conversion of the units is performed as follows:

$$E(Uncont.)_{Xylenes} = 0.1407 \frac{Mg}{yr} \times 2204.62 \frac{lb}{Mg} = \mathbf{310.19} \frac{lb}{yr}$$

$$E(Uncont.)_{NMOC} = 5.711 \frac{Mg}{yr} \times 2204.62 \frac{lb}{Mg} = \mathbf{12590.58} \frac{lb}{yr}$$

Step 4 – Select and record the capture and control efficiencies. Since the capture efficiency is unknown, a value of **75% is assumed**. The control efficiency of a flare however is given in Table 20-1. For xylenes, this efficiency is stated to be **99.7%** and for NMOC is **99.2%**.

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 20-1 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:

$$E(Cont.)_{Xylenes} = 310.19 \frac{lb}{yr} \times \left[1 - \left(\frac{75\%}{100\%} \right) \times \left(\frac{99.7\%}{100\%} \right) \right]$$

$$E(Cont.)_{Xylenes} = 310.19 \frac{lb}{yr} \times [1 - (0.75) \times (0.997)]$$

$$E(Cont.)_{Xylenes} = 310.19 \frac{lb}{yr} \times [1 - (0.74775)]$$

$$E(Cont.)_{Xylenes} = 310.19 \frac{lb}{yr} \times [0.25225]$$

$$\boxed{E(Cont.)_{Xylenes} = 78.25 \frac{lb}{yr}}$$

For NMOC:

$$E(Cont.)_{NMOC} = 12590.58 \frac{lb}{yr} \times \left[1 - \left(\frac{75\%}{100\%} \right) \times \left(\frac{99.2\%}{100\%} \right) \right]$$

$$E(Cont.)_{NMOC} = 12590.58 \frac{lb}{yr} \times [1 - (0.75) \times (0.992)]$$

$$E(Cont.)_{NMOC} = 12590.58 \frac{lb}{yr} \times [1 - (0.744)]$$

$$E(Cont.)_{NMOC} = 12590.58 \frac{lb}{yr} \times [0.256]$$

$$\boxed{E(Cont.)_{NMOC} = 3223.19 \frac{lb}{yr}}$$

20.9 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 Perfromance for 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

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

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

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21 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

21.1 Introduction

Miscellaneous chemicals include a wide variety of items which are point sources of air emissions that are not specifically addressed in any other section of this document. The chemicals which fall into this category are typically items commercially purchased in small quantities such as household cleaners, adhesives, or sealants, and also include lab chemicals and solvents used for degreasing or non-destructive inspections. Though most miscellaneous chemicals are typically exempt from regulatory consideration under federal, state, and local air pollution control agency air quality regulations, these agencies should be consulted prior to excluding this category. Information pertaining to the composition of miscellaneous 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 miscellaneous 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 which have extremely low vapor pressures (e.g., <0.1 mm Hg), are usually not addressed in an air emissions inventory and are considered insignificant. Examples include heavy lubricants/oils, greases, hydraulic fluids, glycol deicers, non-solvent (aqueous) cleaners, etc. **Emissions from miscellaneous chemical use may be either point or fugitive, depending on if an industrial ventilation (non-HVAC) system is used.** Figure 21-1 provides a graphical representation of emissions from miscellaneous chemicals.
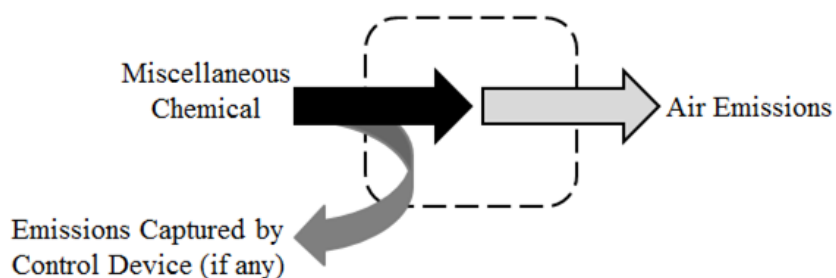
Figure 21-1. Simplified Control Volume for Emissions from Miscellaneous Chemicals

21.1.1 Laboratory Chemicals (LAB)

Chemical laboratories are commonly found at Air Force installations and are typically used for analytical, medical, and/or research purposes. A large variety of chemicals are used in these

laboratories including solvents, acids/bases, and various other 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 pass the air emissions through a filter, which recovers and allows for the disposal of the emitted pollutant. Other fume hoods vent pollutants directly into the atmosphere. **The main pollutants of concern are the VOCs and/or volatile HAPs ingredients in liquid reagents.**

To quantify emissions from laboratory chemicals, the chemicals must be considered a "loss", e.g., the chemical is not part of the product or the solid waste stream. 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 then the maximum amount of the specified chemical that could have potentially been emitted into the air between the two inventory periods.

21.1.2 Non Destructive Inspection (NDI)

Air Force installations with aircraft maintenance operations typically have a Non-Destructive Inspection (NDI) shop where metal parts are inspected for cracks, fractures, and other flaws. NDI shops use a variety of chemicals to inspect and clean metal parts 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.** Ozone Depleting Chemicals (ODCs) may also be considered, as some inspection chemicals may contain methyl chloroform, a known ODC.

Generally, there are two methods used at NDI shops to inspect and clean parts. The first method involves placing chemicals into a tank and then submerging/soaking parts in the chemical. 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. This method results in air emissions as the chemicals evaporate during use within the tank, as the chemicals are loaded into the tank, and also from the evaporation off of 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 have

evaporated 100% into the air and should be multiplied by its density in order to calculate the annual emissions.

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. In order to calculate the emissions of a particular 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.

21.1.3 Printing Operations (PHAT)

Some Air Force 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 due to the fact that printing can occur at high speeds and on both sides of a page. The process involves the use of plates which have an image area 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 which 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 which may result in a high initial investment cost, thus limiting the use of plate-less printing to in-plant and quick printing applications.

21.1.4 Solvent Cleaning Equipment (DEGR)

Solvent cleaning equipment is commonly used by Air Force 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 Civil Engineering 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 (e.g., cause inadequate cleaning or corrosion). **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, perchloroethylene, 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 Air Force 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 allowed to drain from the parts for at least 15 seconds (or until dripping has stopped) before removing. The cover 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 which 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 into 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, including 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. Illustrations of cleaning equipment can be found in Figure 21-2.
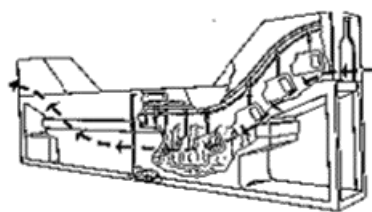
In-line vapor cleaning system   Open top batch vapor cleaning machine
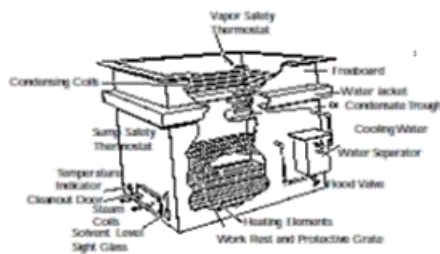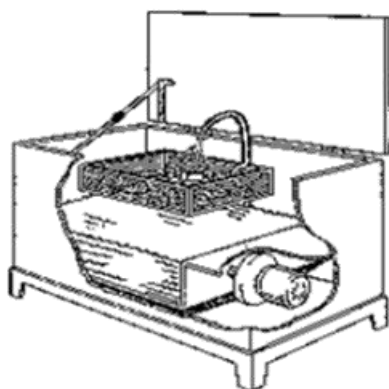
Open top batch cold solvent cleaning machine   Ferris-wheel batch solvent cleaning machine
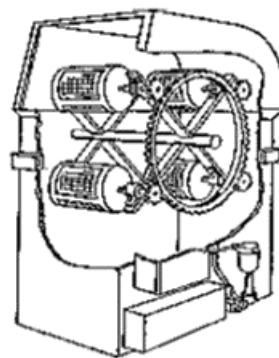
Figure 21-2. Examples of Solvent Cleaning Equipment

21.1.5 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. The former removes the solvent vapors from a gas stream to prepare it for further reclamation and the latter 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 which 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 while 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 (either the water layer or the solvent layer). With salting, solvent is passed through a calcium chloride bed and water is removed by absorption. The purification process is also where reclaimed solvents are stabilized if necessary.

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% of this waste is unreclaimed solvent, the rest of which 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 (this is mainly because 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 emission factors; 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 emission factors, refer to Chapter 4.7 Waste Solvent Reclamation of AP-42.

21.1.6 Hand-Wipe Cleaning (CLN)

Hand-wipe cleaning involves the use of cleaning solvents to remove contaminants from a surface by hand. Typically, at an Air Force installation, this is performed on aircraft and aircraft components, making the use of solvents for this purpose subject to the standards outlined in 40 CFR 63 subpart GG, *National Emission Standards for Aerospace Manufacturing and Rework Facilities*. The source of air emissions from this source is the evaporation of the cleaning solvent which contains a significant amount of VOCs. As with other sources which 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.

21.1.7 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 due to the fact that sealants are not as strong as adhesives but are more elastic which allows for more flexibility between substrates with different thermal coefficients of expansion.

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, and also can 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 which harden through chemical reaction while non-reactive adhesives do not. Reactive adhesives may be either multi-part, which require the mixing of two compounds which chemically react and harden, or single-part which harden through chemical reactions with heat, radiation, or moisture. Non-reactive adhesives include drying adhesives which often may be solvent based. The adhesive hardens as the solvent evaporates.

21.1.8 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 Air Force 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.

21.1.9 General Solvent Use (GSOL)

Solvents used on base which do not fall into the categories listed above (or any other section of this document) may fall into the general solvent use source category. Sources which 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 subject matter expert for any guidance as necessary.

21.2 NSPS and NESHAP Applicability

For processes which fall under the miscellaneous chemicals category, there are several standards which have been enacted to limit the emissions of pollutants into the atmosphere. A new source performance standard (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 which performs rotogravure printing may emit more than 16% 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 miscellaneous chemicals and applications may have applicable NESHAP requirements, provided in the code of federal regulations. For example, 40 CFR 63 subpart T, *National Emission Standards for Halogenated Solvent Cleaning*, applies to any solvent cleaning machine which uses either methylene chloride, perchloroethylene, trichloroethylene, 1,1,1-trichloroethane, carbon tetrachloride, or chloroform in excess of 5% 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 which 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% 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 code of federal regulations, including 40 CFR 63 subparts T, GG and KK, for more information and to verify that the installation is in compliance with these standards.

21.3 Control Techniques

Air emissions control equipment may or may not be installed on any of the equipment involved in any processes which are described under miscellaneous chemical use. Some processes, such as solvent degreasing, may have one or more control devices working in combination to reduce air emissions. Such control devices include condensers or a carbon adsorption system. 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 and the control device manufacturer to get specifics on the control efficiencies.

21.4 Emissions Calculation

Algorithms and emission factors (EFs) used by the Air Force are generally from AP-42; however, EFs for Air Force-unique sources have been developed by the Air Force. The only algorithms and EFs authorized for use in estimating Air Force emissions are those maintained within the Air Program Information Management System (APIMS). Emissions from miscellaneous chemical use may be 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:

$$E_{Pol} = (Q_A - Q_R - Q_C) \times \left(\frac{WP_{Pol}}{100} \right)$$

Equation 21-1

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, 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 21-3.
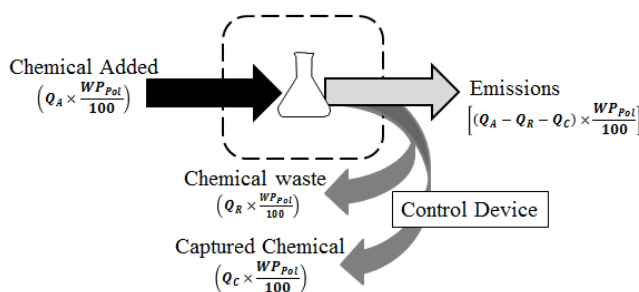
Figure 21-3. Miscellaneous Chemical Control Volume

If the mass of chemical captured by the control device cannot be measured on-site, this value may be estimated for those processes which have a control device in use. 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 21-2

Where,

    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, then the mass may be calculated using the chemical density or specific gravity as follows:

$$Q_X = (V_X \times D) = (V_X \times SG \times 8.33)$$

Equation 21-3

Where,

    Qx   = Annual mass of chemical used, disposed, or captured (lb/yr)
    Vx   = 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)

21.5 Information Resources

Most of the usage information necessary to calculate emissions from miscellaneous chemicals (e.g., name, stock number, and manufacturer of applicable chemicals; identity of shops using the

chemicals; quantity used by each shop) may be obtained from EESOH-MIS (Enterprise Environmental, Safety & Occupational Health Management Information System), HAZMART (Hazardous Materials Pharmacy), Bioenvironmental Engineering, or from the applicable supply office. If necessary, the shops which 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 miscellaneous chemicals can be obtained from the MSDS, other product literature, the commercial vendor (if applicable), or from the chemical manufacturer. For chemicals purchased from a government supply center such as the Defense Logistics Agency (DLA) or the General Services Administration (GSA), information on a solvent can usually be obtained from the applicable supply center (DLA or GSA) where the solvent was purchased.

21.6 Example Problem

Air emissions for selected chemical products have been requested from the local regulatory agency. According to the Enterprise Environmental, Safety, & Occupational Health Management Information System (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 21-3 as shown:

$$Q_X = (V_X \times D)$$

For the General Machinery Cleaner:

$$Q_A = 120.0 \frac{gal}{yr} \times 6.5 \frac{lb}{gal} = \mathbf{780.0} \frac{lb}{yr}$$

$$Q_R = 24.0 \frac{gal}{yr} \times 6.5 \frac{lb}{gal} = \mathbf{156.0} \frac{lb}{yr}$$

$$Q_C = 20.0 \frac{gal}{yr} \times 6.5 \frac{lb}{gal} = \mathbf{130.0} \frac{lb}{yr}$$

For the Contact Adhesive:

$$Q_A = 22.0 \frac{gal}{yr} \times 6.6 \frac{lb}{gal} = \mathbf{145.2} \frac{lb}{yr}$$

$$Q_R = 0.0 \frac{gal}{yr} \times 6.6 \frac{lb}{gal} = \mathbf{0.0} \frac{lb}{yr}$$

$$Q_C = 0.0 \frac{gal}{yr} \times 6.6 \frac{lb}{gal} = \mathbf{0.0} \frac{lb}{yr}$$

Step 2 - Calculate the VOC emissions. Use Equation 21-1, the mass 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:

$$E(Cleaner)_{VOC} = (780.0 - 156.0 - 130.0) \frac{lb}{yr} \times \left(\frac{84\%}{100\%}\right)$$

$$\boldsymbol{E(Cleaner)_{VOC}} = (494) \frac{lb}{yr} \times (0.84) = \mathbf{415.0} \frac{lb}{yr}$$

For the Contact Adhesive:

$$E(Adhesive)_{VOC} = (145.2 - 0.0 - 0.0) \frac{gal}{yr} \times \left(\frac{65\%}{100\%}\right)$$

$$\boldsymbol{E(Adhesive)_{VOC}} = (145.2) \frac{lb}{yr} \times (0.65) = \mathbf{94.4} \frac{lb}{yr}$$

Step 3 – Calculate the total VOC emissions from miscellaneous chemicals. Sum the VOCs emitted from the two compounds calculated above:

$$E_{VOC} = \Sigma\left(E_{VOC_i} + \cdots + E_{VOC_n}\right)$$

$$E_{VOC} = 415.0\frac{lb}{yr} + 94.4\frac{lb}{yr}$$

$$\boxed{E_{VOC} = 509.4\frac{lb}{yr}}$$

Step 4 - Calculate the HAP emissions. Use Equation 21-1 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:

$$E_{Methanol} = (780.0 - 156.0 - 130.0)\frac{lb}{yr} \times \left(\frac{50\%}{100\%}\right)$$

$$\boldsymbol{E_{Methanol}} = (494.0)\frac{lb}{yr} \times (0.5) = \boldsymbol{247.0\frac{lb}{yr}}$$

$$E_{Toluene} = (780.0 - 156.0 - 130.0)\frac{lb}{yr} \times \left(\frac{15\%}{100\%}\right)$$

$$\boldsymbol{E_{Toluene}} = (494.0)\frac{lb}{yr} \times (0.15) = \boldsymbol{74.1\frac{lb}{yr}}$$

For the Contact Adhesive:

$$E_{n-Hexane} = (145.2 - 0 - 0)\frac{lb}{yr} \times \left(\frac{30\%}{100\%}\right)$$

$$\boldsymbol{E_{n-Hexane}} = (145.2)\frac{lb}{yr} \times (0.3) = \boldsymbol{43.6\frac{lb}{yr}}$$

$$E_{Toluene} = (145.2 - 0 - 0)\frac{lb}{yr} \times \left(\frac{20\%}{100\%}\right)$$

$$\boldsymbol{E_{Toluene}} = (145.2)\frac{lb}{yr} \times (0.2) = \boldsymbol{29.0\frac{lb}{yr}}$$

Step 5 - Calculate the total HAP emissions. The total HAP emissions from miscellaneous chemicals are the sum of the HAP constituents calculated in Step 4 as shown:

$$E_{HAP\ (Total)} = \Sigma\left(E_{HAP_i} + \cdots + E_{HAP_n}\right)$$

$$E_{HAP\ (Total)} = \left(247.0\frac{lb}{yr} + 74.1\frac{lb}{yr} + 43.6\frac{lb}{yr} + 29.0\frac{lb}{yr}\right)$$

$$\boxed{E_{HAP\,(Total)} = 393.7\,\frac{lb}{yr}}$$

21.7 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

22 MUNITIONS OPEN BURN/OPEN DETONATION (OBOD)

➢ *Fugitive Source*

22.1 Introduction

OB/OD is often utilized in the Air Force as a means to dispose 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, 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, while 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).

Emissions of concern from OB/OD operations include criteria pollutants, organic and inorganic HAPs, and greenhouse gases. Emissions are fugitive and dependent upon the type and quantity of items that are burned or detonated. A graphical representation of the emissions from Open Burn/Open Detonation is provided in Figure 22-1.
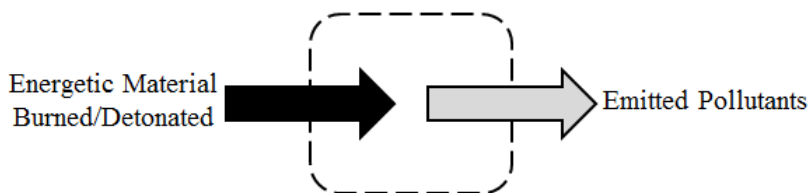
Figure 22-1. Simplified OB/OD Control Volume

22.2 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 is in compliance with these guidelines, refer to the table in 40 CFR 265.382.

22.3 Emission Factors

The DoD has developed the Open Burn/Open Detonation Dispersion Model (OBODM) which contains a database of emission factors for a number of munitions and explosives. More recently, however, the EPA has developed emission factors for several munitions, assembled energetic materials, explosives, and propellants. These emission factors have been published and are available in Chapter 15, "Ordnance Detonation," of AP-42. **This section does not provide emission factors for cartridges. Refer to the Small Arms Firing Range Chapter for this data.** The criteria pollutant emission factors for energetic materials are provided in Table 22-1 while the HAP emission factors are given in Table 22-2.

The emission factors are in units of pound of pollutant per item, but may be converted into units of pound pollutant per pound Net Explosive Weight (NEW). Unit conversion is accomplished by dividing the emission factor (in pounds per item) by the NEW of the item. The default NEW 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" (identified with the abbreviation "ALT") components for a munition that <u>should not</u> be included when calculating the NEW for the item. MIDAS is available at https://midas.dac.army.mil. In order to use MIDAS, you must first register and obtain a password from the Army's Defense Ammunition Center (DAC).

22.4 Emissions Calculation

Algorithms and emission factors (EFs) used by the Air Force are generally from AP-42; however, EFs for Air Force-unique sources have been developed by the Air Force. The only algorithms and EFs authorized for use in estimating Air Force emissions are those maintained within the Air Program Information Management System (APIMS). The following equations may be used to calculate emissions using emission factors.

$$E_{Pol} = Q \times EF_{Pol}$$

Equation 22-1

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 22-2.
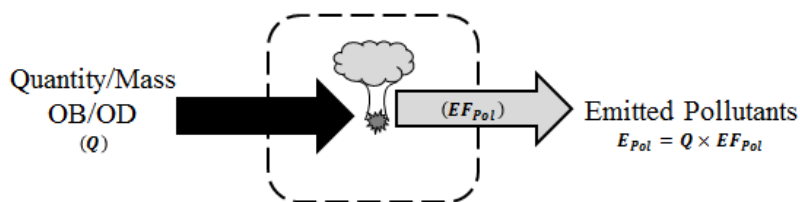
Figure 22-2. OB/OD Control Volume – Without Donor Charge

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:

$$E_{Pol} = \left(Q_{EM} \times EF_{Pol_{EM}}\right) + \left(Q_{DC} \times EF_{Pol_{DC}}\right)$$

Equation 22-2

Where,

Q_{EM}	= Annual quantity or mass of items to be OD during the year (items/yr or lb NEW/yr)
$EF_{Pol_{EM}}$	= Emission factor of munition or energetic material (lb/item or lb/lb NEW)
Q_{DC}	= Annual quantity of donor charge to be OD during the year (lb/yr)
$EF_{Pol_{DC}}$	= 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 22-3.
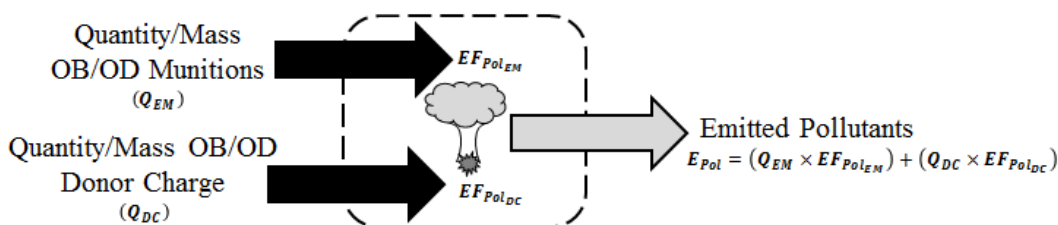
Figure 22-3. OB/OD Control Volume – With Donor Charge

22.5 Information Resources

Information required for calculating emissions from OB/OD operations can be obtained from the base Explosive Ordnance Disposal (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 the Army's Munitions Items Disposition Action System (MIDAS) at https://midas.dac.army.mil.

22.6 Example Problem

Anytown AFB is looking to calculate emissions from the open burn/open detonation of several munitions from the previous year. The Explosive Ordnance Disposal (EOD) shop stated that, during the previous year, 20 ¼ lb demolition block charges (M030) and 12 M4 incendiary bursters (K010) were openly detonated. A donor charge of 10g of TNT was used per M4 burster. Determine the total NO_X and benzene emissions from the open detonation of these munitions.

Step 1 – Select and record the appropriate emission factors. The emission factors for NO_X are provided in Table 22-1. For the demolition block charges, M4 bursters, and TNT, the NO_X emission factors are **3.00E-03 lb/item, 4.20E-03 lb/item, and 9.27E-03 lb/lb NEW** respectively. Similarly, Table 22-2 provides the benzene emission factors for each munition. For the demolition block charges, M4 bursters and TNT, the benzene emission factors are **2.90E-07 lb/item, 5.80E-06 lb/item, and 4.10E-06 lb/lb NEW** respectively.

