Final Report

Screening Level Ecological Risk Assessment for the Open Burning Ground, Radford Army Ammunition Plant

Prepared for

Alliant Ammunition and Powder Company, LLC

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Acronyms and Abbreviations

AAPC	Alliant Ammunition and Powder Company, LLC,
Amsl	Above Mean Sea Level
BAF	Bioaccumulation Factor
BCF	Bioconcentration Factor
BERA	Baseline Ecological Risk Assessment
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980
COPC	Chemical of Potential Concern
ERA	Ecological Risk Assessment
Ft	Feet
ft^3	Cubic Feet
HI	Hazard Index
HQ	Hazard Quotient
ISCST3	Industrial Source Complex Short-Term Dispersion Model
LOAEL	Lowest Observed Adverse Effect Level
LOEC	Lowest Observed Effect Concentration
mg/L	Milligrams per Liter
NOAEL	No Observed Adverse Effect Level
NOEC	No Observed Effect Concentration
OBODM	Open Burn/Open Detonation Dispersion Model
P/E	Propellant and Explosives
POHC	Principal Organic Hazardous Constituents
PAH	Polycyclic Aromatic Hydrocarbon
RAAP	Radford Army Ammunition Plant
RCRA	Resource