Step 2 – Calculate the total TNT used. Since 10 grams of TNT were used for each M4 burster, the total TNT used (in pounds) is calculated as follows:

$$Q_{DC} = 10\frac{g}{item} \times 12\frac{items}{yr} \times \frac{0.00220462\ lb}{g} = \mathbf{0.265}\frac{lb\ NEW}{yr}$$

Step 3 – Calculate emissions from the demolition block charges. Using the emission factors provided in Step 1 and the quantities provided in the problem statement, the emissions from the demolition block charges are calculated using Equation 22-1 as follows:

$$E_{Pol} = Q \times EF_{Pol}$$

For NO_X:

$$E_{NO_X} = 20\frac{items}{yr} \times 0.003\frac{lb}{item} = \mathbf{0.06}\frac{lb}{yr}$$

For Benzene:

$$E_{Benzene} = 20\frac{items}{yr} \times 0.00000029\frac{lb}{item} = \mathbf{0.0000058}\frac{lb}{yr}$$

Step 4 – Calculate emissions from the M4 bursters and donor charges. This is accomplished by taking the emission factors from Step 1, the total mass of TNT used, and Equation 22-2 as shown:

$$E_{Pol} = \left(Q_{EM} \times EF_{Pol_{EM}}\right) + \left(Q_{DC} \times EF_{Pol_{DC}}\right)$$

For NO_X:

$$E_{NO_X} = \left(12 \frac{items}{yr} \times 0.0042 \frac{lb}{item}\right) + \left(0.265 \frac{lb\ NEW}{yr} \times 0.00927 \frac{lb}{lb\ NEW}\right)$$

$$\boldsymbol{E_{NO_X}} = \left(0.0504 \frac{lb}{yr}\right) + \left(0.0025 \frac{lb}{yr}\right) = \boldsymbol{0.0529}$$

For Benzene:

$$E_{benzene} = \left(12 \frac{items}{yr} \times 0.0000058 \frac{lb}{item}\right) + \left(0.265 \frac{lb\ NEW}{yr} \times 0.0000041 \frac{lb}{lb\ NEW}\right)$$

$$\boldsymbol{E_{benzene}} = \left(0.0000696 \frac{lb}{yr}\right) + \left(0.0000010865 \frac{lb}{yr}\right) = \boldsymbol{0.0000706865}$$

Step 5 – Calculate total emissions. Sum the NO_X and benzene emissions from each munition as follows:

$$E_{Pol_{Total}} = \sum_{i=1}^{n} \left(E_{Pol_i} + \cdots + E_{Pol_n}\right)$$

For NO_X:

$$E_{NO_{X_{Total}}} = (0.06 + 0.0529) \frac{lb}{yr}$$

$$\boxed{\boldsymbol{E_{NO_{X_{Total}}}} = \mathbf{1.13E-01} \frac{lb}{yr}}$$

For Benzene:

$$E_{Benzene_{Total}} = (0.0000058 + 0.0000706865) \frac{lb}{yr}$$

$$\boxed{\boldsymbol{E_{Benzene_{Total}}} = \mathbf{7.65E-05} \frac{lb}{yr}}$$

Table 22-1. Criteria Pollutant Emission Factors for OB/OD

Munition Type	DODIC	Item	Units:	Net Explosive Material (NEW)	NOx	CO (630-08-0)	SO$_2$ (7446-09-5)	Pb (7439-92-1)	VOC[1]	PM$_{10}$	PM$_{2.5}$	GHG[2]
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	---	1.80E+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	5.35E+00
	D540	**155-mm Propelling Charges (M3/M3A1)**	**lb/lb NEW**	(3)	**3.90E-02**	**5.90E-01**	**---**	**9.90E-05**	**---**	**1.70E-02**	**8.10E-03**	**2.93E-01**
	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	5.60E+00
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	1.70E-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	1.70E-04
	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	2.47E-01
	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	2.13E-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	6.27E-01
	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	3.30E-02
	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	8.40E-02
	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	---	---	7.70E-02
	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	7.70E-02
	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	4.30E-02
	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	9.10E-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	1.50E-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	1.30E-01
	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	1.70E-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	1.00E+00
	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	2.95E+00
	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	8.85E-02
		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	3.75E-01
		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	4.69E-01
	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	1.42E-02
		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	7.30E-06
		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	1.42E-02
	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	4.96E+00

Table 22-1. Criteria Pollutant Emission Factors for OB/OD (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[1]	PM$_{10}$	PM$_{2.5}$	GHG[2]
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	3.40E-01
	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	1.50E-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	3.60E-03
	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	1.61E+00
	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	9.00E-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	4.60E-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	5.30E-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	---	8.80E-02
	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	---	1.80E-01
	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	---	1.80E-01
	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	---	1.40E-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	---	3.80E-03
	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	---	1.40E-01
	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	1.70E-02
	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	1.10E-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	1.10E-02
	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	---	5.20E-02
	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	8.50E-02
	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	3.60E-04
	L594	Ground Burst Simulator (M115A2)	lb/item	1.41E-01	5.50E-03	2.10E-03	1.50E-04	4.10E-06	1.30E-03	1.90E-01	---	3.40E-03
	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	1.09E-02
	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	---	2.50E-01
	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	---	1.70E-02
	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	---	4.10E-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	---	4.10E-03
	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	2.91E-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	3.93E-01

Table 22-1. Criteria Pollutant Emission Factors for OB/OD (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[1]	PM$_{10}$	PM$_{2.5}$	GHG[2]
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	8.30E-01
	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	3.41E-01
	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	7.20E-01
	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	1.20E+00
	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	8.33E-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	9.50E-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	7.33E-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	4.40E-01
	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	1.10E-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	1.30E+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	1.49E-03
	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	5.00E+00
	M500	Cartridge Actuated Cutter (M21)	lb/item	4.00E-03	1.40E-06	2.10E-04	---	---	---	9.60E-07	7.40E-07	3.48E-04
	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	3.32E-01
	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	1.60E-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	5.40E-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	4.15E-01
	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	1.07E-05
	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	1.21E+00
	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	3.58E-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	1.51E+00
	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**	**2.40E-01**
	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**	**4.40E-01**
	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	2.50E-03
	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	2.98E-02
	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	1.14E-02
	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	2.41E-02
	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	1.11E-02
	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	2.08E-03
	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	9.98E-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	9.95E-03
	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	4.50E-03

Table 22-1. Criteria Pollutant Emission Factors for OB/OD (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[1]	PM10	PM2.5	GHG[2]
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	5.23E-02
	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	7.30E-04
	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	3.11E-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	2.83E-02
	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	2.50E-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	6.15E-03
Energetic Materials[4]	---	**Amatol**	**lb/lb NEW**	**5.00E-01**[5]	1.81E-02	9.70E-03	2.60E-04	3.30E-05	4.50E-04	1.90E-02	---	7.00E-01
	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	---	4.80E-01
	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	---	5.00E-01
	M943	**Cartridge, Impulse, MK 107**	**lb/lb NEW**	---	1.56E-02	1.40E-02	2.60E-04	---	6.40E-04	2.50E-01	---	8.50E-01
	---	**Composition B surrogate**	**lb/lb NEW**	**5.00E-01**[5]	9.49E-03	4.20E-03	1.30E-04	---	1.10E-04	1.20E-02	---	1.10E+00
	---	**Detonating Train**	**lb/lb NEW**	---	9.30E-03	9.40E-03	4.60E-04	1.80E-04	8.50E-04	3.60E-02	---	9.10E-01
	L410	**Flare, IR Countermeasure M206**	**lb/lb NEW**	---	8.10E-03	8.30E-03	1.00E-03	---	6.10E-04	5.50E-01	---	8.10E-01
	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	---	9.40E-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	---	1.40E+00
	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	---	1.10E+00
	L306	**Signal, Illumination, Red Star M158**	**lb/lb NEW**	---	4.10E-03	1.20E-02	1.10E-04	---	7.70E-04	8.20E-02	---	5.10E-01
	---	**Tritonal surrogate**	**lb/lb NEW**	---	8.35E-03	4.70E-03	1.60E-04	1.10E-03	2.80E-04	3.70E-01	---	6.40E-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	---	1.30E+00
	---	**TNT**	**lb/lb NEW**	---	9.27E-03	1.00E-02	1.40E-04	9.00E-06	2.80E-05	7.30E-02	---	1.50E+00

SOURCE: United States EPA. Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources. Fifth edition. Chapter 15.

1. Source document provided an emission factor for total non-methane organic compounds (TNMOC). This value used as a surrogate emission factor for total VOCs.

2. Greenhouse gas emission factor presented in equivalent CO_2 (CO_2e). This value calculated by taking the product of the CO_2 emission factor and its global warming potential (GWP) and adding this to the product of the CH_4 emission factor and its GWP. According to 40 CFR 98, Table A-1, the GWP for CO_2 and CH_4 are 1 and 25 respectively.

3. There are variations in the NEW depending on the charge configuration. Refer to Table 15.4.1-1 of AP-42 for specific data.

4. 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.

5. 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.

"---" – Indicates no data available

Table 22-2. HAP Emission Factors for OB/OD

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**	**(1)**	**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-06	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-06	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-06	---	---	---
	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-06	---	---	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 22-2. HAP Emission Factors for OB/OD (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	---
Mines and Smoke Pots	K042	Practice Canister Mine (Volcano) (M88)	lb/item	1.39E-02	---	---	1.40E-06	---	---	---	---	---	---	3.70E-06	---	---	2.10E-07	---	---	---
Mines and Smoke Pots	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
Mines and Smoke Pots	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
Mines and Smoke Pots	K765	CS Riot Control Agent Capsule	lb/item	---	---	---	---	1.50E-06	---	4.40E-08	---	---	---	---	---	---	8.80E-08	---	---	---
Mines and Smoke Pots	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	---	---	---
Mines and Smoke Pots	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	---	---	---
Signals and Simulators	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	---	---	---
Signals and Simulators	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-06	---	---	---	---	---	1.70E-05	---	---	---
Signals and Simulators	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	---	---	---
Signals and Simulators	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	---	---	---
Signals and Simulators	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	---	---	---
Signals and Simulators	L366	Air Burst Projectile Simulator (M74A1)	lb/item	8.99E-02	---	---	---	---	5.40E-07	---	7.60E-07	---	---	8.90E-05	---	---	3.90E-06	---	---	---
Signals and Simulators	L367	Anti-Tank Guided Missle and Rocket Launching Simulator (M22)	lb/item	3.12E-02	---	---	---	---	---	---	---	---	---	---	---	---	3.20E-06	---	---	---
Signals and Simulators	L410	Aircraft Countermeasure Flare (M206)	lb/item	2.84E-01	---	---	---	---	---	---	---	---	---	---	---	---	8.40E-06	---	---	---
Signals and Simulators	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	---	---	---
Signals and Simulators	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	---	---	---
Signals and Simulators	L592	TOW Blast Simulator	lb/item	5.65E-03	---	---	---	4.40E-07	---	1.90E-07	---	---	---	5.90E-08	---	---	1.10E-07	---	---	---
Signals and Simulators	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	---	---	---
Signals and Simulators	L595	Liquid Projectile Air Burst Simulator (M9)	lb/item	1.38E-01	---	---	1.80E-04	---	---	---	---	---	---	6.30E-08	---	---	2.70E-06	---	---	---
Signals and Simulators	L596	Flash Artillery Simulator (M110)	lb/item	1.88E-01	---	1.00E-06	---	---	---	---	1.80E-05	---	---	4.50E-05	---	---	2.10E-03	---	---	---
Signals and Simulators	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	---	---	---
Signals and Simulators	L599	Illuminating Booby Trap Simulator (M118)	lb/item	1.34E-02	---	---	1.80E-07	---	3.00E-08	1.90E-06	1.50E-07	1.10E-08	---	---	8.40E-06	1.20E-08	---	1.10E-06	---	---
Signals and Simulators	L600	Whistling Booby Trap Simulator (119)	lb/item	1.06E-01	---	---	2.70E-07	---	---	3.40E-08	2.70E-07	---	---	---	---	---	7.10E-06	---	---	---
Signals and Simulators	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	---	---	---
Signals and Simulators	L602	Artillery Flash Simulator (M21)	lb/item	9.38E-02	---	---	---	---	---	3.60E-07	---	---	---	1.20E-04	---	---	1.30E-06	---	---	---
Signals and Simulators	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	---	---	---
Signals and Simulators	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
Fuses and Primers	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	---	---	---
Fuses and Primers	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
Fuses and Primers	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	---
Fuses and Primers	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	---	---	---
Fuses and Primers	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 22-2. HAP Emission Factors for OB/OD (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-06	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	---	---	---	---	---	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+00	---	9.20E-07	3.90E-04	1.40E-05	---	7.70E-05	1.90E-05	---	---	6.00E-07	1.30E-04	7.60E-04	2.90E-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 22-2. HAP Emission Factors for OB/OD (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[3]	---	Amatol	lb/lb NEW	5.00E-01[4]	---	---	---	---	---	---	---	---	---	---	---	---	2.30E-05	---	---	---
	J473	Cartridge, Impulse, ARD446-1	lb/lb NEW	---	---	---	---	---	---	---	---	---	---	---	1.80E-04	---	6.70E-05	---	---	---
	MG11	Cartridge, Impulse, BBU-36/B	lb/lb NEW	---	---	---	---	---	---	---	---	9.30E-06	---	---	---	---	2.10E-05	---	---	---
	M943	Cartridge, Impulse, MK 107	lb/lb NEW	---	---	---	---	---	---	---	---	5.10E-06	---	---	---	---	6.40E-05	---	---	---
	---	Composition B surrogate	lb/lb NEW	5.00E-01[4]	---	---	---	---	---	---	---	---	---	---	---	---	2.60E-06	---	---	---
	---	Detonating Train	lb/lb NEW	---	---	---	---	---	---	---	---	---	---	---	---	---	2.50E-05	---	---	---
	L410	Flare, IR Countermeasure M206	lb/lb NEW	---	---	---	---	---	---	---	---	1.80E-05	---	---	---	---	4.50E-05	---	---	---
	F841	Fuse, Tail Bomb FMU-54 A/B	lb/lb NEW	---	---	---	---	---	---	---	---	1.50E-05	---	---	---	---	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	---	---	---	---	3.40E-05	---	---	---
	L306	Signal, Illumination, Red Star M158	lb/lb NEW	---	---	---	---	---	---	---	---	1.60E-05	---	---	---	---	3.00E-05	---	---	---
	---	Tritonal surrogate	lb/lb NEW	---	---	---	---	---	---	---	---	---	---	---	---	---	5.70E-06	---	---	---
	---	Tritonal surrogate with calcium stearate	lb/lb NEW	---	---	---	---	---	---	---	---	---	---	---	---	---	3.10E-06	---	---	---
	---	TNT	lb/lb NEW	---	---	---	---	---	---	---	---	---	---	---	---	---	4.10E-06	---	---	---

Table 22-2. HAP Emission Factors for OB/OD (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**	(1)	**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-05
	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-06	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-05
	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-04	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	---	---	---	---	---	---	---

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Table 22-2. HAP Emission Factors for OB/OD (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-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-05	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-05	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 22-2. HAP Emission Factors for OB/OD (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	---	---	---	---	---	---	1.70E-07	---	---	---	---	---	---	---
	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 22-2. HAP Emission Factors for OB/OD (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[3]	---	Amatol	lb/lb NEW	5.00E-01[4]	---	---	---	---	---	---	---	---	---	---	3.70E-07	---	---	---	---	---
	J473	Cartridge, Impulse, ARD446-1	lb/lb NEW		---	---	---	---	---	---	---	6.70E-06	---	---	---	---	---	---	---	---
	MG11	Cartridge, Impulse, BBU-36/B	lb/lb NEW		---	---	---	---	---	---	---	2.80E-06	---	---	---	---	---	---	---	---
	M943	Cartridge, Impulse, MK 107	lb/lb NEW		---	---	---	---	---	---	---	2.00E-06	1.40E-03	---	---	---	---	---	---	---
	---	Composition B surrogate	lb/lb NEW	5.00E-01[4]	---	---	---	---	---	---	---	---	---	---	3.60E-07	---	---	---	---	---
	---	Detonating Train	lb/lb NEW		---	---	---	---	---	---	---	9.00E-06	1.10E-05	---	---	---	---	---	6.90E-07	---
	L410	Flare, IR Countermeasure M206	lb/lb NEW		---	---	---	---	---	---	---	3.00E-06	3.40E-05	---	---	---	---	---	3.10E-06	---
	F841	Fuse, Tail Bomb FMU-54 A/B	lb/lb NEW		---	---	---	---	---	---	---	4.50E-06	3.10E-04	---	---	---	---	---	---	---
	F762	Fuse, Tail Bomb FMU-139 A/B	lb/lb NEW		---	---	---	---	---	---	---	2.10E-05	2.30E-03	---	2.70E-06	---	---	---	---	---
	L231	Signal, Illumination, Red Star AN-M43A2	lb/lb NEW		---	---	---	---	---	---	---	1.90E-06	8.80E-05	---	---	---	---	---	---	---
	L306	Signal, Illumination, Red Star M158	lb/lb NEW		---	---	---	---	---	---	---	1.20E-05	1.10E-03	---	---	---	---	---	---	---
	---	Tritonal surrogate	lb/lb NEW		---	---	---	---	---	---	---	9.10E-07	---	---	3.70E-07	---	---	---	---	3.60E-07
	---	Tritonal surrogate with calcium stearate	lb/lb NEW		---	---	---	---	---	---	---	1.30E-06	---	---	---	---	---	---	---	---
	---	TNT	lb/lb NEW		---	---	---	---	---	---	---	1.70E-06	---	---	---	---	---	---	---	---

Table 22-2. HAP Emission Factors for OB/OD (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**	(1)	**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-08	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-06	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 22-2. HAP Emission Factors for OB/OD (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)
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	---	---	---	---	---	---	---	---	---	---	---	---	---
	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 22-2. HAP Emission Factors for OB/OD (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 22-2. HAP Emission Factors for OB/OD (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[3]	---	Amatol	lb/lb NEW	5.00E-01[4]	7.50E-07	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	J473	Cartridge, Impulse, ARD446-1	lb/lb NEW	---	1.20E-06	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	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[4]	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	---	Detonating Train	lb/lb NEW	---	7.00E-07	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	L410	Flare, IR Countermeasure M206	lb/lb NEW	---	1.00E-06	1.60E-04	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	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	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	L306	Signal, Illumination, Red Star M158	lb/lb NEW	---	1.30E-06	1.50E-04	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	---	Tritonal surrogate	lb/lb NEW	---	5.60E-07	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	---	Tritonal surrogate with calcium stearate	lb/lb NEW	---	3.70E-07	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	---	TNT	lb/lb NEW	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

Table 22-2. HAP Emission Factors for OB/OD (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**	**(1)**	---	**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 22-2. HAP Emission Factors for OB/OD (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	---	---	6.10E-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 22-2. HAP Emission Factors for OB/OD (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	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-08	---	---	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 22-2. HAP Emission Factors for OB/OD (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[3]	---	Amatol	lb/lb NEW	5.00E-01[4]	---	---	---	---	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[4]	---	---	---	---	2.00E-06	---	---	---	---	---	---	---	---	---	---	---
	---	Detonating Train	lb/lb NEW		---	---	---	---	6.00E-07	---	---	---	---	---	---	---	---	---	---	---
	L410	Flare, IR Countermeasure M206	lb/lb NEW		---	---	---	---	2.40E-06	---	---	---	---	---	---	---	---	---	---	---
	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	---	---	---	---	---	---	---	---	---	---	---
	L306	Signal, Illumination, Red Star M158	lb/lb NEW		---	---	---	---	7.00E-07	---	---	---	---	---	---	---	---	---	---	---
	---	Tritonal surrogate	lb/lb NEW		---	---	---	---	2.50E-06	---	---	---	---	---	---	---	---	---	---	---
	---	Tritonal surrogate with calcium stearate	lb/lb NEW		---	---	---	---	1.60E-06	---	---	---	---	---	---	---	---	---	---	---
	---	TNT	lb/lb NEW		---	---	---	---	4.70E-07	---	---	---	---	---	---	---	---	---	---	---

Table 22-2. HAP Emission Factors for OB/OD (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**	**(1)**	**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	---	---	---	---	---	---	---	---	---	---	---	---	---	2.90E-02	3.70E-05	---
	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	---	---	6.80E-05	---	---	---	---	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	---	---	---	4.70E-06	5.90E-06	---
	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-05	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	---	---	---	---	---	---	6.20E-06	---	---
		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 22-2. HAP Emission Factors for OB/OD (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-06	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-06	1.10E-06	---
	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 22-2. HAP Emission Factors for OB/OD (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	---	---	---	---	---	---	---	---	---	3.80E-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-06	---
	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	1.20E-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	---	---	---	---	---	---	---	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-06	---	5.30E-05	1.70E-05	---
	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	---	---	---	---	---	---	---	---	---	---	---	---	---	4.40E-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 22-2. HAP Emission Factors for OB/OD (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[3]	---	Amatol	lb/lb NEW	5.00E-01[4]	---	---	---	---	---	---	---	5.60E-07	---	---	---	---	---	---	---	---
	J473	Cartridge, Impulse, ARD446-1	lb/lb NEW		---	---	---	---	---	---	---	1.50E-06	---	---	---	---	---	---	---	---
	MG11	Cartridge, Impulse, BBU-36/B	lb/lb NEW		---	---	---	---	---	---	---	1.70E-06	---	---	---	---	---	---	---	---
	M943	Cartridge, Impulse, MK 107	lb/lb NEW		---	---	---	---	---	---	---	5.30E-07	---	---	---	---	---	---	---	---
	---	Composition B surrogate	lb/lb NEW	5.00E-01[4]	---	---	---	---	---	---	---	5.50E-07	---	---	---	---	---	---	---	---
	---	Detonating Train	lb/lb NEW		---	---	---	---	---	---	---	1.80E-06	---	---	---	---	---	---	---	---
	L410	Flare, IR Countermeasure M206	lb/lb NEW		---	---	---	---	---	---	---	6.80E-07	---	---	---	---	---	---	---	---
	F841	Fuse, Tail Bomb FMU-54 A/B	lb/lb NEW		---	---	---	---	---	---	---	4.40E-07	---	---	---	---	---	---	---	---
	F762	Fuse, Tail Bomb FMU-139 A/B	lb/lb NEW		---	---	---	---	---	---	---	6.50E-07	---	---	---	---	---	---	---	---
	L231	Signal, Illumination, Red Star AN-M43A2	lb/lb NEW		---	---	---	---	---	---	---	8.10E-07	---	---	---	---	---	---	---	---
	L306	Signal, Illumination, Red Star M158	lb/lb NEW		---	---	---	---	---	---	---	1.10E-06	---	---	---	---	---	---	---	---
	---	Tritonal surrogate	lb/lb NEW		---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	---	Tritonal surrogate with calcium stearate	lb/lb NEW		---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	---	TNT	lb/lb NEW		---	---	---	---	---	---	---	9.30E-07	---	---	---	---	---	---	---	---

Table 22-2. HAP Emission Factors for OB/OD (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	---	---	---	---	6.50E-10	2.00E-11
	D533	155-mm Propelling Charge, Zone 7 (M119A2)	lb/item	2.25E+01	---	---	---	---	---	---	---	---	1.50E-05	2.40E-05	---	---	---	---	---	---
	D540	**155-mm Propelling Charges (M3/M3A1)**	**lb/lb NEW**	**(1)**	**---**	**---**	**---**	**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	---	---	---	---	1.50E-10	---
	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	---	---	---	---	---	3.40E-11	1.70E-12
		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 22-2. HAP Emission Factors for OB/OD (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-06	---	---	---	---	---	---	---	---	---	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	2.80E-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 22-2. HAP Emission Factors for OB/OD (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-02	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 22-2. HAP Emission Factors for OB/OD (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[3]	---	Amatol	lb/lb NEW	5.00E-01[4]	---	---	---	---	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[4]	---	---	---	---	1.40E-04	---	---	---	---	---	---	---	---	---	---	---
	---	Detonating Train	lb/lb NEW	---	---	---	---	---	4.20E-05	---	---	---	---	---	---	---	---	---	---	---
	L410	Flare, IR Countermeasure M206	lb/lb NEW	---	---	---	---	---	4.10E-04	---	---	---	---	---	---	---	---	---	---	---
	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	---	---	---	---	---	---	---	---	---	---	---
	L306	Signal, Illumination, Red Star M158	lb/lb NEW	---	---	---	---	---	1.00E-04	---	---	---	---	---	---	---	---	---	---	---
	---	Tritonal surrogate	lb/lb NEW	---	---	---	---	---	1.80E-05	---	---	---	---	---	---	---	---	---	---	---
	---	Tritonal surrogate with calcium stearate	lb/lb NEW	---	---	---	---	---	1.60E-04	---	---	---	---	---	---	---	---	---	---	---
	---	TNT	lb/lb NEW	---	---	---	---	---	1.80E-04	---	---	---	---	---	---	---	---	---	---	---

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Table 22-2. HAP Emission Factors for OB/OD (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	---	---	---	---	---	1.70E-04	2.10E-11[2]	---	---	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-06	---	2.80E-12	---	6.40E-05
	D540	**155-mm Propelling Charges (M3/M3A1)**	**lb/lb NEW**	**(1)**	**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 22-2. HAP Emission Factors for OB/OD (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-Tetrachlorobroethane (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 22-2. HAP Emission Factors for OB/OD (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	---	---	---	---	---	---	---	---

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Table 22-2. HAP Emission Factors for OB/OD (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[3]	---	Amatol	lb/lb NEW	5.00E-01[4]	---	---	---	---	3.70E-07	---	---	---	---	---	---	---	---	---	---	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	---	---	---	---	---	---	---	---	---	---	---	---	9.40E-06	---	---	---	9.00E-06
	---	Composition B surrogate	lb/lb NEW	5.00E-01[4]	---	---	---	---	1.80E-05	---	---	---	---	---	---	---	---	---	---	6.00E-06
	---	Detonating Train	lb/lb NEW	---	---	---	---	---	1.10E-05	---	---	---	---	---	---	4.10E-06	---	---	---	4.20E-06
	L410	Flare, IR Countermeasure M206	lb/lb NEW	---	---	---	---	---	---	---	---	---	---	---	---	7.10E-06	---	---	---	2.80E-05
	F841	Fuse, Tail Bomb FMU-54 A/B	lb/lb NEW	---	---	---	---	---	---	---	---	---	---	---	---	7.80E-06	---	---	---	3.20E-05
	F762	Fuse, Tail Bomb FMU-139 A/B	lb/lb NEW	---	---	---	---	---	---	---	---	---	---	---	---	2.90E-05	---	---	---	2.30E-05
	L231	Signal, Illumination, Red Star AN-M43A2	lb/lb NEW	---	---	---	---	---	---	---	---	---	---	---	---	4.50E-06	---	---	---	3.00E-05
	L306	Signal, Illumination, Red Star M158	lb/lb NEW	---	---	---	---	---	---	---	---	---	---	---	---	2.20E-06	---	---	---	2.50E-05
	---	Tritonal surrogate	lb/lb NEW	---	---	---	---	---	2.70E-06	---	---	---	---	---	---	---	---	---	---	1.80E-06
	---	Tritonal surrogate with calcium stearate	lb/lb NEW	---	---	---	---	---	3.70E-07	---	---	---	---	---	---	---	---	---	---	---
	---	TNT	lb/lb NEW	---	---	---	---	---	---	---	---	---	---	---	---	1.50E-06	---	---	---	5.10E-06

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Table 22-2. HAP Emission Factors for OB/OD (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**	**(1)**	---	**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	---	---	---	---	---	---	---	---	---	---	---

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Table 22-2. HAP Emission Factors for OB/OD (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-06
	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 22-2. HAP Emission Factors for OB/OD (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 22-2. HAP Emission Factors for OB/OD (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[3]	---	Amatol	lb/lb NEW	5.00E-01[4]	---	3.70E-07	---	---	---	---	---	---	---	---	---
	J473	Cartridge, Impulse, ARD446-1	lb/lb NEW	---	---	1.20E-06	---	---	---	---	---	---	---	---	---
	MG11	Cartridge, Impulse, BBU-36/B	lb/lb NEW	---	---	---	---	---	---	---	---	---	1.70E-06	---	---
	M943	Cartridge, Impulse, MK 107	lb/lb NEW	---	---	---	---	---	---	---	---	---	2.40E-06	---	---
	---	Composition B surrogate	lb/lb NEW	5.00E-01[4]	---	---	---	---	---	---	---	---	---	---	---
	---	Detonating Train	lb/lb NEW	---	---	---	---	---	---	---	---	---	1.30E-06	---	---
	L410	Flare, IR Countermeasure M206	lb/lb NEW	---	---	---	---	---	---	---	---	---	1.50E-06	---	---
	F841	Fuse, Tail Bomb FMU-54 A/B	lb/lb NEW	---	---	---	---	---	---	---	---	---	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	---	---	---	---	---	---	---	---	---	2.30E-06	---	---
	L306	Signal, Illumination, Red Star M158	lb/lb NEW	---	---	---	---	---	---	---	---	---	1.10E-06	---	---
	---	Tritonal surrogate	lb/lb NEW	---	---	---	---	---	---	---	---	---	---	---	---
	---	Tritonal surrogate with calcium stearate	lb/lb NEW	---	---	---	---	---	---	---	---	---	---	---	---
	---	TNT	lb/lb NEW	---	---	---	---	---	---	---	---	---	---	---	---

SOURCE: United States EPA. Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources. Fifth edition. Chapter 15.

1. NEW is dependent on the configuration. Refer to Table 15.4.4-1 in AP-42 for assistance in selecting the appropriate NEW.

2. Source states that this is a "toxic equivalent".

3. 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.

4. 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

"---" – Indicates either that no data is available or compound was not detected or detected at only the background level.

22.7 References

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

USEPA 2008a, Section 15.7-"Mines and Smoke Pots," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, October 2008

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

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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

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23 OZONE DEPLETING CHEMICALS (ODC)

➢ *Fugitive Sources*

23.1 Introduction

Ozone depleting chemicals (ODC) 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 which is harmful to life on earth. It is important to keep ODCs to a minimum due to their dangerous health effects and environmental effects. Estimating emissions of ozone depleting chemicals is not only important for air emission inventory purposes, but may also be necessary for Toxic Release Inventory (TRI) reporting under the Emergency Planning and Community Right to Know Act (EPCRA).

ODCs are classified as being either class I or class II based on their ozone depleting potential (ODP), with class I regarded as having a greater ozone depleting potential than class II substances.   These substances contain compounds such as chlorofluorocarbons (CFC), hydrochlorofluorocarbons (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, fire extinguishers, in dry cleaning as solvents for cleaning, and as agricultural fumigants at Air Force installations. **Emissions of ozone depleting substances are typically fugitive in nature** and a graphic representation of emissions is given in Figure 23-1.

Since 1993, the Air Force has reduced the consumption of ODCs by 96% and is expected to replace ozone depleting chemicals in the future with non-hazardous substances according to the Department of Defense. This initiative is the result of increased awareness of the global warming potentials (GWP) of each pollutant as climate change has become an increasingly more prevalent topic. The global warming potential of a gas is a measure of its ability to trap heat in the atmosphere and uses carbon dioxide (CO_2) as the baseline reference. For example, methane (CH_4) is stated to have a global warming potential 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 ozone depleting chemicals is provided in Table 23-1 and Table 23-2.
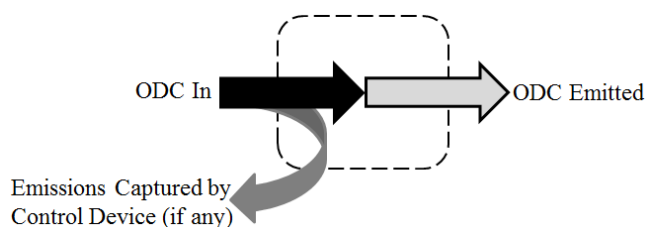
Figure 23-1. Simple Control Volume for Emissions from Ozone Depleting Chemicals

Table 23-1. List of Class I Ozone Depleting Substances

Group	Compound	Chemical Name	ODP[1]	GWP[2]
Group I	CFC-11 (CFC1$_3$)	Trichlorofluoromethane	1.00	4000
	CFC-12 (CF$_2$Cl$_2$)	Dichlorodifluoromethane	1.00	8500
	CFC-113 (C$_2$F$_3$Cl$_3$)	Trichlorotrifluoroethane	0.80	5000
	CFC-114 (C$_2$F$_4$Cl$_2$)	Dichlorotetrafluoroethane	1.00	9300
	CFC-115 (C$_2$F$_5$Cl)	Monochloropentafluoroethane	0.60	9300
Group II	Halon 1211 (CF$_2$ClBr)	Bromochlorodifluoromethane	3.00	1890[3]
	Halon 1301 (CF$_3$Br)	Bromotrifluoromethane	10.00	7140[3]
	Halon 2402 (C$_2$F$_4$Br$_2$)	Dibromotetrafluoroethane	6.00	1640[3]
Group III	CFC-13 (CF$_3$Cl)	Chlorotrifluoromethane	1.00	11700
	CFC-111 (C$_2$FCl$_5$)	Pentachlorofluoroethane	1.00	---
	CFC-112 (C$_2$F$_2$Cl$_4$)	Tetrachlorodifluoroethane	1.00	---
	CFC-211 (C$_3$FCl$_7$)	Heptachlorofluoropropane	1.00	---
	CFC-212 (C$_3$F$_2$Cl$_6$)	Hexachlorodifluoropropane	1.00	---
	CFC-213 (C$_3$F$_3$Cl$_5$)	Pentachlorotrifluoropropane	1.00	---
	CFC-214 (C$_3$F$_4$Cl$_4$)	Tetrachlorotetrafluoropropane	1.00	---
	CFC-215 (C$_3$F$_5$Cl$_3$)	Trichloropentafluoropropane	1.00	---
	CFC-216 (C$_3$F$_6$Cl$_2$)	Dichlorohexafluoropropane	1.00	---
	CFC-217 (C$_3$F$_7$Cl)	Chloroheptafluoropropane	1.00	---
Group IV	CCl$_4$	Carbon Tetrachloride	1.10	1400
Group V	C$_2$H$_3$Cl$_3$	1,1,1-Trichloroethane	0.10	110
Group VI	CH$_3$Br	Bromomethane	0.70	5[3]
Group VII	CHFBr$_2$	Dibromofluoromethane	1.00	---
	CHF$_2$Br	Bromodifluoromethane	0.74	---
	CH$_2$FBr	Bromofluoromethane	0.73	---
	C$_2$HFBr$_4$	Tetrabromofluoroethane	0.80	---
	C$_2$HF$_2$Br$_3$	Tribromodifluoroethane	1.80	---
	C$_2$HF$_3$Br$_2$	Dibromotrifluoroethane	1.60	---
	C$_2$HF$_4$Br	Bromotetrafluorethane	1.20	---
	C$_2$H$_2$FBr$_3$	Tribromofluoroethane	1.10	---
	C$_2$H$_2$F$_2$Br$_2$	Dibromodifluoroethane	1.50	---
	C$_2$H$_2$F$_3$Br	Bromotrifluoroethane	1.60	---
	C$_2$H$_2$FBr$_2$	Dibromofluoroethane	1.70	---
	C$_2$H$_3$F$_2$Br	Bromodifluoroethane	1.10	---
	C$_2$H$_4$FBr	Bromofluoroethane	0.10	---
	C$_3$HFBr$_6$	Hexabromofluoropropane	1.50	---

Table 23-1. List of Class I Ozone Depleting Substances (cont.)

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Group	Compound	Chemical Name	ODP[1]	GWP[2]
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[4]	---
	$C_3H_3FBr_4$	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	---

1. 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.
2. 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.
3. SOURCE: "Scientific Assessment of Ozone Depletion: 2010," World Meteorological Organization (WMO), 2010.
4. SOURCE: "Handbook for the Montreal Protocol on Substances that Deplete the Ozone Layer Ninth edition," Ozone Secretariat, United Nations Environment Programme (UNEP), 2012.

"---" Indicates no data available

Table 23-2. List of Class II Ozone Depleting Chemicals

Compound	Chemical Name	ODP[1]	GWP[2]
HCFC-21 (CHFCl$_2$)	Dichlorofluoromethane	0.04	---
HCFC-22 (CHF$_2$Cl)	Monochlorodifluoromethane	0.055	1700
HCFC-31 (CH$_2$FCl)	Monochlorofluoromethane	0.02	---
HCFC-121 (C$_2$HFCl$_4$)	Tetrachlorofluoroethane	0.04	---
HCFC-122 (C$_2$HF$_2$Cl$_3$)	Trichlorodifluoroethane	0.08	---
HCFC-123 (C$_2$HF$_3$Cl$_2$)	Dichlorotrifluoroethane	0.02	93
HCFC-124 (C$_2$HF$_4$Cl)	Monochlorotetrafluoroethane	0.022	480
HCFC-131 (C$_2$H$_2$FCl$_3$)	Trichlorofluoroethane	0.05	---
HCFC-132 (C$_2$H$_2$F$_2$Cl$_2$)	Dichlorodifluoroethane	0.05	---
HCFC-133 (C$_2$H$_2$F$_3$Cl)	Monochlorotrifluoroethane	0.06	---
HCFC-141b (C$_2$H$_3$FCl$_2$)	Dichlorofluoroethane	0.11	630
HCFC-142b (C$_2$H$_3$F$_2$Cl)	Monochlorodifluoroethane	0.065	2000
HCFC-151 (C$_2$H$_4$FCl)	Chlorofluoroethane	0.005	---
HCFC-221 (C$_3$HFCl$_6$)	Hexachlorofluoropropane	0.07	---
HCFC-222 (C$_3$HF$_2$Cl$_5$)	Pentachlorodifluoropropane	0.09	---
HCFC-223 (C$_3$HF$_3$Cl$_4$)	Tetrachlorotrifluoropropane	0.08	---
HCFC-224 (C$_3$HF$_4$Cl$_3$)	Trichlorotetrafluoropropane	0.09	---
HCFC-225ca (C$_3$HF$_5$Cl$_2$)	Dichloropentafluoropropane	0.025	170
HCFC-225cb (C$_3$HF$_5$Cl$_2$)	Dichloropentafluoropropane	0.033	530
HCFC-226 (C$_3$HF$_6$Cl)	Monochlorohexafluoropropane	0.1	---
HCFC-231 (C$_3$H$_2$FCl$_5$)	Pentachlorofluoropropane	0.09	---
HCFC-232 (C$_3$H$_2$F$_2$Cl$_4$)	Tetrachlorodifluoropropane	0.1	---
HCFC-233 (C$_3$H$_2$F$_3$Cl$_3$)	Trichlorotrifluoropropane	0.23	---
HCFC-234 (C$_3$H$_2$F$_4$Cl$_2$)	Dichlorotetrafluoropropane	0.28	---
HCFC-235 (C$_3$H$_2$F$_5$Cl)	Monochloropentafluoropropane	0.52	---
HCFC-241 (C$_3$H$_3$FCl$_4$)	Tetrachlorofluoropropane	0.09	---
HCFC-242 (C$_3$H$_3$F$_2$Cl$_3$)	Trichlorodifluoropropane	0.13	---
HCFC-243 (C$_3$H$_3$F$_3$Cl$_2$)	Dichlorotrifluoropropane	0.12	---
HCFC-244 (C$_3$H$_3$F$_4$Cl)	Monochlorotetrafluoropropane	0.14	---
HCFC-251 (C$_3$H$_4$FCl$_3$)	Trichlorofluoropropane	0.01	---
HCFC-252 (C$_3$H$_4$F$_2$Cl$_2$)	Dichlorodifluoropropane	0.04	---
HCFC-253 (C$_3$H$_4$F$_3$Cl)	Monochlorotrifluoropropane	0.03	---
HCFC-261 (C$_3$H$_5$FCl$_2$)	Dichlorofluoropropane	0.02	---
HCFC-262 (C$_3$H$_5$F$_2$Cl)	Monochlorodifluoropropane	0.02	---
HCFC-271 (C$_3$H$_6$FCl)	Monochlorofluoropropane	0.03	---

1. 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 is provided.

2. 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.

"---" Indicates 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 which catalyze the reactions which lead to additional ozone layer destruction. Unfortunately, this cooling is not just caused by the destruction of the ozone layer by ODCs, but also by the presence of greenhouse gases (GHG) in the atmosphere. The greenhouse gases work to warm the earth's surface while radiatively cooling the atmosphere, thereby exacerbating the ozone destruction problem. Several ODC's work to both destroy the ozone and also serve as greenhouse gases while some processes which initially utilized ODC's are substituting GHGs under the assumption that these chemicals are more environmentally friendly. In addition to the estimation of ODC emissions, it may be beneficial to determine the emissions of greenhouse gases. A list of greenhouse gases and their respective global warming potentials are provided in Table 23-3.

23.2 Control Techniques

Since ozone depleting substances are found in chemicals which are used in a variety of processes, it may be very easy to double count these emissions when performing an air emissions inventory. 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.

23.3 Emissions Calculation

Algorithms and emission factors (EFs) used by the Air Force are generally from AP-42; however, EFs for Air Force-unique sources have been developed by the Air Force. The only algorithms and EFs authorized for use in estimating Air Force emissions are those maintained within the Air Program Information Management System (APIMS). ODC emissions may be estimated using a mass balance approach to calculate total emissions produced from the variety of sources located on an 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 incinerators, carbon adsorbers, or refrigeration units. In these cases, the efficiency of the control device must be considered when calculating ODC emissions. Calculation of emissions from ODCs is shown below using Equation 23-1.

Table 23-3. Greenhouse Gas List with Their Respective Global Warming Potentials (GWP)

Name	Chemical Formula	Global Warming Potential (100 yr.)	Name	Chemical Formula	Global Warming Potential (100 yr.)
Carbon dioxide	CO_2	1	HFE-43-10pccc (H-Galden 1040x, HG-11)	$CHF_2OCF_2OC_2F_4OCHF_2$	1,870
Methane	CH_4	25	HFE-125	CHF_2OCF_3	14,900
Nitrous oxide	N_2O	298	HFE-134 (HG-00)	CHF_2OCHF_2	6,320
HFC-23	CHF_3	14,800	HFE-143a	CH_3OCF_3	756
HFC-32	CH_2F_2	675	HFE-227ea	$CF_3CHFOCF_3$	1,540
HFC-41	CH_3F	92	HFE-236ca12 (HG-10)	$CHF_2OCF_2OCHF_2$	2,800
HFC-125	C_2HF_5	3,500	HFE-236ea2 (Desflurane)	$CHF_2OCHFCF_3$	989
HFC-134	$C_2H_2F_4$	1,100	HFE-236fa	$CF_3CH_2OCF_3$	487
HFC-134a	CH_2FCF_3	1,430	HFE-245cb2	$CH_3OCF_2CF_3$	708
HFC-143	$C_2H_3F_3$	353	HFE-245fa1	$CHF_2CH_2OCF_3$	286
HFC-143a	$C_2H_3F_3$	4,470	HFE-245fa2	$CHF_2OCH_2CF_3$	659
HFC-152	CH_2FCH_2F	53	HFE-254cb2	$CH_3OCF_2CHF_2$	359
HFC-152a	CH_3CHF_2	124	HFE-263fb2	$CF_3CH_2OCH_3$	11
HFC-161	CH_3CH_2F	12	HFE-329mcc2	$CF_3CF_2OCF_2CHF_2$	919
HFC-227ea	C_3HF_7	3,220	HFE-338mcf2	$CF_3CF_2OCH_2CF_3$	552
HFC-236cb	$CH_2FCF_2CF_3$	1,340	HFE-338pcc13 (HG-01)	$CHF_2OCF_2CF_2OCHF_2$	1,500
HFC-236ea	CHF_2CHFCF_3	1,370	HFE-347mcc3 (HFE-7000)	$CH_3OCF_2CF_2CF_3$	575
HFC-236fa	$C_3H_2F_6$	9,810	HFE-347mcf2	$CF_3CF_2OCH_2CHF_2$	374
HFC-245ca	$C_3H_3F_5$	693	HFE-347pcf2	$CHF_2CF_2OCH_2CF_3$	580
HFC-245fa	$CHF_2CH_2CF_3$	1,030	HFE-356mec3	$CH_3OCF_2CHFCF_3$	101
HFC-365mfc	$CH_3CF_2CH_2CF_3$	794	HFE-356pcc3	$CH_3OCF_2CF_2CHF_2$	110
HFC-43-10mee	$CF_3CFHCFHCF_2CF_3$	1,640	HFE-356pcf2	$CHF_2CH_2OCF_2CHF_2$	265
Sulfur hexafluoride	SF_6	22,800	HFE-356pcf3	$CHF_2OCH_2CF_2CHF_2$	502
Trifluoromethyl sulphur pentafluoride	SF_5CF_3	17,700	HFE-365mcf3	$CF_3CF_2CH_2OCH_3$	11
Nitrogen trifluoride	NF_3	17,200	HFE-374pc2	$CH_3CH_2OCF_2CHF_2$	557
PFC-14 (Perfluoromethane)	CF_4	7,390	HFE-449s1 (HFE-7100)	$C_4F_9OCH_3$	297
PFC-116 (Perfluoroethane)	C_2F_6	12,200	HFE-569sf2 (HFE-7200)	$C_4F_9OC_2H_5$	59
PFC-218 (Perfluoropropane)	C_3F_8	8,830	Sevoflurane (HFE-347mmz1)	$CH_2FOCH(CF_3)_2$	345
Perfluorocyclopropane	$C-C_3F_6$	17,340	HFE-356mm1	$(CF_3)_2CHOCH_3$	27
PFC-3-1-10 (Perfluorobutane)	C_4F_{10}	8,860	HFE-338mmz1	$CHF_2OCH(CF_3)_2$	380
PFC-318 (Perfluorocyclobutane)	$C-C_4F_8$	10,300	(Octafluorotetramethy-lene) hydroxymethyl group	$X-(CF_2)_4CH(OH)-X$	73
PFC-4-1-12 (Perfluoropentane)	C_5F_{12}	9,160	HFE-347mmy1	$CH_3OCF(CF_3)_2$	343
PFC-5-1-14 (Perfluorohexane, FC-72)	C_6F_{14}	9,300	Bis(trifluoromethyl)-methanol	$(CF_3)_2CHOH$	195
PFC-9-1-18	$C_{10}F_{18}$	7,500	2,2,3,3,3-pentafluoropropanol	$CF_3CF_2CH_2OH$	42
HCFE-235da2 (Isoflurane)	$CHF_2OCHClCF_3$	350	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 23-1

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 ozone depleting chemicals is provided in Figure 23-2.
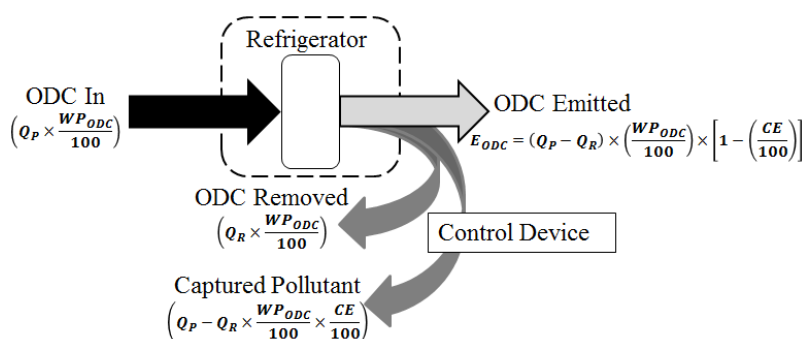
Figure 23-2. Detailed Control Volume of Emissions from Ozone Depleting Chemicals

23.4 Information Resources

Records/data maintained by the Hazardous Materials Pharmacy 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 ozone-containing products (typically sterilants and coatings), the manufacturer of the control device should be contacted to determine the estimated control efficiency.

23.5 Example Problem

According to base Civil Engineering, approximately 1,900 lb of pure HCFC-22 were added to base air conditioning systems during the year while 650 lb were removed/recovered. Calculate the annual emissions of HCFC-22. No control device was used in this process.

Step 1 – Calculate emissions. The problem statement provided all of the information necessary to calculate the emissions from this process. Using the data provided and Equation 23-1, the resulting emissions of HCFC-22 is calculated as follows:

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

$$E_{HCFC-22} = \left(1900\frac{lb}{yr} - 650\frac{lb}{yr}\right) \times \left(\frac{100\%}{100\%}\right) \times \left[1 - \left(\frac{0\%}{100\%}\right)\right]$$

$$E_{HCFC-22} = \left(1900\frac{lb}{yr} - 650\frac{lb}{yr}\right) \times (1) \times [1]$$

$$\boxed{E_{HCFC-22} = 1,250\frac{lb}{yr}}$$

23.6 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

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24 PESTICIDE APPLICATION (PEST)

➤ *Fugitive Source*

24.1 Introduction

Pesticides are used at most Air Force installations as a means of controlling plant and animal life. Pesticides include herbicides, insecticides, fungicides, and rodenticides, and 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.** Emissions may occur either during application or within 30 days after application. Although PM emissions may occur as the result of use of granular or dust/powder pesticides, they are considered negligible and are therefore not addressed in this document. A graphic representation describing emissions from pesticide application is provided in Figure 24-1.
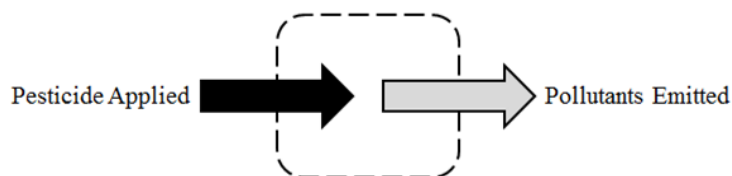

Figure 24-1. Simplified Pesticide Application Control Volume

24.2 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 incorporation limits the amount of pesticide available to evaporate from the soil surface into the atmosphere. Emission factors 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 emission factors are in units of pound pollutant per pound pesticide and have been reproduced here and provided in Table 24-1.

Table 24-1. 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

Since the emission factors are dependent on the vapor pressure of the active ingredients, it will also be imperative to know this information. 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 (Armed Forces Pest Management Board 2014). Table 24-2 provides the vapor pressures of the active ingredients for both those pesticides and several others given in section 9.2.2 of AP-42. Note that several pesticides provided in AP-42 are not given in Table 24-2 because their use has since been cancelled due to growing concern over the adverse effects they pose to humans and the environment.

Table 24-2. Vapor Pressures for Common Pesticide Active Ingredients

Active Ingredient	Vapor Pressure (mmHg)	Active Ingredient	Vapor Pressure (mmHg)	Active Ingredient	Vapor Pressure (mmHg)
Abamectin	4.73E-09	Dimethoate	2.50E-05	Nithiazine	1.30E-07
Alachlor	1.40E-05	Dinocap	4.00E-08	Norflurazon	2.00E-08
Aldicarb	3.00E-05	Diquat Dibromide	1.00E-04	Oxamyl	2.30E-04
Aldoxycarb	9.00E-05	Disulfoton	1.50E-04	Oxyfluorfen	2.00E-07
Allethrin	5.85E-06	Diuron	1.00E-07	Parathion	5.00E-06
Aluminum Phosphide	0.00E+00	d-Phenothrin (sumithrin)	1.43E-07	PCNB	1.10E-04
Aminopyralid	7.00E-11	Endosulfan	1.70E-07	P-Dichlorobenzene	1.76E+00
Amitraz	2.60E-06	EPTC	3.40E-02	Pendimethalin	9.40E-06
Amitrole	4.40E-07	Ethalfluralin	8.80E-05	Permethrin	5.25E-08
Atrazine	2.90E-07	Ethion	2.40E-06	Phorate	6.40E-04
Azinphos-methyl	2.00E-07	Ethoprop	3.80E-04	Phosmet	4.90E-07
Azoxystrobin	8.20E-13	Etofenprox	6.10E-09	Picaridin	4.40E-04
Benefin	6.60E-05	Fenamiphos	1.00E-06	Piperonyl Butoxide	1.50E-07
Beta-Cyfluthrin	4.20E-10	Fenoxycarb	5.90E-08	Profenofos	9.00E-07
Bifenthrin	1.34E-07	Fenthion	2.80E-06	Prometon	2.33E-06
Boric Acid	1.00E-04	Fipronil	1.50E-08	Prometryn	1.20E-06
Bromacil	2.48E-07	Fluometuron	9.40E-07	Propachlor	2.30E-04
Bromadiolone	1.60E-10	Fluridone	9.75E-08	Propanil	4.00E-05
Bromoxynil butyrate ester	1.00E-04	Hydramethylnon	2.03E-08	Propargite	3.00E-03
Captan	8.00E-08	Hydroprene	3.00E-04	Propoxur	9.70E-06
Carbaryl	3.12E-07	Imazapic ammonium salt	1.76E+01	Pyrethrin I	2.03E-05
Carbofuran	6.00E-07	Imazapyr isopropylamine salt	1.75E+01	Pyrethrin II	3.98E-07
Chlorfenapyr	7.36E-08	Imidacloprid	3.00E-12	Resmethrin	1.13E-08
Chloroneb	3.00E-03	Isopropylamine salt of glyphosate	1.75E-07	Siduron	4.00E-09
Chloropicrin	1.80E+01	Lambda-Cyhalothrin	1.50E-09	Simazine	2.20E-08
Chlorpyrifos	1.70E-05	Lindane	3.30E-05	Spinosad	1.50E-10
Clomazone	1.40E-04	Linuron	1.70E-05	Sulfometuron Methyl	5.50E-16
Cyfluthrin	2.25E-09	Malathion	2.33E-05	Tebuthiuron	2.03E-06
Cypermethrin	1.73E-09	Methamidophos	8.00E-04	Temephos	7.13E-08
Cyromazine	3.40E-09	Methiocarb	1.20E-04	Terbacil	3.10E-07
2,4-D Acid	8.00E-06	Methomyl	5.40E-06	Terbufos	3.20E-04
2,4-D Dimethyl Amine Salt	1.00E-07	Methoprene	2.37E-05	Tetramethrin	1.58E-05
2,4-D 2-Ethylhexyl ester	3.60E-06	Methyl parathion	1.50E-05	Thiobencarb	2.20E-05
DCNA	1.30E-06	Methylisothiocyanate	2.10E+01	Thiodicarb	1.00E-07
DCPA	2.50E-06	Metolachlor	3.10E-05	Triallate	1.10E-04
Deltamethrin	9.30E-11	Metribuzin	1.00E-05	Tribufos	1.60E-06
Dichlobenil	1.00E-03	Mevinphos	1.30E-04	Trichlofon	2.00E-06
1,3-Dichloropropene	2.90E+01	Molinate	5.60E-03	Triclopyr	7.50E-07
Dichlorvos	1.58E-02	N,N-Diethyl-M-Toluamide (DEET)	5.60E-03	Trifluralin	1.10E-04
Dicofol	4.00E-07	Naled	2.00E-04	Triforine	2.00E-07
Dicrotofos	1.60E-04	Naled (Dibrom)	1.95E-03	Warfarin	2.25E-05
Difethialone	9.98E-08	Naphthalene	8.70E-02	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, 2013 and respective SDS.

24.3 Emissions Calculation

Algorithms and emission factors (EFs) used by the Air Force are generally from AP-42; however, EFs for Air Force-unique sources have been developed by the Air Force. The only algorithms and

EFs authorized for use in estimating Air Force emissions are those maintained within the Air Program Information Management System (APIMS).

There are two methods for calculating emissions from pesticide application. The preferred method is a mass balance method which assumes all VOCs and HAPs in the pesticide are emitted to the atmosphere. The alternative method utilizes emission factors. Both approaches are described below.

24.3.1 Calculations Using Mass Balance

To use the mass balance method, the mass of pesticide applied and the weight percent VOC or HAP must be known. Calculation of emissions from pesticide application is performed as follows:

$$E_{Pol} = Q \times \left(\frac{WP_{Pol}}{100}\right)$$

Equation 24-1

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 24-2.

Pesticide Applied
$\left(Q \times \frac{WP_{Pol}}{100}\right)$

Pesticide

Emissions
$E_{Pol} = Q \times \left(\frac{WP_{Pol}}{100}\right)$
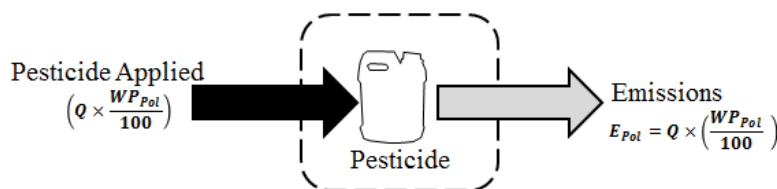
Figure 24-2. Pesticide Application – Mass Balance Method

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:

$$Q = (V \times D) = (V \times SG \times 8.33)$$

Equation 24-2

Where,

> **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)

24.3.2 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 emission factor method, may be employed. 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 MSDS, or at least a range provided. Emissions using the emission factor method are calculated as follows:

$$E_{Pol} = Q \times \left[\left(\frac{WP_{Active}}{100} \right) \times EF + \left(\frac{WP_{Inert}}{100} \right) \times \left(\frac{WP_{Pol-Inert}}{100} \right) \right]$$

Equation 24-3

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 24-3.**

A more detailed control volume for emissions from pesticide application describing the emission factor method is provided in Figure 24-3.
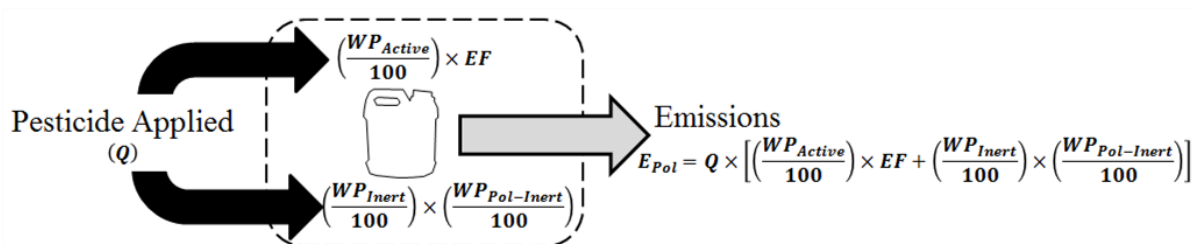

Figure 24-3. Pesticide Application Control Volume – Emission Factor Method

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 also provided in this document in Table 24-3.

Table 24-3. 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

24.4 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 Armed Forces Pest Management Board's website at http://www.afpmb.org/content/dod-standard-pesticides-and-pest-control-equipment.

24.5 Example Problem

Anytown AFB incorporated 30 gal of an insecticide into the soil during the 2013 calendar year. According to the SDS, the composition of the insecticide, by weight percent, is as follows: 9.7% Lambda-Cyhalothrin (active ingredient), 1% Cumene, 1% Xylenes, 14.2% ethane, and 74.1% 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.

Step 1 – 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 21-3 as shown:

$$Q = (V \times SG \times 8.33)$$

$$Q = \left(30\,\frac{\cancel{gal}}{yr} \times 1.036 \times 8.33\,\frac{lb}{\cancel{gal}}\right)$$

$$Q = \left(249.9\,\frac{lb}{yr} \times 1.036\right) = 258.90\,\frac{lb}{yr}$$

Step 2 – Calculate individual HAP emissions. The ingredients in the pesticide which are designated as HAPs include cumene and xylene. The weight percent of these HAPs in the pesticide are 1% each. The mass of the individual HAPs emitted are calculated using Equation 24-1 as shown:

$$E_{Pol} = Q \times \left(\frac{WP_{Pol}}{100}\right)$$

For Cumene:

$$E_{Cumene} = 258.90\,\frac{lb}{yr} \times \left(\frac{1\cancel{\%}}{100\cancel{\%}}\right)$$

$$E_{Cumene} = 258.90\,\frac{lb}{yr} \times (0.01)$$

$$\boxed{E_{Cumene} = 2.59\,\frac{lb}{yr}}$$

For Xylenes:

$$E_{Xylene} = 258.90 \frac{lb}{yr} \times \left(\frac{1\%}{100\%}\right)$$

$$E_{Xylene} = 258.90 \frac{lb}{yr} \times (0.01)$$

$$\boxed{E_{Xylene} = 2.59 \frac{lb}{yr}}$$

Step 3 – Calculate total HAPs. The total HAPs emitted is the sum of the individual HAPs calculated in Step 2 as shown:

$$E_{HAP} = 2.59 \frac{lb}{yr} + 2.59 \frac{lb}{yr}$$

$$\boxed{E_{HAP} = 5.18 \frac{lb}{yr}}$$

Step 4 – Select and record emission factor. Since the weight percent VOC in the pesticide is unknown, the emission factor method is employed. The problem stated the vapor pressure of the active ingredient is 1.50E-09 mmHg. A review of Table 24-1 shows that the emission factor is **2.70E-03 lb/lb.**

Step 5 – Determine the weight percent of VOC in the inert portion of the pesticide. The pesticide is 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:

$$WP_{VOC-Inert} = \frac{\sum_i^n WP_{VOC_i} + \cdots + WP_{VOC_n}}{WP_{Inert}} \times 100$$

$$\boldsymbol{WP_{VOC-Inert}} = \frac{1\%+1\%+74.1\%}{1\%+1\%+14.2\%+74.1\%} \times 100 = \mathbf{84.3\%}$$

Step 6 – Calculate total VOCs. The total VOCs emitted from pesticide application is calculated using the mass of pesticide applied as calculated in Step 2, the emission factor recorded in Step 4, the weight percent of the VOC in the inert portion of the pesticide as calculated in Step 5, and Equation 24-3 as follows:

$$E_{Pol} = Q \times \left[\left(\frac{WP_{Active}}{100} \right) \times EF + \left(\frac{WP_{Inert}}{100} \right) \times \left(\frac{WP_{Pol-Inert}}{100} \right) \right]$$

$$E_{VOC} = 258.90 \frac{lb}{yr} \times \left[\left(\frac{9.7\%}{100\%} \right) \times 0.0027 \frac{lb}{lb} + \left(\frac{90.3\%}{100\%} \right) \times \left(\frac{84.3\%}{100\%} \right) \right]$$

$$E_{VOC} = 258.90 \frac{lb}{yr} \times \left[(0.097) \times 0.0027 \frac{lb}{lb} + (0.903) \times (0.843) \right]$$

$$E_{VOC} = 258.90 \frac{lb}{yr} \times \left[0.0002619 \frac{lb}{lb} + 0.761229 \right]$$

$$E_{VOC} = 258.90 \frac{lb}{yr} \times \left[0.7614909 \frac{lb}{lb} \right]$$

$$\boxed{E_{VOC} = 197.15 \frac{lb}{yr}}$$

24.6 References

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

25 SITE REMEDIATION (RDL) – NOT A STATIONARY SOURCE

➢ *Point/Fugitive Source*
➢ *Transitory Source*

Air Force policy does not consider this a stationary source of emissions. However, if the regulator insists this category be included as a stationary source, contact the Air Force air quality Subject Matter Expert (SME) for permission/guidance on emissions calculations

25.1 Introduction

Air Force installations occasionally have sites that are contaminated with hazardous substances as a result of chemical leaks, spills, or prior disposal practices. Identification, investigation, and cleanup of these contaminants on active Air Force and Base Realignment and Closure (BRAC) installations falls under the jurisdiction of the DoD's Environmental Restoration Program (ERP).

Air Force site remediation sources are considered as transitory sources because they may 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 Air Force Installation Restoration Program (IRP) and performed under the authority of the Comprehensive Environmental Response and Compensation Liability Act (CERCLA) or as a Resource Conservation and Recovery Act (RCRA) permit. Additionally, all Environmental Restoration Program (ERP) activities must meet the substantive requirements of the CAA and, if non-CERCLA, will need to 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 Force Transitory Source Guide.

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26 SMALL ARMS FIRING RANGE (MUN)

➤ *Point Source* – Indoor ranges
➤ *Fugitive Source* – Outdoor ranges

26.1 Introduction

Most Air Force 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. **Indoor ranges are therefore considered point sources of emissions while outdoor ranges are considered fugitive sources.** Note that small arms ranges may be considered either mobile or stationary. 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, greenhouse gases, and HAPs. Carbon monoxide 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 26-1 below.
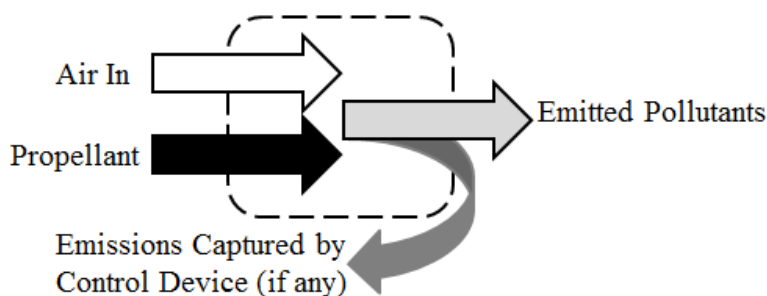

Figure 26-1. Simplified Control Volume for Emissions from Small Arms Stationary Ranges

26.2 Emission Factors

Chapter 15 of the *Compilation of Air Pollutant Emission Factors* (AP-42) provides emission factors for several types of ordnance based on size and type. These emission factors are presented in units of lb per item and pound per pound Net Explosive Weight (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 speciated VOC emission factors for cartridges likely to be used at a small arms stationary range are provided in Table 26-1 and Table 26-2 respectively. Refer to chapter 15 of AP-42 for additional information if needed.

Table 26-1. 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$_{2.5}$	GHG[1]
A011	12 Gage #00 Shot Cartridge	4.20E-05	1.50E-03	2.00E-05	7.40E-05	6.70E-05	1.63E-03
A017	12 Gage #9 Shot Cartridge	2.10E-05	1.00E-03	7.40E-06	2.10E-05	2.00E-05	1.11E-03
A059	5.56mm Ball Cartridge	8.50E-05	1.60E-03	5.10E-06	3.90E-05	2.80E-05	1.11E-03
A063	5.56mm Tracer Cartridge	6.50E-05	1.40E-03	2.70E-06	4.90E-05	3.30E-05	9.18E-04
A065	5.56mm Practice Ball Cartridge	1.90E-05	4.00E-04	3.10E-06	1.10E-05	1.00E-05	3.75E-04
A066	5.56mm Ball Cartridge	5.60E-05	1.80E-03	1.30E-05	3.80E-05	3.20E-05	1.33E-03
A068	5.56mm Tracer Cartridge	1.70E-05	1.60E-03	2.80E-06	6.70E-05	5.10E-05	1.14E-03
A131	7.62mm Tracer Cartridge	4.30E-05	2.80E-03	7.80E-06	9.10E-05	5.80E-05	2.10E-03
A136	7.62mm Ball Match Cartridge	4.10E-05	3.00E-03	6.20E-06	6.20E-05	4.70E-05	2.18E-03
A143	7.62mm Ball Cartridge	9.70E-05	2.30E-03	4.90E-06	5.10E-05	3.80E-05	1.45E-03
A363	9mm Ball Cartridge	1.50E-05	3.10E-04	6.80E-06	2.40E-05	2.00E-05	2.35E-04
A518	.50 Caliber SLAP Ball Cartridge	8.50E-05	9.60E-03	2.00E-05	2.10E-04	1.80E-04	7.30E-03
A518	.50 Caliber SLAP Tracer Cartridge	1.30E-04	1.10E-02	1.70E-04	8.60E-04	3.40E-04	8.10E-03
A525	.50 Caliber Armor Piercing Cartridge	3.30E-05	1.60E-02	2.10E-05	9.70E-04	4.40E-04	1.05E-02
A557	.50 Caliber Ball Cartridge and Tracer Cartridge	1.20E-03	1.10E-02	1.30E-05	3.10E-04	1.90E-04	8.35E-03

SOURCE: 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.

1. Greenhouse gas (GHG) emission factors are the sum of CO_2 and CH_4 multiplied by their respective global warming potentials (GWP) and presented in units of equivalent CO_2 (CO_2e). The GWP of CO_2 and CH_4 are 1 and 25 respectively as given in 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.

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Table 26-2. Speciated VOC Emission Factors for Cartridges Used at Small Arms Firing Ranges

Pollutant	HAP[1]	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 26-2. Speciated VOC Emission Factors for Cartridges Used at Small Arms Firing Ranges (cont.)

Pollutant	HAP[1]	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 26-2. Speciated VOC Emission Factors for Cartridges Used at Small Arms Firing Ranges (cont.)

Pollutant	HAP[1]	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
m,p-Xylene	X	7.60E-09	---	3.50E-09	1.70E-09	9.70E-10	---	---	9.60E-09	---	5.30E-09	4.50E-09	3.20E-08	---	1.60E-08	2.00E-08
o-Xylene	X	5.40E-09	---	2.80E-09	2.50E-09	5.50E-10	---	---	1.60E-08	---	4.20E-09	3.00E-09	1.90E-08	---	2.70E-08	3.80E-08

SOURCE: 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.

1. An "X" indicates that this compound is a HAP.

"---" Indicates No Data Available

26.3 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 a 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 employed, 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 actually 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.

26.4 Emissions Calculation

Algorithms and Emission Factors (EFs) used by the Air Force are generally from AP-42; however, EFs for Air Force-unique sources have been developed by the Air Force. The only algorithms and EFs authorized for use in estimating Air Force emissions are those maintained within the Air Program Information Management System (APIMS). Emissions from small arms are the product of the number of total rounds fired and the appropriate emission factor. 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:

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

Equation 26-1

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 26-2.
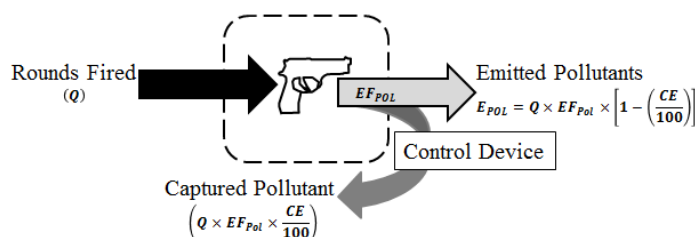
Figure 26-2. Small Arms Stationary Ranges Control Volume

26.5 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 Bioenvironmental Engineering, base Civil Engineering, or the filter manufacturer for assistance in determining the control efficiency of the filter.

26.6 Example Problem

Anytown AFB 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% for Pb and 0% for CO, calculate the total CO and Pb emissions at this range.

Step 1 – Select and record the appropriate emission factors. For A059 rounds, the emission factors for CO and Pb are **1.60E-03** and **5.10E-06** lb/item respectively. For the A363 rounds, the CO and Pb emission factors are **3.10E-04** and **6.80E-06** lb/item respectively.

Step 2 – Calculate CO emissions for each ammunition type. Use the emission factors recorded in Step 1, the number of rounds fired as given in the problem statement, and Equation 26-1 as shown:

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

For A059 rounds:

$$E(A059)_{CO} = 212{,}715\,\frac{item}{yr} \times 0.0016\,\frac{lb}{item} \times \left[1 - \left(\frac{0\%}{100\%}\right)\right]$$

$$\boldsymbol{E(A059)_{CO}} = 212{,}715\,\frac{\cancel{item}}{yr} \times 0.0016\,\frac{lb}{\cancel{item}} \times [1] = \boldsymbol{340.34\frac{lb}{yr}}$$

For A363 rounds:

$$E(A363)_{CO} = 97,275 \ \frac{item}{yr} \times 0.00031 \frac{lb}{item} \times \left[1 - \left(\frac{0\%}{100\%}\right)\right]$$

$$\boldsymbol{E(A363)_{CO}} = 97,275 \ \frac{\cancel{item}}{yr} \times 0.00031 \frac{lb}{\cancel{item}} \times [1] = \boldsymbol{30.16} \frac{\boldsymbol{lb}}{\boldsymbol{yr}}$$

Step 3 – Calculate total CO emissions. Sum the CO emissions calculated in Step 2 as follows:

$$E(Total)_{CO} = 340.34 \frac{lb}{yr} + 30.16 \frac{lb}{yr}$$

$$\boxed{\boldsymbol{E(Total)_{CO} = 370.5} \frac{\boldsymbol{lb}}{\boldsymbol{yr}}}$$

Step 4 – Calculate Pb emissions for each round. Use the emission factors recorded in Step 1, the number of rounds fired, the filter control efficiency, and Equation 26-1 as shown:

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

For the A059 rounds:

$$E(A059)_{Pb} = 212,715 \frac{item}{yr} \times 0.0000051 \frac{lb}{item} \times \left[1 - \left(\frac{90\%}{100\%}\right)\right]$$

$$\boldsymbol{E(A059)_{Pb}} = 212,715 \frac{\cancel{item}}{yr} \times 0.0000051 \frac{lb}{\cancel{item}} \times [0.1] = \boldsymbol{0.11} \frac{\boldsymbol{lb}}{\boldsymbol{yr}}$$

For the A363 rounds:

$$E(A363)_{Pb} = 97,275 \frac{item}{yr} \times 0.0000068 \frac{lb}{item} \times \left[1 - \left(\frac{90\%}{100\%}\right)\right]$$

$$\boldsymbol{E(A363)_{Pb}} = 97,275 \frac{item}{yr} \times 0.0000068 \frac{lb}{item} \times [0.1] = \boldsymbol{0.07} \frac{\boldsymbol{lb}}{\boldsymbol{yr}}$$

Step 5 – Calculate total Pb emissions. Sum the Pb emissions calculated in Step 4 as follows:

$$E(Total)_{Pb} = 0.11 \frac{lb}{yr} + 0.07 \frac{lb}{yr}$$

$$\boxed{\boldsymbol{E(Total)_{Pb} = 0.18} \frac{\boldsymbol{lb}}{\boldsymbol{yr}}}$$

26.7 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

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27 STATIC ROCKET ENGINE TESTING (RTST)

 ➢ *Point source* – if testing occurs in an enclosure
 ➢ *Fugitive source* – if testing is not performed in an enclosure

27.1 Introduction

Rocket engine testing is performed at certain Air Force 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 because often the rocket is attached to a test stand.

Emissions of concern from rocket engine testing include the 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 or not the testing is performed in an enclosed facility. A simple control volume for rocket engine testing is provided in Figure 27-1.
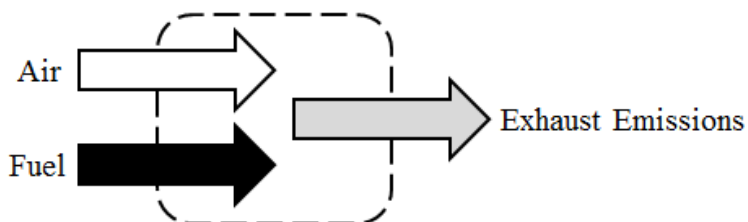
Figure 27-1. Simplified Rocket Engine Test Control Volume

27.2 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 specifically for 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 not to exceed limit and states that air sampling emissions test results must be retained for a minimum of two years. For information regarding the emission limits and compliance and reporting requirements, refer to 40 CFR 63 subpart PPPPP and 40 CFR 61 subpart D.

27.3 Emission Factors

The EPA has developed emission factors 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. The 2.75 inch Flechette with the MK40 Mod 3 motor (DODIC H459) and the 2.75 inch M267 with the MK66 Mod 3 motor (DODIC (H974) may be fired from both low speed and high performance aircraft. Criteria pollutant and HAP emission factors for these rockets are provided in Table 27-1 and Table 27-2. **Note that these emission factors are only associated with the use of the rocket motor; emissions associated with the impact and/or detonation of the warhead are not addressed here.** If an emission factor is unavailable for the rocket engine being tested, a surrogate engine may be used to calculate emissions. The emission factors provided are in units of pounds per item, though AP-42 also provides emission factors based on pounds per pound Net Explosive Weight (NEW). Refer to section 15.6 of AP-42 for additional information.

Table 27-1. 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}	$PM_{2.5}$	GHG[1]
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	2.95E+00
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	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

1. Greenhouse gas (GHG) emission factors the sum of CO_2, CH_4, and N_2O multiplied by their respective global warming potentials (GWP) and presented in units of equivalent CO_2 (CO_2e). The GWP of CO_2, CH_4, and N_2O are 1, 25, and 298 as given in Table A-1 of 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

"---" – Indicates No Data Available

Table 27-2. HAP Emission Factors for Rocket Engine Testing

Compound (CAS)	Emission Factor (lb/item)		Compound (CAS)	Emission Factor (lb/item)	
	2.75-inch Fletchette, MK40 Mod 3 Motor	2.75-inch Practice Warhead, MK66 Mod 3 Motor (M267)		2.75-inch Fletchette, MK40 Mod 3 Motor	2.75-inch Practice Warhead, MK66 Mod 3 Motor (M267)
Acenaphthene (83-32-9)	4.80E-07	3.80E-07	Total Dioxin/Furan Compounds (---)	1.70E-10	---
Acenaphthylene (208-96-8)	3.00E-05	1.30E-05	Fluoranthene (206-44-0)	---	6.20E-06
Acetaldehyde (75-07-0)	4.80E-04	2.00E-04	Fluorene (86-73-7)	3.70E-06	2.00E-06
Acetonitrile (75-05-8)	2.20E-04	8.70E-05	Formaldehyde (50-00-0)	3.40E-04	2.50E-04
Acrylonitrile (107-13-1)	4.80E-05	2.60E-05	1,2,3,4,6,7,8-Heptachlorodibenzo-p-dioxin (35822-46-9)	1.80E-11	---
Anthracene (120-12-7)	1.20E-06	1.00E-06	Hydrochloric Acid (7647-01-0)	---	1.70E-03
Benzene (71-43-2)	1.70E-03	3.80E-04	Hydrogen Cyanide (74-90-8)	4.20E-03	7.40E-04
Benzo[a]anthracene (56-55-3)	1.70E-06	7.60E-07	Indeno[1,2,3-cd]pyrene (193-39-5)	4.20E-06	1.00E-06
Benzo[b]fluoranthene (205-99-2)	2.00E-06	6.20E-07	Lead (7439-92-1)	5.10E-02	7.00E-02
Benzo[k]fluoranthene (207-08-9)	1.50E-06	5.40E-07	Manganese (7439-96-5)	5.00E-05	4.70E-05
Benzo[g,h,i]perylene (191-24-2)	1.30E-05	2.50E-06	Methylene Chloride (75-09-2)	2.80E-03	1.30E-04
Benzo[a]pyrene (50-32-8)	2.80E-06	1.20E-06	Naphthalene (91-20-3)	1.10E-04	8.60E-06
Benzo[e]pyrene (192-97-2)	3.10E-06	8.00E-07	1,2,3,4,6,7,8,9-Octachlorodibenzo-p-dioxin (3268-87-9)	1.50E-10	---
Cadmium (7440-43-9)	1.20E-03	6.60E-04	Phenanthrene (85-01-8)	1.20E-05	7.40E-06
Chloromethane (74-87-3)	1.20E-05	---	Phenol (108-95-2)	2.20E-05	---
Chromium (7440-47-3)	4.10E-06	1.40E-05	Pyrene (129-00-0)	2.80E-05	1.10E-05
Chrysene (218-01-9)	2.10E-06	7.40E-07	Styrene (100-42-5)	3.50E-05	1.70E-05
Dibenz[a,h]anthracene (53-70-3)	1.00E-07	5.40E-08	Toluene (108-88-3)	1.10E-04	4.70E-05

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.

"---" Indicates No Data Available

27.4 Emission Calculations

Algorithms and Emission Factors (EFs) used by the Air Force are generally from AP-42; however, EFs for Air Force-unique sources have been developed by the Air Force. The only algorithms and EFs authorized for use in estimating Air Force emissions are those maintained within the Air Program Information Management System (APIMS). Emissions from rocket engine testing may be calculated by multiplying the appropriate emission factor by the number of rocket engines tested per year or NEW of propellant, as shown in Equation 27-1:

$$E_{Pol} = Q \times EF_{Pol}$$

Equation 27-1

Where,

E_{Pol} = Emissions of a particular pollutant (lb/yr)

Q = Annual quantity of rocket engines tested or Net Explosive Weight (NEW) of propellant (items/yr or lb NEW/yr)

EF_{Pol} = Emission Factor (lb/item or lb/lb NEW)

A detailed control volume describing the calculation of emissions from static rocket engine testing is provided in Figure 27-2:
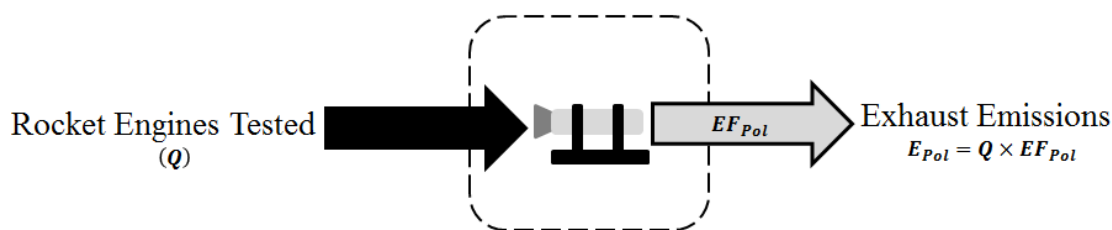

Figure 27-2. Static Rocket Engine Testing Control Volume

27.5 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 Subject Matter Expert prior to using any emission factors not provided here for approval or guidance.

27.6 Example Problem

Anytown AFB 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 emission factors. The particulate emission factors are provided in Table 27-1 while the benzene emission factor is provided in Table 27-2. For PM_{10}, $PM_{2.5}$, and Benzene, the emission factors are **0.11**, **0.10**, and **0.0017 lb/item**, respectively.

Step 2 - Calculate emissions. This is accomplished by using the emission factors recorded in Step 1 and Equation 27-1 as shown:

$$E_{Pol} = Q \times EF_{Pol}$$

For PM_{10}:

$$E_{PM_{10}} = 23 \frac{items}{yr} \times 0.11 \frac{lb}{item}$$

$$E_{PM_{10}} = 2.53 \frac{lb}{yr}$$

For PM$_{2.5}$:

$$E_{PM_{2.5}} = 23 \frac{items}{yr} \times 0.10 \frac{lb}{item}$$

$$E_{PM_{2.5}} = 2.30 \frac{lb}{yr}$$

For Benzene:

$$E_{Benzene} = 23 \frac{items}{yr} \times 0.0017 \frac{lb}{item}$$

$$E_{Benzene} = 3.91E - 02 \frac{lb}{yr}$$

27.7 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

28 STATIONARY INTERNAL COMBUSTION ENGINES (ICOM)

➢ *Point Source*

28.1 Introduction

Stationary internal combustion (ICOM) engines typically found at an Air Force base may include generators, pumps, and compressors. Stationary ICOM engines should not be confused with nonroad engines in that 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 nonroad ICOM engines are outlined in the mobile source emissions guide.**

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 turbines, 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 volume 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 are able to 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 due to the fact that 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, whereas an engine which operates with excess oxygen 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 turbines may be more advantageous than reciprocating engines because of their lower operational cost, lower levels of CO and VOC emissions, and potential for use in cogeneration systems. However, the large initial cost of a gas turbine engine means that they are not commonly found at Air Force installations, though some bases may have large electric generators powered by gas turbines. Most likely, the only turbine engines at an Air Force installation will be found on the jet aircraft whose emissions are described in the mobile source emissions guide. **Stationary ICOM engines and gas turbines are considered point sources** and a simple representation of these emissions is provided in Figure 28-1.
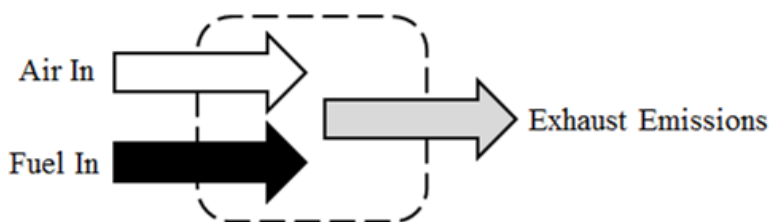
Figure 28-1. Simplified Control Volume for Emissions from Stationary ICOM Engines

28.2 NSPS and NESHAP Applicability

Internal combustion engines comprise a large list of pollutant emitting equipment. The number of devices which 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 New Source Performance Standard (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 diesel engines with a displacement of less than 30 liters per cylinder. These standards outline the emissions limits for criteria pollutants for diesel engines based on horsepower (hp). Similarly, 40 CFR 60 subpart JJJJ,

Standards of Performance for Stationary Spark Ignition Internal Combustion Engines, provides emissions limits for spark ignition reciprocating internal combustion engines based on horsepower and manufacture date. Finally, 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 subparts GG, *Standards of Performance for Stationary Gas Turbines*, and 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, National Emission Standards for Hazardous Air Pollutants (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. 40 CFR 63 subpart YYYY, *National Emission Standards for Hazardous Air Pollutants for Stationary Combustion Turbines*, specifies the HAP emission 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 emission limits and operational limits for both spark and compression ignition reciprocating internal combustion engines. Consult the sections listed above in the Code of Federal Regulations for more information or to verify that the engines located on site are in compliance with these standards.

28.3 Greenhouse Gas Mandatory Reporting Rule

The EPA has established mandatory greenhouse gas reporting requirements for owners and operators of facilities that directly emit greenhouse gases into the atmosphere. According to 40 CFR 98.2, any facility operating stationary fuel combustion sources whose aggregate maximum rated heat input capacity is 30 MMBtu/hr and emits 25,000 metric tons of CO_2e or more per year in combined emissions from all stationary fuel combustion sources 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 greenhouse gas reporting requirements.

28.4 Emission Factors

Chapter 3 of AP-42 provides emission factors for stationary ICOM engines based on the fuel 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 which served as a basis for the development of the emission factors found in AP-42. Though these emission factors may apply to older engines, their use in emissions calculations for newer engines may result in the

overestimation of pollutant emissions. In place of the actual emission factors that are provided in AP-42, the minimum required emission standards should be used to reflect the increased efficiency and reduced emissions of the newer equipment replacing older inventory. These minimum federal emission standards adopted by the EPA are known as New Source Performance Standards (NSPS). The NSPS thresholds were proposed to set standards not only for newly manufactured engines, but also older engines which have been rebuilt or modified.

For the purpose of emissions calculations for stationary ICOM equipment, the emission factors presented in the subsequent tables were selected from AP-42 or the emissions threshold as set by the NSPS. Any NSPS emission thresholds (which all new or reconstructed engines must comply with) that are less than the emission factor provided in AP-42 were used for ICOM engines. If the NSPS emission threshold was greater than the emission factors in AP-42, then the AP-42 values were used since these are based on actual test data. For simplicity, Table 28-3 and Table 28-4 provide emission factors for two time spans: those engines which were manufactured prior to 2007 (or 2011 for engines >3000 horsepower and displacement ≤10Liters/cylinder) and those engines manufactured or modified after this date. Though this simplification may lead to reduced emissions than if using AP-42 emission factors, it is possible to reduce emissions further by consulting the CFRs directly to determine additional thresholds and implementation years not given here.

28.4.1 Reciprocating Engines – Compression Ignition (CI)

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, 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 (FAHS) are not required to comply with these standards and have their own set of emission factors in Table 28-3. These emission factors represent a worst-case scenario. If any installations in these parts of Alaska have NSPS ICOM engines, then the applicable emission factors should be used instead. Additionally, fire pumps have alternate emission factors and are separated in the table based on their maximum engine horsepower. The table provides emission factors 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 document.

28.4.1.1 NO$_X$ Emission Factor Determination Using the NSPS

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 non-methane hydrocarbons (NMHC) and nitrogen oxide compounds (NO$_X$). 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. In those instances, the relationship

of NO_X to NMHC is established using the data from AP-42. By using the ratio of NO_X to the total NO_X and NMHC as defined by the emission factors in AP-42, then setting this ratio equal to those established by the emission standards, the percentage of NO_X in the combined NO_X and NMHC emission factor may be estimated. 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,

$(NO_X+NMHC)_{NSPS}$ =   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.**

28.4.1.2   VOC Emission Factor Determination Using NSPS

In order to further complicate the process of determining a NO_X emission factor, AP-42 does not provide an emission factor for NMHC. This value must be calculated using the total organic compounds (TOC) emission factor 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, volatile organic compounds (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 Resource 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 emission factor is estimated using the equation provided above. The conversion factors are provided in Table 28-1.

Table 28-1. 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.

28.4.1.3   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$_X$ emission factor was taken directly from AP-42. For large CI engines (engines > 600 horsepower), the SO$_X$ emission factor given in AP-42 is a function of the sulfur content of the fuel used. In the following emission factor tables, the SO$_X$ emission factor given was calculated using the fuel data given in Table 28-2.

Table 28-2. Data for Common Fuels Used in Stationary ICOM Engines

Fuel Type	Heating Value (Btu/Unit Fuel)[1]	Sulfur Content (wt. %)[2]
Diesel	138,000 Btu/gal	0.0015[3]
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[4]
Digester Gas	655 Btu/ft^3	---

1. SOURCE 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.
2. 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.
3. SOURCE: "Regulatory Announcement: Clean Air Nonroad Diesel Rule," U.S. Environmental Protection Agency (EPA), Office of Transportation and Air Quality, May 2004.
4. SOURCE: This value assumes a typical sulfur compound concentration of 46.9 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.

"---" – Indicates No Data Available

28.4.1.4   Greenhouse Gas (GHG) Emission Factor Calculation

As attention to global climate change intensifies, the estimation of greenhouse gas (GHG) emissions becomes increasingly more significant. For CI engines, AP-42 does not provide an emission factor for all three of the most common greenhouse gases: Nitrous Oxide (N$_2$O), Methane (CH$_4$), and Carbon Dioxide (CO$_2$). For a complete picture of the total GHG emissions, a general

emission factor given in the Federal Register was used to determine the N_2O and CH_4 emission factors. These emission factors were then multiplied by their respective global warming potentials (GWP) and added to the CO_2 emission factor for a composite GHG emission factor. A GWP is a measure of the amount of heat a gas can retain.

28.4.1.5   HAP Speciation Emission Factor Determination

The National Emission Standards for Hazardous Air Pollutants (NESHAP) for stationary reciprocating internal combustion engines are given in 40 CFR 63 subpart ZZZZ. AP-42 provides speciated HAP emission factors in a lb/MMBtu format. These emission factors are given in Table 28-4, for engines manufactured pre-2007, those manufactured in 2007 and later, and rural Alaskan locations. Emission factors for 2007 and later were estimated using a similar method for determining NO_X emissions described above in cases where a combined NO_X+NMHC threshold was given. These emission factors were estimated using the ratio of the specific HAP to total VOC in AP-42 and then applying this ratio to the NSPS calculated VOC total.

Table 28-3. Criteria Pollutant Emission Factors for Stationary Compression Ignition Internal Combustion Engines

Maximum Engine Power	Displacement (L/cylinder)	Model Year	NO_X[2] (lb/hp-hr)[8]	(lb/MMBtu)	CO[3] (lb/hp-hr)[8]	(lb/MMBtu)	SO_X[3] (lb/hp-hr)[8]	(lb/MMBtu)	VOC[4] (lb/hp-hr)[8]	(lb/MMBtu)	PM_{10}[3] (lb/hp-hr)[8]	(lb/MMBtu)	$PM_{2.5}$[3] (lb/hp-hr)[8]	(lb/MMBtu)	GHG[5] (lb/hp-hr)[8]	(lb/MMBtu)
All Dual Fuel Engines																
All			1.80E-02(3)	2.70E+00(3)	7.50E-03	1.16E+00	7.31E-06	7.02E-04	1.32E-03(6)	2.00E-01(6)	7.00E-04(7)	1.00E-01(7)	7.00E-04(7)	1.00E-01(7)	7.73E-01	1.10E+02
Diesel Fuel Engines																
hp ≤ 600	< 10	Pre-2007 and Fire Pumps	3.57E-02(3)	4.41E+00(3)	7.68E-03	9.50E-01	2.35E-03	2.90E-01	2.79E-03(3)	3.44E-01(3)	2.51E-03	3.10E-01	2.51E-03	3.10E-01	1.33E+00	1.64E+02
		2007 - Present	1.15E-02	1.42E+00	7.68E-03	9.50E-01	2.35E-03	2.90E-01	8.98E-04	1.11E-01	1.32E-03(2)	1.63E-01(2)	1.32E-03(2)	1.63E-01(2)	1.33E+00	1.65E+02
600 < hp ≤ 3000	< 10	Pre-2007 and Fire Pumps	2.59E-02(3)	3.20E+00(3)	6.88E-03	8.50E-01	1.23E-05	1.52E-03	7.16E-04(3)	8.86E-02(3)	8.09E-04	1.00E-01	8.09E-04	1.00E-01	1.33E+00	1.64E+02
		2007 - Present	1.03E-02	1.27E+00	5.75E-03	7.11E-01	1.23E-05	1.52E-03	7.04E-04	8.70E-02	3.29E-04(2)	4.06E-02(2)	3.29E-04(2)	4.06E-02(2)	1.34E+00	1.66E+02
	10 ≤ D < 30	Pre-2007 and Fire Pumps	2.59E-02(3)	3.20E+00(3)	6.88E-03	8.50E-01	1.23E-05	1.52E-03	7.16E-04(3)	8.86E-02(3)	8.09E-04	1.00E-01	8.09E-04	1.00E-01	1.33E+00	1.64E+02
		2007 - Present	1.76E-02	2.18E+00	6.88E-03	8.50E-01	1.23E-05	1.52E-03	4.88E-04	6.03E-02	8.09E-04	1.00E-01	8.09E-04	1.00E-01	1.34E+00	1.66E+02
hp > 3000	< 10	Pre-2007 and Fire Pumps	2.59E-02(3)	3.20E+00(3)	6.88E-03	8.50E-01	1.23E-05	1.52E-03	7.16E-04(3)	8.86E-02(3)	8.09E-04	1.00E-01	8.09E-04	1.00E-01	1.33E+00	1.64E+02
		2011 - Present	1.03E-02	1.27E+00	5.75E-03	7.11E-01	1.23E-05	1.52E-03	7.04E-04	8.70E-02	3.29E-04(2)	4.06E-02(2)	3.29E-04(2)	4.06E-02(2)	1.34E+00	1.66E+02
	10 ≤ D < 30	Pre-2007 and Fire Pumps	2.59E-02(3)	3.20E+00(3)	6.88E-03	8.50E-01	1.23E-05	1.52E-03	7.16E-04(3)	8.86E-02(3)	8.09E-04	1.00E-01	8.09E-04	1.00E-01	1.33E+00	1.64E+02
		2007 - Present	1.76E-02	2.18E+00	6.88E-03	8.50E-01	1.23E-05	1.52E-03	4.88E-04	6.03E-02	8.09E-04	1.00E-01	8.09E-04	1.00E-01	1.34E+00	1.66E+02

1. Values either AP-42 or NSPS worst-case for years specified. All engines with displacement ≥10L/cylinder assumed to be >600 hp. Fire pumps assumed to be ≤600hp.

2. SOURCE (unless otherwise stated): 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. 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 in AP-42. Conversion of organics using ratios given in Table 28-1.

3. SOURCE: U.S. EPA. *Compilation of Air Pollutant Emission Factors Volume I: Stationary Point and Area Sources*. Fifth Edition. 2000. Chapter 3. For SO_X emission factors, where necessary, a sulfur weight percent of 0.0015 and 0.0007 were used for diesel and natural gas respectively. For dual fuel engines or engines >600hp, if ULSD is not used, then calculate the sulfur emission factor using the following equations. For dual fuel engines $4.06E-04 S_1 + 9.57E-03 S_2$ (lb/hp-hr) and $0.05 S_1 + 0.895 S_2$ (lb/MMBtu). For alternative fuel with engines >600hp use: $8.09E-03 S_1$ (lb/hp-hr) or $1.01 S_1$ (lb/MMBtu). Where S_1 is the sulfur content of the fuel oil and S_2 is the sulfur content of natural gas. For example, if the sulfur content is 1.5%, then S=1.5.

4. SOURCE (unless otherwise stated): VOC emission factors were estimated using the THC or NMHC values as determined in note 2. TOC emission factor given in AP-42 assumed to be equal to TOG.

5. The Greenhouse gas (GHG) emission factor is the total of the emission factors for CO_2, CH_4, and N_2O multiplied by their respective global warming potentials (GWP) to convert the emission factor into equivalent CO_2 (CO_2e). Missing emission factors taken from tables C-1 and C-2 of 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. The GWP for CH_4 is 25 and for N_2O is 298.

6. This value determined by subtracting the methane emission factor from the TOC in AP-42.

7. Emission Factors from large stationary diesel fuel engines were used as a surrogate.

8. An average BSFC 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.

9. This is an NSPS emission threshold.

Table 28-4. HAP Emission Factors for Stationary Compression Ignition Internal Combustion Engines

Compound	Emission Factors															
	hp≤600				600<hp≤3000						hp>3000					
	Pre-2007 and Fire Pumps[1]		Displacement <10L/clyinder[2] 2007 - Present		Pre-2007 and Fire Pumps[1]		Displacement <10L/clyinder[2] 2007 - Present		Displacement 10≤D≤30L/clyinder[2] 2007 - Present		Pre-2007 and Fire Pumps[1]		Displacement <10L/clyinder[2] 2011 - Present		Displacement 10≤D≤30L/clyinder[2] 2007 - Present	
	(lb/hp-hr)[3]	(lb/MMBtu)	(lb/hp-hr)[3]	(lb/MMBtu)	(lb/hp-hr)[3]	(lb/MMBtu)	(lb/hp-hr)[3]	(lb/MMBtu)	(lb/hp-hr)[3]	(lb/MMBtu)	(lb/hp-hr)[3]	(lb/MMBtu)	(lb/hp-hr)[3]	(lb/MMBtu)	(lb/hp-hr)[3]	(lb/MMBtu)
1,3-Butadiene	3.16E-07	3.91E-05	1.02E-07	1.26E-05	---	---	---	---	---	---	---	---	---	---	---	---
Acenaphthene	1.15E-08	1.42E-06	3.70E-09	4.57E-07	3.79E-08	4.68E-06	3.72E-08	4.60E-06	2.58E-08	3.19E-06	3.79E-08	4.68E-06	3.72E-08	4.60E-06	2.58E-08	3.19E-06
Acenaphthylene	4.09E-08	5.06E-06	1.32E-08	1.63E-06	7.47E-08	9.23E-06	7.33E-08	9.07E-06	5.08E-08	6.28E-06	7.47E-08	9.23E-06	7.33E-08	9.07E-06	5.08E-08	6.28E-06
Acetaldehyde	6.20E-06	7.67E-04	2.00E-06	2.47E-04	2.04E-07	2.52E-05	2.00E-07	2.48E-05	1.39E-07	1.72E-05	2.04E-07	2.52E-05	2.00E-07	2.48E-05	1.39E-07	1.72E-05
Acrolein	7.48E-07	9.25E-05	2.41E-07	2.98E-05	6.37E-08	7.88E-06	6.26E-08	7.74E-06	4.34E-08	5.36E-06	6.37E-08	7.88E-06	6.26E-08	7.74E-06	4.34E-08	5.36E-06
Anthracene	1.51E-08	1.87E-06	4.87E-09	6.02E-07	9.95E-09	1.23E-06	9.77E-09	1.21E-06	6.77E-09	8.37E-07	9.95E-09	1.23E-06	9.77E-09	1.21E-06	6.77E-09	8.37E-07
Benz(a)anthracene	1.36E-08	1.68E-06	4.38E-09	5.41E-07	5.03E-09	6.22E-07	4.94E-09	6.11E-07	3.42E-09	4.23E-07	5.03E-09	6.22E-07	4.94E-09	6.11E-07	3.42E-09	4.23E-07
Benzene	7.55E-06	9.33E-04	2.43E-06	3.01E-04	6.28E-06	7.76E-04	6.17E-06	7.62E-04	4.27E-06	5.28E-04	6.28E-06	7.76E-04	6.17E-06	7.62E-04	4.27E-06	5.28E-04
Benzo(a)pyrene	1.52E-09	1.88E-07	4.90E-10	6.06E-08	2.08E-09	2.57E-07	2.04E-09	2.52E-07	1.42E-09	1.75E-07	2.08E-09	2.57E-07	2.04E-09	2.52E-07	1.42E-09	1.75E-07
Benzo(b)fluoranthene	8.02E-10	9.91E-08	2.58E-10	3.19E-08	8.98E-09	1.11E-06	8.82E-09	1.09E-06	6.11E-09	7.56E-07	8.98E-09	1.11E-06	8.82E-09	1.09E-06	6.11E-09	7.56E-07
Benzo(g,h,i)perylene	3.96E-09	4.89E-07	1.27E-09	1.58E-07	4.50E-09	5.56E-07	4.42E-09	5.46E-07	3.06E-09	3.78E-07	4.50E-09	5.56E-07	4.42E-09	5.46E-07	3.06E-09	3.78E-07
Benzo(k)fluoranthene	1.25E-09	1.55E-07	4.04E-10	4.99E-08	1.76E-09	2.18E-07	1.73E-09	2.14E-07	1.20E-09	1.48E-07	1.76E-09	2.18E-07	1.73E-09	2.14E-07	1.20E-09	1.48E-07
Chrysene	2.86E-09	3.53E-07	9.20E-10	1.14E-07	1.24E-08	1.53E-06	1.22E-08	1.50E-06	8.42E-09	1.04E-06	1.24E-08	1.53E-06	1.22E-08	1.50E-06	8.42E-09	1.04E-06
Dibenz(a,h)anthracene	4.72E-09	5.83E-07	1.52E-09	1.88E-07	2.80E-09	3.46E-07	2.75E-09	3.40E-07	1.91E-09	2.36E-07	2.80E-09	3.46E-07	2.75E-09	3.40E-07	1.91E-09	2.36E-07
Fluoranthene	6.16E-08	7.61E-06	1.98E-08	2.45E-06	3.26E-08	4.03E-06	3.20E-08	3.96E-06	2.22E-08	2.74E-06	3.26E-08	4.03E-06	3.20E-08	3.96E-06	2.22E-08	2.74E-06
Fluorene	2.36E-07	2.92E-05	7.61E-08	9.41E-06	1.04E-07	1.28E-05	1.02E-07	1.26E-05	7.05E-08	8.71E-06	1.04E-07	1.28E-05	1.02E-07	1.26E-05	7.05E-08	8.71E-06
Formaldehyde	9.55E-06	1.18E-03	3.07E-06	3.80E-04	6.38E-07	7.89E-05	6.27E-07	7.75E-05	4.34E-07	5.37E-05	6.38E-07	7.89E-05	6.27E-07	7.75E-05	4.34E-07	5.37E-05
Indeno(1,2,3-c,d)pyrene	3.03E-09	3.75E-07	9.77E-10	1.21E-07	3.35E-09	4.14E-07	3.29E-09	4.07E-07	2.28E-09	2.82E-07	3.35E-09	4.14E-07	3.29E-09	4.07E-07	2.28E-09	2.82E-07
Naphthalene	6.86E-07	8.48E-05	2.21E-07	2.73E-05	1.05E-06	1.30E-04	1.03E-06	1.28E-04	7.16E-07	8.85E-05	1.05E-06	1.30E-04	1.03E-06	1.28E-04	7.16E-07	8.85E-05
Phenanthrene	2.38E-07	2.94E-05	7.66E-08	9.47E-06	3.30E-07	4.08E-05	3.24E-07	4.01E-05	2.25E-07	2.78E-05	3.30E-07	4.08E-05	3.24E-07	4.01E-05	2.25E-07	2.78E-05
Pyrene	3.87E-08	4.78E-06	1.25E-08	1.54E-06	3.00E-08	3.71E-06	2.95E-08	3.64E-06	2.04E-08	2.53E-06	3.00E-08	3.71E-06	2.95E-08	3.64E-06	2.04E-08	2.53E-06
Toluene	3.31E-06	4.09E-04	1.07E-06	1.32E-04	2.27E-06	2.81E-04	2.23E-06	2.76E-04	1.55E-06	1.91E-04	2.27E-06	2.81E-04	2.23E-06	2.76E-04	1.55E-06	1.91E-04
Xylenes	2.31E-06	2.85E-04	7.43E-07	9.18E-05	1.56E-06	1.93E-04	1.53E-06	1.90E-04	1.06E-06	1.31E-04	1.56E-06	1.93E-04	1.53E-06	1.90E-04	1.06E-06	1.31E-04

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

2. SOURCE: Values under this category calculated using the pollutant to total VOC ratio from AP-42. This ratio was multiplied to the total VOC for this engine size and year.

3. An average BSFC of 8089 Btu/hp-hr used for unit conversion for diesel fuel. These values from Shires, Theresa M., et al, "Compendium of Greenhouse Gas Emissions Estimation Methodologies for the Oil and Natural Gas Industry," August 2009.

"---" – Indicates No Data Available

28.4.2 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. However, in order to use these emission thresholds, one must know a great deal of information about an engine in order to select the correct standard, which complicates the process of performing an AEI. Because of this, and the fact that there are likely to be very few stationary SI engines on an Air Force base, the only emission factors presented here come directly from AP-42. These emission factors are given in Table 28-5. Note that for natural gas, the emission factors are given in units of lb/MMBtu; however, these emission factors may be converted to units of lb/hp-hr if the heat input and horsepower are known. The conversion formula is given below:

$$EF_{\frac{lb}{hp-hr}} = EF_{\frac{lb}{MMBtu}} \times HI \times \frac{1}{hp}$$

Where,

$EF_{lb/hp\text{-}hr}$	=	Emission Factor in units of lb/hp-hr
$EF_{lb/MMBtu}$	=	Emission Factor in units of lb/MMBtu
HI	=	Heat input (MMBtu/hr)
hp	=	Engine power (hp)

28.4.3 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 emission factors given in section 3.1 of AP-42. While there are likely to be very few turbine engines found at an Air Force installation, those that are in operation may use diesel, natural gas, landfill gas, or digester gas as the primary fuel. The emission factors for turbines using these fuels may be found in Table 28-6. Additionally, Table 28-7 provides HAP speciation data for both SI engines and Turbine engines.

Table 28-5. Criteria Pollutant Emission Factors for Stationary Spark Ignition Internal Combustion Engines

Fuel	Emission Factors[1]													
	NOx[1]		CO[1]		SOx		VOC		PM$_{10}$		PM$_{2.5}$		GHG[2]	
	(lb/hp-hr)[3]	(lb/MMBtu)	(lb/hp-hr)[3]	(lb/MMBtu)	(lb/hp-hr)[3]	(lb/MMBtu)	(lb/hp-hr)[3]	(lb/MMBtu)	(lb/hp-hr)[3]	(lb/MMBtu)	(lb/hp-hr)[3]	(lb/MMBtu)	(lb/hp-hr)[3]	(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	1.15E+00	1.46E+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	6.02E+00	7.66E+02
Natural Gas - 4 Stroke Rich Burn	1.78E-02	2.27E+00	2.76E-02	3.51E+00	4.56E-06	5.80E-04	2.33E-04	2.96E-02	7.47E-05	9.50E-03	7.47E-05	9.50E-03	5.78E+00	7.35E+02
Gasoline	1.10E-02	1.63E+00	6.96E-03	9.90E-01	5.91E-04	8.40E-02	1.49E-02[4]	2.08E+00[4]	7.21E-04	1.00E-01	7.21E-04	1.00E-01	1.08E+00	1.55E+02

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

1. NOx and CO emission factors for Natural gas assume engine operates at <90% load.

2. The Greenhouse gas (GHG) emission factor is the total of the emission factors for CO_2, CH_4, and N_2O multiplied by their respective global warming potentials (GWP) to convert the emission factor into equivalent CO_2 (CO_2e). Missing emission factors taken from tables C-1 and C-2 of 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. The GWP for CH_4 and N_2O are 25 and 298 respectively.

3. For natural gas, an average BSFC of 7858 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

4. Value converted from TOC to VOC assuming TOC is equal to TOG and using the ratios provided in Table 28-1 for 2-stroke gasoline engines.

Table 28-6. Criteria Pollutant Emission Factors for Stationary Turbine Internal Combustion Engines

Turbine Type	Control Type	Emission Factors												
		NO_X		CO		SO_X[1]		VOC		PM_{10}		$PM_{2.5}$		GHG[2]	
		(lb/hp-hr)[3]	(lb/MMBtu)	(lb/hp-hr)[3]	(lb/MMBtu)	(lb/hp-hr)[3]	(lb/MMBtu)	(lb/hp-hr)[3]	(lb/MMBtu)	(lb/hp-hr)[3]	(lb/MMBtu)	(lb/hp-hr)[3]	(lb/MMBtu)	(lb/hp-hr)[3]	(lb/MMBtu)
Natural Gas-Fired	Uncontrolled	3.32E-03	3.20E-01	8.51E-04	8.20E-02	9.76E-06	9.40E-04	2.18E-05	2.10E-03	6.85E-05	6.60E-03	6.85E-05	6.60E-03	1.15E+00	1.11E+02
	Water-Steam Injection	1.35E-03	1.30E-01	3.11E-04	3.00E-02	---[4]	---[4]	---[4]	---[4]	---[4]	---[4]	---[4]	---[4]	---[4]	---[4]
	Lean-Premix	1.03E-03	9.90E-02	1.56E-04	1.50E-02	---[4]	---[4]	---[4]	---[4]	---[4]	---[4]	---[4]	---[4]	---[4]	---[4]
Diesel Gas-Fired	Uncontrolled	7.11E-03	8.80E-01	2.67E-05	3.30E-03	2.04E-04	2.53E-02	3.31E-06	4.10E-04	9.69E-06	1.20E-03	9.69E-06	1.20E-03	1.27E+00	1.57E+02
	Water-Steam Injection	1.94E-03	2.40E-01	6.14E-04	7.60E-02	---[4]	---[4]	---[4]	---[4]	---[4]	---[4]	---[4]	---[4]	---[4]	---[4]
Landfill Gas-Fired	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	4.06E-01	5.02E+01
Digester Gas-Fired	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	2.18E-01	2.70E+01

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

1. 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.

2. The Greenhouse gas (GHG) emission factor is the total of the emission factors for CO_2, CH_4, and N_2O multiplied by their respective global warming potentials (GWP) to convert the emission factor into equivalent CO_2 (CO_2e). Missing emission factors taken from tables C-1 and C-2 of 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. The GWP for CH_4 is 25 and for N_2O is 298.

3. A BSFC of 10,379 Btu/hp-hr was used for unit conversion for natural gas turbines and a BSFC of 8078 Btu/hp-hr 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.

4. No emission factors are given for this pollutant with this control device. It is recommended that the emission factor from the uncontrolled turbine using the appropriate fuel is used in place of this missing emission factor.

"---" – Indicates No Data Available

Table 28-7. HAP Emission Factors for Stationary Turbine and Spark Ignition ICOM Engines

Compound	Emission Factors (lb/MMBtu)						
	Natural Gas			Gas Turbines			
	2-Stroke Lean Burn	4-Stroke Lean Burn	4-Stroke Rich Burn	Natural Gas	Diesel	Landfill Gas	Digester Gas
1,1,2,2,-Tetrachloroethane	6.63E-05	4.00E-05	2.53E-05	---	---	---	---
1,1,2-Trichloroethane	5.27E-05	3.18E-05	1.53E-05	---	---	---	---
1,1-Dichloroethane	3.91E-05	2.36E-05	1.13E-05	---	---	---	---
1,2-Dichloropropane	4.46E-05	2.69E-05	1.30E-05	---	---	---	---
1,3-Butadiene	8.20E-04	2.67E-04	6.63E-04	4.30E-07	1.60E-05	---	9.80E-06
1,3-Dichloropropene	4.38E-05	2.64E-05	1.27E-05	---	---	---	---
1,4-Dichlorobenzene	---	---	---	---	---	---	2.00E-05
2,2,4-Trimethylpentane	8.46E-04	2.50E-04	---	---	---	---	---
Acenaphthene	1.33E-06	1.25E-06	---	---	---	---	---
Acenaphthylene	3.17E-06	5.53E-06	---	---	---	---	---
Acetaldehyde	7.76E-03	8.36E-03	2.79E-03	4.00E-05	---	---	5.30E-05
Acetonitrile	---	---	---	---	---	1.20E-05	---
Acrolein	7.78E-03	5.14E-03	2.63E-03	6.40E-06	---	---	---
Anthracene	7.18E-07	---	---	---	---	---	---
Benz(a)anthracene	3.36E-07	---	---	---	---	---	---
Benzene	1.94E-03	4.40E-04	1.58E-03	1.20E-05	5.50E-05	2.10E-05	---
Benzo(a)pyrene	5.68E-09	---	---	---	---	---	---
Benzo(b)fluoranthene	8.51E-09	1.66E-07	---	---	---	---	---
Benzo(g,h,i)perylene	2.48E-08	4.14E-07	---	---	---	---	---
Benzo(k)fluoranthene	4.26E-09	---	---	---	---	---	---
Benzyl Chloride	---	---	---	---	---	1.20E-05	---
Biphenyl	3.95E-06	2.12E-04	---	---	---	---	---
Carbon Tetrachloride	6.07E-05	3.67E-05	1.77E-05	---	---	1.80E-06	2.00E-05
Chlorobenzene	4.44E-05	3.04E-05	1.29E-05	---	---	2.90E-06	1.60E-05
Chloroethane	---	1.87E-06		---	---	---	---
Chloroform	4.71E-05	2.85E-05	1.37E-05	---	---	1.40E-06	1.70E-05
Chrysene	6.72E-07	6.93E-07	---	---	---	---	---
Dibenz(a,h)anthracene	---	---	---	---	---	---	---
Ethylbenzene	1.08E-04	3.97E-05	2.48E-05	3.20E-05	---	---	---
Ethylene Dibromide	7.34E-05	4.43E-05	2.13E-05	---	---	---	---
Ethylene Dichloride	4.22E-05	2.36E-05	1.13E-05	---	---	---	1.50E-05
Fluoranthene	3.61E-07	1.11E-06	---	---	---	---	---
Fluorene	1.69E-06	5.67E-06	---	---	---	---	---
Formaldehyde	5.52E-02	5.28E-02	2.05E-02	7.10E-04	2.80E-04	---	1.90E-04
Indeno(1,2,3-c,d)pyrene	9.93E-09	---	---	---	---	---	---
Methanol	2.48E-03	2.50E-03	3.06E-03	---	---	---	---
Methylene Chloride	1.47E-04	2.00E-05	4.12E-05	---	---	2.30E-06	1.30E-05
n-Hexane	4.45E-04	1.11E-03	---	---	---	---	---
Naphthalene	9.63E-05	7.44E-05	9.71E-05	1.30E-06	3.50E-05	---	---
Phenanthrene	3.53E-06	1.04E-05	---	---	---	---	---
Phenol	4.21E-05	2.40E-05	---	---	---	---	---
Propylene Oxide	---	---	---	2.90E-05	---	---	---
Pyrene	5.84E-07	1.36E-06	---	---	---	---	---
Styrene	5.48E-05	2.36E-05	1.19E-05	---	---	---	---
Tetrachloroethylene	---	---	---	---	---	2.50E-06	2.10E-05
Toluene	9.63E-04	4.08E-04	5.58E-04	1.30E-04	---	1.10E-04	---
Trichloroethylene	---	---	---	---	---	1.90E-06	1.80E-05
Vinyl Chloride	2.47E-05	1.49E-05	7.18E-06	---	---	1.60E-06	3.60E-05
Vinylidene Chloride	---	---	---	---	---	---	1.50E-05
Xylenes	2.68E-04	1.84E-04	1.95E-04	6.40E-05	---	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.

"---" – Indicates No Data Available

28.5 Emissions Calculation

Algorithms and emission factors (EFs) used by the Air Force are generally from AP-42; however, EFs for Air Force-unique sources have been developed by the Air Force. The only algorithms and EFs authorized for use in estimating Air Force emissions are those maintained within the Air Program Information Management System (APIMS).

28.5.1 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 emission factor. The emissions are calculated as follows:

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

Equation 28-1

Where,

E_{Pol} = Annual emissions of pollutant (lb/yr)
Q = Annual quantity of fuel consumed (gal/yr) or (ft³/yr)
HV = Heating value of the fuel used from Table 28-2 (Btu/gal) or (Btu/ft³)
10^6 = Factor to convert Btu to MMBtu (MMBtu/Btu)
EF_{Pol} = Emission factor from Table 28-3, Table 28-4, Table 28-5, Table 28-6, or Table 28-7 (lb/MMBtu)

A detailed representation of the emissions from stationary ICOM engines is provided in Figure 28-2.
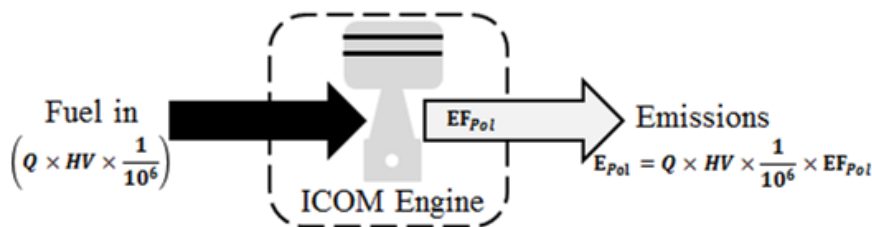
Figure 28-2. Stationary ICOM Control Volume - Fuel Consumption Method

28.5.2 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 emission factor. To use the load factor method, the engine's rated power, operating time, and typical load factor must be known. Table 28-8 provides typical load factors for several categories of ICOM engines, but actual site-specific

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loading factors should be used whenever possible. With the selected emission factor and loading factor, the ICOM emissions are calculated using the following equation:

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

Equation 28-2

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 28-3, Table 28-4, Table 28-5, Table 28-6, or Table 28-7 (lb/hp-hr)

Table 28-8. Typical Load Factors for Common Stationary ICOM Equipment

Equipment Type	Diesel Load Factor[1]	Non-Diesel Load Factor[2]
Air Compressor	48	56
Generator Set	74	68
Pumps	74	69
Refrigeration/AC	43[2]	46
Welders	45	68

1. SOURCE (Unless otherwise noted): "Software User's Guide: URBEMIS2007 for Windows," South Coast Air Quality Management District (SCAQMD), November 2007.
2. 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 28-3.
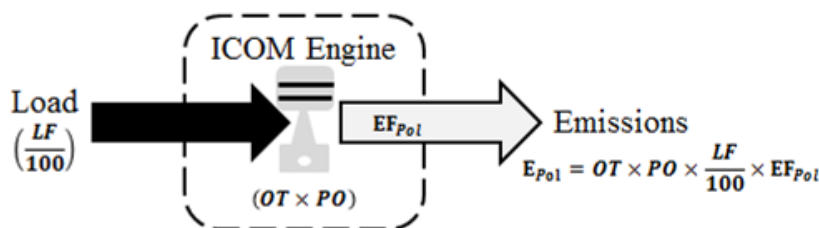
Figure 28-3. Stationary ICOM Control Volume - Load Factor Method

28.5.3 Discouraged Methods

Previous source guides have proposed alternative methods for emergency generators using the peak demand of the generator. This method makes the assumption that the peak electrical demand

is approximately the same as the power output of the generator. This method is not recommended because this assumes that the generator was properly sized. Unfortunately, the peak demand is not a good indicator as to the total horsepower of the generator since the generator may be working at a variety of operating loads. As a result, this calculation method may significantly underestimate emissions and should no longer be used.

28.6 Information Resources

All emission factors presented are conservative by necessity since each applies to a large range of equipment sizes and designs. For data required for emissions calculations, contact the group responsible for operating/maintaining stationary ICOM equipment on base, typically Civil Engineering, and consult the equipment spec sheets or contact the manufacturer directly. Since the emission factors provided are applicable to a wide range of equipment sizes, the accuracy of emissions calculations may be enhanced by reviewing the CFR 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. Additionally, if the engine's brake specific fuel consumption (BSFC) is available, either through the spec sheet or from the manufacturer, then that value should be used for emission factor 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 then be used in place of the averages provided in Table 28-2.

28.7 Example Problems

28.7.1 Problem #1 - Fuel Consumption Method

Anytown AFB is looking to determine the NO_X emissions from a natural gas-fired generator 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.

Step 1 – **Select and Record Emission Factor and fuel Heating Value.** The emission factors for natural gas-fired engines are provided in Table 28-5. For a 4-stroke, lean burn engine, the NO_X emission factor is **8.47E-01 lb/MMBtu**. Similarly, Table 28-2 shows the Heating Value of Natural Gas to be **1,026 Btu/ft^3.**

Step 2 – **Choose a calculation method and record the appropriate equation.** For demonstration purposes, the 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:

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

Step 3 – Calculate Emissions. Using the fuel quantity data and emission factor, NO_X emissions may be calculated using Equation 28-1.

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

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

28.7.2 Problem #2 - Load Factor Method

Anytown AFB must calculate emissions from a stationary diesel-fired generator. Calculate the VOC emitted by this generator from last year using the load factor method. The installation is <u>not</u> located in Alaska. The generator was manufactured in 2004, and operated for 550 hours last year. The generator is 1250 hp and the engine has a displacement of 2.0L/cyl.

Step 1 – Select and Record Emission Factor and load factor. The emission factors for stationary diesel ICOM engines are provided in Table 28-3. For a 1250hp diesel engine manufactured in 2004 with 2.0L per cylinder displacement, the VOC emission factor is **7.16E-04 lb/hp-hr**. Similarly, Table 28-8 shows that the typical load factor for a diesel generator is **74**.

Step 2 – 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:

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

Step 3 – Calculate Emissions. Using the data above, VOC emissions are calculated as follows:

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

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

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

28.8 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

EIA 2005, "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

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 1998, 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 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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29 STORAGE TANKS (AST, UST)

➢ *Point Source*

29.1 Introduction

Storage tanks located on Air Force installations are used for storage of materials, commonly including fuels such as JP-8, Jet A, MOGAS, and diesel, or even 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 and may be above ground (AST) or underground (UST). According to the Environmental Protection Agency (EPA), an underground storage tank is defined as a tank or piping system that has 10% or more of its combined volume underground, while above ground storage tanks have more than 90% 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 document.**

Emissions from storage tanks are generated by vapor losses, which include working losses and breathing losses. These are the result of a higher pressure environment inside the tank than outside, causing the hydrocarbon vapor to escape through any openings. Underground storage tanks typically do not emit as much as aboveground tanks because they are enclosed and contribute to emissions primarily by changing liquid levels within the tank. 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 29-1.
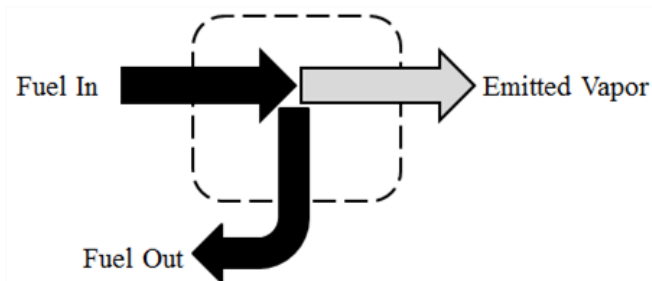
Figure 29-1. Simplified Control Volume for Emissions from Storage Tanks

29.1.1 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 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 in order to equalize pressure when an imbalance occurs from changes in temperature or pressure. The resulting 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 which slides against the shell wall in order 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.

29.2 NSPS Applicability

There are several New Source Performance Standards (NSPS) set by the EPA that apply to storage tanks. 40 CFR 60 subpart K 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. For those tanks whose contents have a true vapor pressure exceeding 11.1 psia, the storage tank must be equipped with a vapor recovery system. Similarly, 40 CFR 60 subpart Ka specifies the design 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 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 National Emission Standard for Hazardous Air Pollutants (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 is in compliance with the requirements outlined in this NESHAP, refer to 40 CFR 63 subpart CCCCCC.

29.3 Emissions Calculation

Algorithms and Emission Factors (EFs) used by the Air Force are generally from AP-42; however, EFs for Air Force-unique sources have been developed by the Air Force. The only algorithms and EFs authorized for use in estimating Air Force emissions are those maintained within the Air Program Information Management System (APIMS).

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 hazardous air pollutant 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 Air Emission Inventories. A link to download TANKS can be found at www.epa.gov/ttn/chief/software/tanks/. Note that 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". **If possible, emissions calculations for all storage tanks should be performed using the TANKS program. If using an unsupported operating system, then consult Chapter 7 of AP-42 for algorithms applicable to calculating emissions from storage tanks. Note that the TANKS model is incorporated into APIMS.**

29.4 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 needed to run the TANKS model including 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.

29.5 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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30 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

30.1 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 document. **Also, emissions from architectural coatings are not addressed here, but may be found in the "Construction" section of the Transitory Guide.**

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 emissions control devices. Surface coating operations are conducted either in a paint booth, dip tank, hangar, or applied outdoors. **Surface coating applications which occur indoors and use an industrial (non-HVAC) ventilation system are considered point sources, while 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 particulate matter.** A graphic representation of the emissions from surface coating operations is given in Figure 30-1.
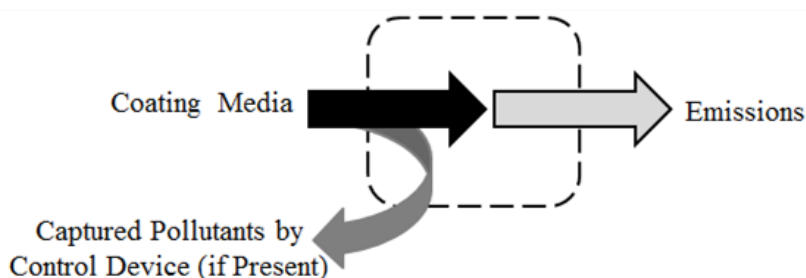
Figure 30-1. Simplified Control Volume for Emissions from Surface Coating Operations

Surface coating operations are those which involve the application of paints, primers, thinners, stains, varnishes, shellacs, glazes, etc. in liquid or powder form for decorative and/or protective purposes to a substrate. 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 whether or not a control device is used.

Conventional coatings contain a minimum of 30% solvents by volume but commonly contain as much as 70% to 85% solvents by volume. The solvents in conventional coatings, which evaporate after application, provide a liquid medium for synthetic polymers that form a film over the surface to which they are applied. The solvents may contain one or more components such as acetates, aromatics, glycol ethers, aliphatic hydrocarbons, and/or water. Increased environmental awareness has led to a steady reduction in the amount of solvents in surface coatings. Those coatings which contain 30% 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 are capable of producing 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 of solvent based coatings. Waterborne coatings may be cured through evaporation, oven baking, or the application of UV light.

With the exception of 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 which draws air either across or downward onto the object being coated, and 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 30-35% 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, which have higher coating efficiency (approximately 60-90% of applied coating adheres to the intended surface) and thus have 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. This results in fewer VOC emissions due to lower volumetric flow, which results in reduced overspray. Air-assisted airless spraying atomizes the coating material at 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% 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 employs 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. If not, then it is called a reverse roll coater.

Dip coating involves the total immersion of parts into a dip tank that contains the coating. The parts are then removed from the tank and held over it to allow excess coating to drip back into the tank. 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.

30.2 NESHAP Applicability

There are several 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. 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, such as 40 CFR 63 subparts MMMM, *National Emission Standards for Hazardous Air Pollutants for Surface Coating of Miscellaneous Metal Parts and Products*, and PPPP, *National Emission Standards for Hazardous Air Pollutants for Surface Coating of Plastic Parts and Products*, which apply to the coating of metal or plastic components respectively; 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 is in compliance with the aerospace NESHAP, should it apply, please review 40 CFR 63 subpart GG. Additionally, 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.

30.3 Emission Factors

In 2001, the California Air Resources Board 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 30-1 gives the typical VOC content for the most common solvent-based and water-based surface coatings likely found at an Air Force 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 30-1. VOC emissions calculation is discussed in Section 30.5.

Table 30-1. VOC and PM Emission Factors for Surface Coatings

Coating Category		Emission Factors (lb/gal)					
		VOC		PM_{10}[1]		$PM_{2.5}$[1]	
		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[2]		---	---	---	---
	Concrete Surface Retarders	6.5[2]		---	---	---	---
Fire Retardant/Resistive Coatings	Clear	7.1[2]	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	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[3]	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[2]		---	---	---	---
	High Gloss	2.8	0.81	6.8	3.2	6.6	2.9
	Medium Gloss	3.1	0.43	7.4	3.6	7.1	3.3
	Low Gloss	2.8	0.61	7.5	3.0	7.2	2.8
	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	0.69	2.5	1.6	2.4	1.4
Shellacs	Clear	4.7	4.7[3]	2.2	---	2.1	---
	Opaque	4.2	4.2[3]	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	2.9	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.

1. 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 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.

2. 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.

3. Source document does not provide a value for this coating. Conservatively assumed to be equal to the solvent-based formulation.

"---" Indicates No Data Available

30.4 Control Techniques

Emissions from surface coatings result from the evaporation of the solvents which are: part of the paint's composition, used for thinning the paint, or used for paint clean up. To calculate VOC emissions from surface coating, the assumption is that all VOC's within the coating evaporate completely. To reduce emissions from surface coating operations, there are three methods: coating substitutions, process changes, and add-on control devices.

Substituting paint for more environmentally friendly coatings may greatly reduce the amount of VOC's 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." Additionally, process changes may not be feasible, but there is a difference in the VOC, HAP, and/or particulate emissions depending on the application method used for surface coating application. Using a method which reduces overspray may significantly reduce VOC and PM emissions. While it may be impractical to modify the application methods, high volume surface coating installations should evaluate the advantages and disadvantages of modifying the application method for surface coatings on typical substrates 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 take into account the capture and removal efficiency of the device.** For emissions calculations from surface coating operations which utilize a control device, contact the manufacturer for an estimate of the control efficiency.

30.5 Emissions Calculation

Algorithms and Emission Factors (EFs) used by the Air Force are generally from AP-42; however, EFs for Air Force-unique sources have been developed by the Air Force. The only algorithms and EFs authorized for use in estimating Air Force emissions are those maintained within the Air Program Information Management System (APIMS). There are two methods for calculating emissions from surface coating operations. The first method uses a mass balance equation, while the second method employs the use of emission factors for emissions calculations. The two methods are described below.

30.5.1 Calculations Using Mass Balance

Surface coatings result in 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, as these calculations employ additional terms to account for loss and recapture of particulates. Calculation of each pollutant is described below.

30.5.1.1   VOC and Organic HAP Emissions Calculation

The preferred method for calculating emissions from surface coating operations is through a simple mass balance equation. 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 30-1.

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

Equation 30-1

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 (%).

A more detailed control volume representing the calculation of VOC and organic HAPs through mass balance is given in Figure 30-2.
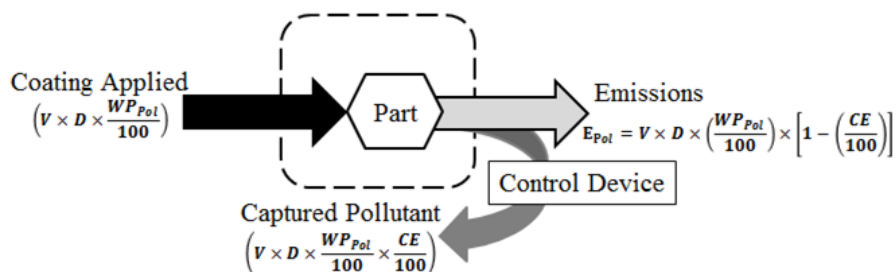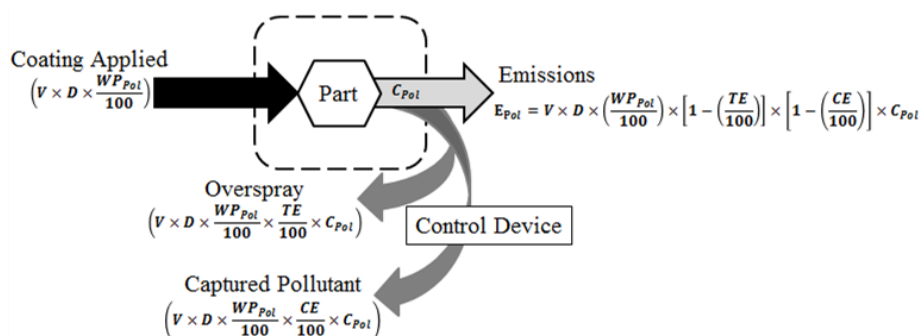

Figure 30-2. Surface Coatings Control Volume – Mass Balance Method

30.5.1.2   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 which 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 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 30-2. Due to the variability in the transfer efficiency, use of these values will be much less accurate than actual shop data.

Table 30-2. 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[1]
Flow Coating	85[1]
Electrodeposition	95[1]
Brush Coating	99[2]

SOURCE (Unless otherwise stated): Efficiencies provided are the lowest values of a range provided by "Surface Coating & Transfer Efficiency = $avings," Spokane Regional Clean Air Agency, Compliance Assistance Program (CAP), 2012 which cites the South Coast Air Quality Management District (SCAQMD) as the original source.

1. 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.

2. 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 30-2 below.

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

Equation 30-2

Where,

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 (%)

A more detailed control volume representing the calculation of VOC and organic HAPs through mass balance is given in Figure 30-3.

Figure 30-3. Surface Coatings Control Volume – Mass Balance Method

If emissions of a specific HAP are required and the weight percent is unknown, yet the weight percent of the HAP containing compound is known, then the weight percent of the HAP may be determined using Equation 30-3.

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

Equation 30-3

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 (%)

30.5.2 Calculations Using Emission Factors

The emission factor 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 emission factor method should be used only for NEPA assessments and is provided here to be used for that purpose only. Emission factors were developed using the sales weighted average density and the VOC and solids weight percent. The VOC, PM_{10}, and $PM_{2.5}$ emission factors are provided in Table 30-1 and calculation is described in Equation 30-4.

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

Equation 30-4

Where,

E_{Pol} = Pollutant Emissions (lb/yr)
V = Volume of coating used per year (gal/yr)
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 emission factors is given in Figure 30-4.
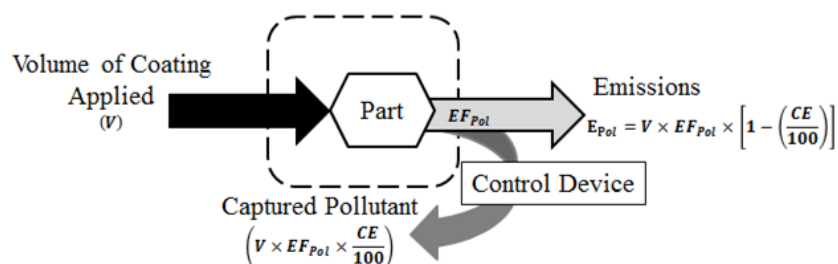
Figure 30-4. Surface Coatings Control Volume – Emission Factor Method

30.6 Information Resources

Most information required to calculate the emissions from surface coating applications can be obtained from the shops that apply the surface coatings. Bioenvironmental Engineering should be able to provide a list of all shops that perform surface coating operations in a controlled space (e.g. paint booth). Information on the quantity of each specific coating delivered to a shop should be available from records/databases maintained by the Hazardous Materials Pharmacy 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 (e.g. SDS, container label, and technical specification sheets) or the coating manufacturer. For surface coatings, if the solids content of a coating is unknown, it can be estimated by subtracting out 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 Air Force are purchased through the GSA. Information on these coatings can be obtained from the GSA via one of the following sources:

- GSA's Environmental Products Guide at http://www.gsa.gov/enviro
- GSA's 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, so the manufacturer may need to know this information regarding the typical pieces being treated in order to provide a more accurate value. In the absence of this information, Table 30-2 may be used as a last resort. The most difficult value to obtain may be the fallout efficiency, which may be determined through on-site testing. If so desired, a conservative emission calculation is possible by assuming this value to be equal to zero.

30.7 Example Problems

30.7.1 Problem #1 - Mass Balance Method

Anytown AFB 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%. The spray booth is equipped with a particulate control device with a stated efficiency of 90%. The shop supervisor states that 95 gal of the epoxy were 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% by weight, and a solids content of 55% by weight. Additionally, the coating label states that it has 8% 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, 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%, 55%, and 8%,** respectively. The transfer efficiency is **75%** and the control efficiency for the particulate filter is stated as **90%**.

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:

$$D = SG \times D_{Water}$$

$$\boldsymbol{D = 1.2 \times 8.33 \frac{lb}{gal} = 9.996 \frac{lb}{gal}}$$

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%. Using Equation 30-1, VOC and xylene emissions are calculated as follows:

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

For VOC:

$$E_{VOC} = 95 \frac{gal}{yr} \times 9.996 \frac{lb}{gal} \times \left(\frac{40\%}{100\%}\right) \times \left[1 - \left(\frac{0\%}{100\%}\right)\right]$$

$$E_{VOC} = 95 \frac{gal}{yr} \times 9.996 \frac{lb}{gal} \times \left(\frac{40\%}{100\%}\right) \times [1]$$

$$E_{VOC} = 95 \frac{\cancel{gal}}{yr} \times 9.996 \frac{lb}{\cancel{gal}} \times (0.4) \times [1]$$

$$\boxed{E_{VOC} = 379.8 \frac{lb}{yr}}$$

For Xylene:

$$E_{Xylene} = 95 \frac{gal}{yr} \times 9.996 \frac{lb}{gal} \times \left(\frac{8\%}{100\%}\right) \times \left[1 - \left(\frac{0\%}{100\%}\right)\right]$$

$$E_{Xylene} = 95 \frac{gal}{yr} \times 9.996 \frac{lb}{gal} \times \frac{8\%}{100\%} \times [1]$$

$$E_{Xylene} = 95 \frac{\cancel{gal}}{yr} \times 9.996 \frac{lb}{\cancel{gal}} \times (0.08) \times [1]$$

$$\boxed{E_{Xylene} = 76.0 \frac{lb}{yr}}$$

Step 4 – 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.

$$Q = V \times D$$

$$Q = 95 \frac{\cancel{gal}}{yr} \times 9.996 \frac{lb}{\cancel{gal}} = 949.6 \frac{lb}{yr}$$

Step 5 – Calculate PM$_{10}$ and PM$_{2.5}$ emissions. Since the problem stated that the epoxy is solvent based, the percentage of PM$_{10}$ and PM$_{2.5}$ to total PM is 0.960 and 0.925 respectively. Using Equation 30-2, 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 PM$_{10}$:

$$E_{PM_{10}} = 949.6 \frac{lb}{yr} \times \left(\frac{55\%}{100\%}\right) \times \left[1 - \left(\frac{75\%}{100\%}\right)\right] \times \left[1 - \left(\frac{90\%}{100\%}\right)\right] \times 0.960$$

$$E_{PM_{10}} = 949.6 \frac{lb}{yr} \times (.55) \times [1 - (0.75)] \times [1 - (0.90)] \times 0.960$$

$$E_{PM_{10}} = 949.6 \frac{lb}{yr} \times (.55) \times [0.25] \times [0.10] \times 0.960$$

$$\boxed{E_{PM_{10}} = 12.5 \frac{lb}{yr}}$$

For PM$_{2.5}$:

$$E_{PM_{2.5}} = 949.6 \frac{lb}{yr} \times \left(\frac{55\%}{100\%}\right) \times \left[1 - \left(\frac{75\%}{100\%}\right)\right] \times \left[1 - \left(\frac{90\%}{100\%}\right)\right] \times 0.925$$

$$E_{PM_{2.5}} = 949.6 \frac{lb}{yr} \times (.55) \times [1 - (0.75)] \times [1 - (0.90)] \times 0.925$$

$$E_{PM_{10}} = 949.6 \frac{lb}{yr} \times (.55) \times [0.25] \times [0.10] \times 0.925$$

$$\boxed{E_{PM_{2.5}} = 12.1 \frac{lb}{yr}}$$

30.7.2 Problem #2 - Emission Factor Method

Anytown AFB is interested in performing a NEPA assessment for the proposed project that will involve the application of a variety of different 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 emissions factors. Since this calculation is for a NEPA assessment on a proposed project, this problem is best suited to be calculated using the emission factor method. Knowing that the fire retardant coating is water based, while the other coatings are solvent based, the emission factors for each coating are selected from Table 30-1. These are provided in the following table.

	Coating Type	Emission Factors (lb/gal)

Volume Used (gal/yr)		VOC	PM₁₀	PM₂.₅
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

Step 2 – Calculate emissions from each coating. Using Equation 30-4 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:
For VOC:

$$E_{VOC} = 25\frac{gal}{yr} \times 0.1\frac{lb}{gal} \times \left[1 - \left(\frac{0\%}{100\%}\right)\right]$$

$$\boldsymbol{E_{VOC}} = 25\frac{gal}{yr} \times 0.1\frac{lb}{gal} \times [1] = \boldsymbol{2.5\frac{lb}{yr}}$$

For PM₁₀:

$$E_{PM_{10}} = 25\frac{gal}{yr} \times 3.0\frac{lb}{gal} \times \left[1 - \left(\frac{0\%}{100\%}\right)\right]$$

$$\boldsymbol{E_{PM_{10}}} = 25\frac{gal}{yr} \times 3.0\frac{lb}{gal} \times [1] = \boldsymbol{75.0\frac{lb}{yr}}$$

For PM₂.₅:

$$E_{PM_{2.5}} = 25\frac{gal}{yr} \times 2.8\frac{lb}{gal} \times \left[1 - \left(\frac{0\%}{100\%}\right)\right]$$

$$\boldsymbol{E_{PM_{2.5}}} = 25\frac{gal}{yr} \times 2.8\frac{lb}{gal} \times [1] = \boldsymbol{70.0\frac{lb}{yr}}$$

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

Step 3 – Sum total emissions from each coating.

$$E_{Pol} = \sum_{i=1}^{n} \left(E_{Pol_i} + \cdots + E_{Pol_n} \right)$$

For VOC:

$$E_{VOC} = (2.5 + 114.0 + 210.0 + 375.0)\frac{lb}{yr}$$

$$\boxed{E_{VOC} = 701.5\frac{lb}{yr}}$$

For PM$_{10}$:

$$E_{PM_{10}} = (75.0 + 159.0 + 860.0 + 812.5)\frac{lb}{yr}$$

$$\boxed{E_{PM_{10}} = 1906.5\frac{lb}{yr}}$$

For PM$_{2.5}$:

$$E_{PM_{2.5}} = (70.0 + 153.0 + 830.0 + 775.0)\frac{lb}{yr}$$

$$\boxed{E_{PM_{2.5}} = 1828.0\frac{lb}{yr}}$$

30.8 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

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

31 WASTEWATER COLLECTION AND TREATMENT (WWT)

➤ *Point/Fugitive Source* – Refer to permit for final determination

31.1 Introduction

Wastewater treatment incorporates chemical, biological, and mechanical procedures in order to remove, reduce, or neutralize contaminants found in industrial or household water discharge located on an Air Force Installation. Wastewater treatment plants may be classified as either primary, secondary, or tertiary 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 employed. Tertiary treatment refers to any additional treatment of waste water 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 waste water 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 greenhouse gases. 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 in order to volatilize undesirable substances from the liquid and 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 includes 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 employed when ultraviolet (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 is more dense and easier to dispose. During this

process, methane and hydrogen sulfide gas is 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 section titled "external combustion" of this document.**

Wastewater treatment plants serve as a source of greenhouse gas (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. Aerobic systems, on the other hand, primarily produce CO_2. Both systems will also result in 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 31-1.
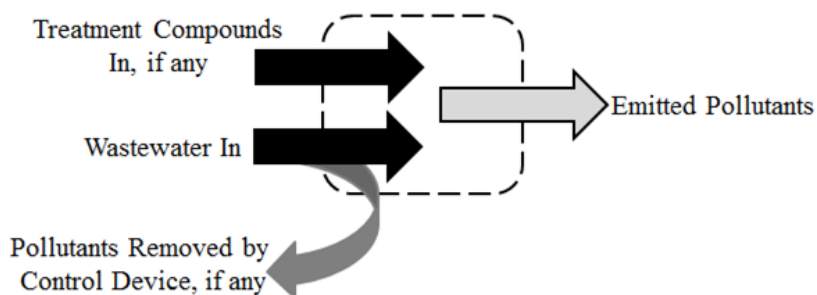
Figure 31-1. Simplified Control Volume for Emissions from Wastewater Collection and Treatment

31.2 NESHAP Applicability

The EPA has developed several National Emission Standards for Hazardous Air Pollutants (NESHAP) 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 it is located at a POTW which 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 has to 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.

31.3 Emission Factors

Emission factors for the volatilization of the components of the influent wastewater have not been developed, so the calculation of these emissions is performed either by modeling or by using a mass balance approach. Emission factors from the use of flares burning digester gas have been developed by the San Diego Air Pollution Control District. The emission factors and method of air emissions calculations for digester flares may be found in the "external combustion" section of this document.

31.4 Control Techniques

Air is often treated at wastewater treatment plants to both reduce the amount of harmful pollutants emitted into the atmosphere and for the purpose of odor control. These methods include the use of packed tower scrubbers, misting wet scrubbers, carbon adsorbers, filters, and thermal oxidizers that each work in combination with a well-designed ventilation system. Packed bed 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%.

Digester gases resulting from the degradation of sludge may be used as fuel for boilers, generators, or other internal combustion engines or simply 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 document.

31.5 Emissions Calculation

Algorithms and emission factors (EFs) used by the Air Force are generally from AP-42; however, EFs for Air Force-unique sources have been developed by the Air Force. The only algorithms and EFs authorized for use in estimating Air Force emissions are those maintained within the Air Program Information Management System (APIMS).

The most accurate wastewater emissions estimates can be obtained through on-site testing of a facility (i.e., tracer studies or direct measurement of emissions from openings), as the design and arrangement of collection, treatment, and storage systems, which may influence emissions, are facility-specific. If actual data is unavailable, emission models can be used.   Calculating air emissions from waste water 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:

$$E_{Pol} = Q \times [IC_{Pol} - EC_{Pol}] \times 3.785 \times (2.205 \times 10^{-9})$$

Equation 31-1

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 x 10⁻⁹ = Factor for converting units from micrograms to pounds (lb/µg)

A more detailed control volume describing the air pollutants emitted during wastewater plant operation is provided in Figure 31-2:
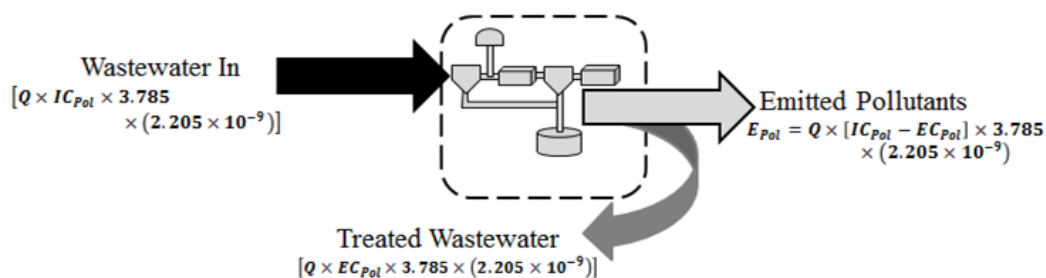
Figure 31-2. Wastewater Collection and Treatment Control Volume

31.6 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 Bioenvironmental Engineering office should be contacted as they are usually responsible for performing the sampling.

31.7 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 base Bioenvironmental Engineer (BEE) was contacted for this information. A review of the BEE's analytical results shows that past sampling had been performed for Total Organic Compounds (TOC) and for two chemicals (toluene and xylenes) which are on the list of HAPs. 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 31-1 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:

$$E_{VOC} = 262{,}545{,}000 \frac{gal}{yr} \times [225 - 102] \frac{\mu g}{L} \times 3.785 \frac{L}{gal} \times (2.205 \times 10^{-9}) \frac{lb}{\mu g}$$

$$E_{VOC} = 262{,}545{,}000 \frac{\cancel{gal}}{yr} \times [123] \frac{\cancel{\mu g}}{\cancel{L}} \times 3.785 \frac{\cancel{L}}{\cancel{gal}} \times (2.205 \times 10^{-9}) \frac{lb}{\cancel{\mu g}}$$

$$\boxed{E_{VOC} = 269.52 \frac{lb}{yr}}$$

For Toluene:

$$E_{Toluene} = 262{,}545{,}000 \frac{gal}{yr} \times [3 - .5] \frac{\mu g}{L} \times 3.785 \frac{L}{gal} \times (2.205 \times 10^{-9}) \frac{lb}{\mu g}$$

$$E_{Toluene} = 262{,}545{,}000 \frac{\cancel{gal}}{yr} \times [2.5] \frac{\cancel{\mu g}}{\cancel{L}} \times 3.785 \frac{\cancel{L}}{\cancel{gal}} \times (2.205 \times 10^{-9}) \frac{lb}{\cancel{\mu g}}$$

$$\boxed{E_{Toluene} = 5.48 \frac{lb}{yr}}$$

For Xylenes:

$$E_{Xylene} = 262{,}545{,}000 \frac{gal}{yr} \times [9 - 6] \frac{\mu g}{L} \times 3.785 \frac{L}{gal} \times (2.205 \times 10^{-9}) \frac{lb}{\mu g}$$

$$E_{Xylene} = 262{,}545{,}000 \frac{\cancel{gal}}{yr} \times [3] \frac{\cancel{\mu g}}{\cancel{L}} \times 3.785 \frac{\cancel{L}}{\cancel{gal}} \times (2.205 \times 10^{-9}) \frac{lb}{\cancel{\mu g}}$$

$$\boxed{E_{Xylene} = 6.57 \frac{lb}{yr}}$$

31.8 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

USEPA 1995, Section 4.3-" Waste Water Colection, 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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32 WELDING (WELD)

- ➤ *Fugitive Source*

32.1 Introduction

Welding operations may be performed at various maintenance, transportation, and Civil Engineering shops on Air Force installations. 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 emission factors. 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 which 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 in order 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 on 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 considered 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 32-1.
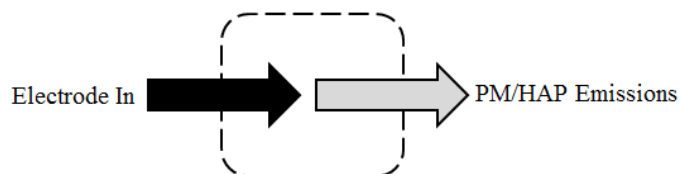

Figure 32-1. Simplified Welding Control Volume

32.2 Emission Factors

The main pollutants of concern associated with welding operations include PM_{10}, $PM_{2.5}$, and inorganic metallic HAPs. The majority of PM emissions from welding operations are less than one micron in size, so all of the PM emissions associated with welding operations are assumed to be equal to PM_{10} and $PM_{2.5}$. AP-42 provides emission factors 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 attempting to calculate the emissions from each rod and welding process, the worst case scenario for emissions for each pollutant is assumed. This approach simplifies the process of data collection while still providing a conservative emissions estimate for a low emitting source. The worst case emission factors for each pollutant are provided in Table 32-1.

Table 32-1. Particulate and Inorganic HAP Emission Factors for Welding Operations

Emission Factor (lb/10^3lb)						
$PM_{10/2.5}$[1]	Co	Cr[2]	Cr[+6 (2)]	Mn[1]	Ni[1]	Pb[3]
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.

1. Electrode type: 14Mn-4Cr
2. Electrode type: E310
3. Electrode type: E7028

32.3 Control Techniques

Emissions from welding operations results in the release of particulates which 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.

32.4 Emission Calculations

Algorithms and emission factors (EFs) used by the Air Force are generally from AP-42; however, EFs for Air Force-unique sources have been developed by the Air Force. The only algorithms and EFs authorized for use in estimating Air Force emissions are those maintained within the Air Program Information Management System (APIMS). In order 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 emission factor (EF), and if a control device is present, then may be multiplied by the control efficiency of the control device.

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

Equation 32-1

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 32-2.
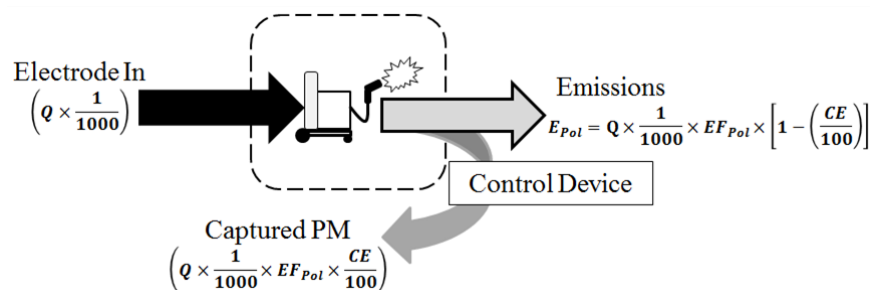
Figure 32-2. Welding Control Volume

32.5 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, Civil Engineering, and Transportation organizations. If necessary, Bioenvironmental Engineering 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.

32.6 Example Problem

Anytown AFB 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 1400lb. Calculate the annual emissions of PM_{10}, $PM_{2.5}$, and inorganic HAPs, assuming no control devices were used.

Step 1 – Select and record emission factors. The worst-case emission factors are provided in Table 32-1. The emission factors are: **81.6 lb/10³lb** for $PM_{10/2.5}$, **0.001 lb/10³lb** for Co, **2.53 lb/10³lb** for Cr, **1.88 lb/10³lb** for Cr^{+6}, **23.2 lb/10³lb** for Mn, **1.71 lb/10³lb** for Ni, and **0.162 lb/10³lb** for Pb.

Step 2 – Calculate emissions. Using the data provided in the problem statement and the emission factors recorded in Step 1, the emissions for each pollutant may be calculated using Equation 32-1 as follows:

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

Since the emission factor is the same, for $PM_{10/2.5}$:

$$E_{PM_{10/2.5}} = 1400\frac{lb}{yr} \times \frac{1}{1000}\frac{10^3 lb}{lb} \times 81.6\frac{lb}{10^3 lb} \times \left[1 - \left(\frac{0\%}{100\%}\right)\right]$$

$$E_{PM_{10/2.5}} = 1400\frac{\text{lb}}{yr} \times \frac{1}{1000}\frac{10^3 lb}{\text{lb}} \times 81.6\frac{lb}{10^3 lb} \times [1]$$

$$E_{PM_{10/2.5}} = 1.400\frac{10^3 lb}{yr} \times 81.6\frac{lb}{10^3 lb} \times [1]$$

$$\boxed{E_{PM_{10/2.5}} = \mathbf{114.24}\frac{\text{lb}}{\textbf{yr}}}$$

For Co:

$$E_{Co} = 1400\frac{lb}{yr} \times \frac{1}{1000}\frac{10^3 lb}{lb} \times 0.001\frac{lb}{10^3 lb} \times \left[1 - \left(\frac{0\%}{100\%}\right)\right]$$

$$E_{Co} = 1400\frac{\text{lb}}{yr} \times \frac{1}{1000}\frac{10^3 lb}{\text{lb}} \times 0.001\frac{lb}{10^3 lb} \times [1]$$

$$E_{Co} = 1.400\frac{10^3 lb}{yr} \times 0.001\frac{lb}{10^3 lb} \times [1]$$

$$\boxed{E_{Co} = \mathbf{0.0014}\frac{\textit{lb}}{\textbf{yr}}}$$

For Cr:

$$E_{Cr} = 1400\frac{lb}{yr} \times \frac{1}{1000}\frac{10^3 lb}{lb} \times 2.53\frac{lb}{10^3 lb} \times \left[1 - \left(\frac{0\%}{100\%}\right)\right]$$

$$E_{Cr} = 1400\frac{\text{lb}}{yr} \times \frac{1}{1000}\frac{10^3 lb}{\text{lb}} \times 2.53\frac{lb}{10^3 lb} \times [1]$$

$$E_{Cr} = 1.400\frac{10^3 lb}{yr} \times 2.53\frac{lb}{10^3 lb} \times [1]$$

$$\boxed{E_{Cr} = \mathbf{3.54}\frac{\textit{lb}}{\textbf{yr}}}$$

For Cr^{+6}:

$$E_{Cr^{+6}} = 1400\frac{lb}{yr} \times \frac{1}{1000}\frac{10^3 lb}{lb} \times 1.88\frac{lb}{10^3 lb} \times \left[1 - \left(\frac{0\%}{100\%}\right)\right]$$

$$E_{Cr^{+6}} = 1400\frac{\text{lb}}{yr} \times \frac{1}{1000}\frac{10^3 lb}{\text{lb}} \times 1.88\frac{lb}{10^3 lb} \times [1]$$

$$E_{Cr^{+6}} = 1.400\frac{10^3 lb}{yr} \times 1.88\frac{lb}{10^3 lb} \times [1]$$

$$\boxed{E_{Cr^{+6}} = 2.63\frac{lb}{yr}}$$

For Mn:

$$E_{Mn} = 1400\frac{lb}{yr} \times \frac{1}{1000}\frac{10^3 lb}{lb} \times 23.2\frac{lb}{10^3 lb} \times \left[1 - \left(\frac{0\%}{100\%}\right)\right]$$

$$E_{Mn} = 1400\frac{\cancel{lb}}{yr} \times \frac{1}{1000}\frac{10^3 lb}{\cancel{lb}} \times 23.2\frac{lb}{10^3 lb} \times [1]$$

$$E_{Mn} = 1.400\frac{\cancel{10^3 lb}}{yr} \times 23.2\frac{lb}{\cancel{10^3 lb}} \times [1]$$

$$\boxed{E_{Mn} = 32.48\frac{lb}{yr}}$$

For Ni:

$$E_{Ni} = 1400\frac{lb}{yr} \times \frac{1}{1000}\frac{10^3 lb}{lb} \times 1.71\frac{lb}{10^3 lb} \times \left[1 - \left(\frac{0\%}{100\%}\right)\right]$$

$$E_{Ni} = 1400\frac{\cancel{lb}}{yr} \times \frac{1}{1000}\frac{10^3 lb}{\cancel{lb}} \times 1.71\frac{lb}{10^3 lb} \times [1]$$

$$E_{Ni} = 1.400\frac{\cancel{10^3 lb}}{yr} \times 1.71\frac{lb}{\cancel{10^3 lb}} \times [1]$$

$$\boxed{E_{Ni} = 2.39\frac{lb}{yr}}$$

For Pb:

$$E_{Pb} = 1400\frac{lb}{yr} \times \frac{1}{1000}\frac{10^3 lb}{lb} \times 0.162\frac{lb}{10^3 lb} \times \left[1 - \left(\frac{0\%}{100\%}\right)\right]$$

$$E_{Pb} = 1400\frac{\cancel{lb}}{yr} \times \frac{1}{1000}\frac{10^3 lb}{\cancel{lb}} \times 0.162\frac{lb}{10^3 lb} \times [1]$$

$$E_{Pb} = 1.400\frac{\cancel{10^3 lb}}{yr} \times 0.162\frac{lb}{\cancel{10^3 lb}} \times [1]$$

$$\boxed{E_{Pb} = 0.23\frac{lb}{yr}}$$

32.7 Resources

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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33 WET COOLING TOWERS (COOL)

> *Fugitive Sources*

33.1 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 moisture content at or near saturation. Even at saturation, cooling can take place since a temperature increase results in an increase in heat capacity which 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 which increases the contact time between the water and the air maximizing the heat transfer. Virtually all Air Force 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 are assumed to become suspended particulate matter (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 given in Figure 33-1.

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.
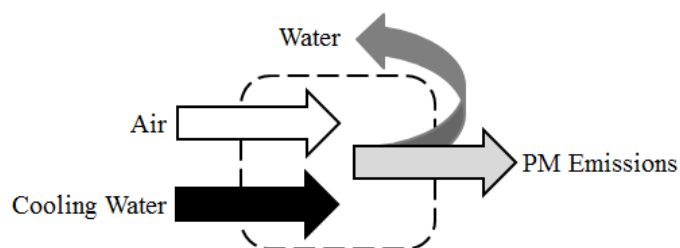
Figure 33-1. Simplified Control Volume for Emissions from Wet Cooling Towers

33.2 Emission Calculations

Algorithms and Emission Factors (EFs) used by the Air Force are generally from AP-42; however, EFs for Air Force-unique sources have been developed by the Air Force. The only algorithms and EFs authorized for use in estimating Air Force emissions are those maintained within the Air Program Information Management System (APIMS).

Emissions of particulate matter less than ten micrometers in diameter (PM_{10}) from wet cooling towers may be calculated using the methodology presented in section 13.4 of AP-42, which 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 PM_{10}. However, this method has been shown to be overly conservative and predicts significantly higher PM_{10} emissions than would actually occur. 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).

Based on AP-42, PM emissions from cooling towers can be calculated by multiplying the total circulation water (Q) by a total liquid drift factor (TLD) and then multiplying the concentration of TDS in the circulating water. This is shown in Equation 33-1.

$$E_{Pol} = Q \times \frac{1}{1000} \times TLD \times TDS \times \frac{1}{10^6} \times C_{Pol}$$

Equation 33-1

Where,

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

Q = Quantity of circulating water per year (gal/yr)

1000 = Factor converting from gal to 10^3 gal (10^3 gal/gal)

TLD = Total liquid drift factor. **If unknown, use value from AP-42. Table 13.4-1 of AP-42 states this is equal to 1.7** (lb/10^3 gal)

TDS = Total dissolved solids. **If unknown, use value from AP-42. The notes from Table 13.4.1 of AP-42 states this is equal to 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$_{2.5}$.**

Assuming induced draft coolers only, an average TLD of 1.7 lb/10^3 gal (USEPA 1995), and an average TDS of 12,000 ppm (USEPA 1995) then Equation 33-1 may be simplified as follows:

$$E_{Pol} = Q \times (2.04 \times 10^{-5}) \times C_{Pol}$$

Equation 33-2

Where,

2.04E-05 = Numeric simplification assuming TLD of 1.7 lb/10^3 gal and TDS of 12,000 ppm (lb/gal)

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 33-3.

$$Q = WFR \times D$$

Equation 33-3

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 33-2.
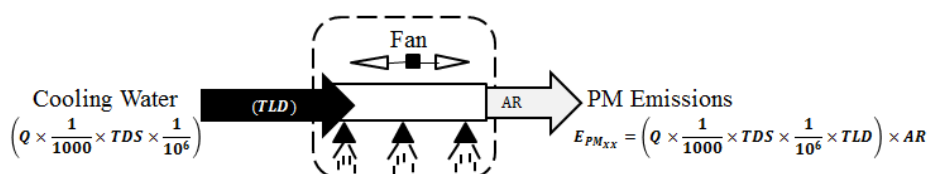
Figure 33-2. Wet Cooling Towers Control Volume

33.3 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 particular shop(s) responsible for operating the cooling tower(s) should be contacted for the necessary information.

33.4 Example Problem

A base has a cooling tower located at the Bioenvironmental Engineering 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. Determine if this is significant and if so, determine the PM_{10} and $PM_{2.5}$ emissions.

Step 1 – Calculate the annual circulating water flow rate. Assuming that an average month has 30 days, the annual circulating water flow rate is calculated using Equation 33-3 as follows:

$$Q = 20{,}100 \left(\frac{gal}{day} \right) \times 7 \left(\frac{month}{yr} \right) \times 30 \left(\frac{day}{month} \right) = \mathbf{4,221,000} \frac{gal}{yr}$$

Step 2 – Calculate PM_{10} and $PM_{2.5}$ emissions. Insert the Q value calculated in Step 1 and the CPol values for PM_{10} and $PM_{2.5}$ (which are stated as 0.700 and 0.420 respectively) into Equation 33-2.

For PM_{10}:

$$E_{Pol} = Q \times (2.04 \times 10^{-5})$$

$$E_{PM_{10}} = 4{,}221{,}000 \frac{gal}{yr} \times (2.04 \times 10^{-5}) \frac{lb}{gal} \times 0.700$$

$$\boxed{E_{PM_{10}} = \mathbf{60.3} \frac{lb}{yr}}$$

For $PM_{2.5}$:

$$E_{PM_{2.5}} = 4{,}221{,}000 \frac{gal}{yr} \times (2.04 \times 10^{-5}) \frac{lb}{gal} \times 0.420$$

$$E_{PM_{2.5}} = 36.2 \frac{lb}{yr}$$

33.5 References

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 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

34 WOODWORKING (WOOD)

➢ *Point Source*

34.1 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 Air Force installations have operations that generate airborne particulate in the form of dust from woodworking. Typical woodworking shops on an Air Force base include Wood Hobby, Packing & Crating, and some Civil Engineering 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 (fabric filter), 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 34-1 provides a graphic representation of emissions from woodworking operations.
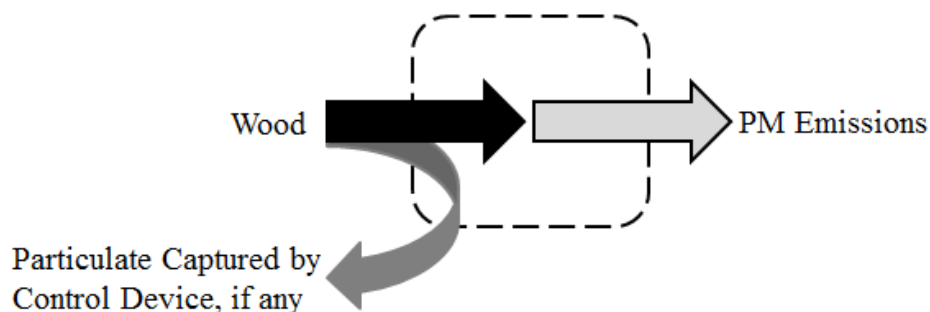

Figure 34-1. Simplified Control Volume for Emissions from Woodworking

34.2 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 may be an inexpensive method for dust suppression and works to wet the surface material so that dust settles when saturated.

34.3 Emissions Calculation

Algorithms and emission factors (EFs) used by the Air Force are generally from AP-42; however, EFs for Air Force-unique sources have been developed by the Air Force. The only algorithms and EFs authorized for use in estimating Air Force emissions are those maintained within the Air Program Information Management System (APIMS).

The only pollutant of concern in woodworking waste collection operations is particulate matter (PM). Algorithms and Emission Factors (EFs) used by the Air Force are generally from AP-42; however, EFs for Air Force-unique sources have been developed by the Air Force. Given there are no longer algorithms or EFs for woodworking in AP-42, particulate emissions from woodworking operations can be calculated using a mass balance approach based on the estimated efficiency of the control device and the amount of sawdust collected during the year. Assuming that all PM that is released into the air from woodworking operations passes through the dust collection system, PM emissions may be estimated as follows:

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

Equation 34-1

Where,

E_{Pol} = Annual emissions of pollutant (lb/yr)
MS_{Tot} = Mass of total sawdust produced. This may be calculated in Equation 34-2. (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 34-1.

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 34-2.

$$MS_{Tot} = \frac{MS_{Col}}{CE/100}$$

Equation 34-2

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 34-1.

Table 34-1. Fractional Concentrations of Woodworking Dusts

Process Type	PM$_{10}$	PM$_{2.5}$
Sanding	0.920	0.885
Sawing	0.400	0.283
General Woodworking[1]	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.

1. 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 34-3.

$$MS_{Col} = VS_{Col} \times D$$

Equation 34-3

Where,

$\quad$ **VS$_{Col}$** $\quad$ = $\quad$ Volume of sawdust collected (ft^3/yr)

$\quad$ **D** $\quad\quad$ = $\quad$ Density of the sawdust. Provided in Table 34-2 (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 34-2.

Table 34-2. 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.

A more detailed representation of the emissions from woodworking is provided in Figure 34-2.
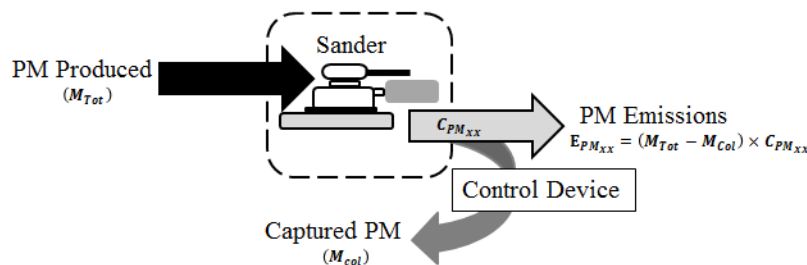

Figure 34-2. Woodworking Control Volume

34.4 Information Resources

Information on woodworking operations can be obtained from the specific shops/organizations which operate woodworking equipment (e.g., Wood Hobby Shop, Civil Engineering, Packing & Crating Shop, etc.). The base Bioenvironmental Engineering shop may be able to help identify the shops with these operations. Contact the control device manufacturer to determine the control efficiency as needed.

34.5 Example Problem

A base has a Wood Hobby Shop that vents sawdust from ripping and cutting with table saws and sanding through a cyclone separator followed by a fabric filter. The cyclone/filter manufacturer estimates the efficiency of the combined cyclone and filter (in regards to collecting sawdust) to be approximately 95%. The total amount of sawdust produced at the shop is not directly known. However, the rectangular bin used to collect the captured sawdust is 3 ft wide, 4 ft long and 6 ft high. According to the shop supervisor, the bin is emptied once a month (12 times per year) and the height of the sawdust in the bin is typically 5 ft at the time it is emptied. Calculate the annual PM$_{10}$ and PM$_{2.5}$ emissions.

Step 1 – 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, and that height should be used when calculating the sawdust volume, <u>not</u> the bin height.**

$$\mathbf{VS_{Col}} = (3\text{ft} \times 4\text{ft} \times 5\text{ft}) \times 12\,\frac{1}{\text{yr}} = \mathbf{720\,\frac{ft^3}{yr}}$$

Step 2 – 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 34-2 states that the average sawdust density is **15.0 lb/ft³**.

Step 3 - 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 34-3 as shown:

$$MS_{Col} = VS_{Col} \times D$$

$$\mathbf{MS_{Col}} = 720 \frac{ft^3}{yr} \times 15.0 \frac{lb}{ft^3} = \mathbf{10,800} \frac{\boldsymbol{lb}}{\boldsymbol{yr}}$$

Step 4 – 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 34-2.

$$MS_{Tot} = \frac{MS_{Col}}{CE/100}$$

$$MS_{Tot} = \frac{10,800 \frac{lb}{yr}}{95\%/100\%}$$

$$\mathbf{MS_{Tot}} = \frac{10,800 \frac{lb}{yr}}{0.95} = \mathbf{11,368.4} \frac{\boldsymbol{lb}}{\boldsymbol{yr}}$$

Step 5 – Select and record the fractional concentrations of PM₁₀ and PM₂.₅. These values are given as **0.452 and 0.343** respectively.

Step 6 – Calculate PM₁₀ and PM₂.₅ emissions. Insert the MS_{Col} calculated in Step 3, the MS_{Tot} calculated in Step 4, and the aerodynamic ratios recorded for PM_{10} and $PM_{2.5}$ in Step 5 into Equation 34-1:

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

For PM₁₀:

$$E_{PM_{10}} = \left(11,368.4 \frac{lb}{yr} - 10,800 \frac{lb}{yr}\right) \times 0.452$$

$$E_{PM_{10}} = \left(568.4 \frac{lb}{yr}\right) \times 0.452$$

$$\boxed{E_{PM_{10}} = 256.9 \frac{lb}{yr}}$$

For PM$_{2.5}$:

$$E_{PM_{2.5}} = \left(11{,}368.4 \frac{lb}{yr} - 10{,}800 \frac{lb}{yr}\right) \times 0.343$$

$$E_{PM_{2.5}} = \left(568.4 \frac{lb}{yr}\right) \times 0.343$$

$$\boxed{E_{PM_{2.5}} = 195.0 \frac{lb}{yr}}$$

34.6 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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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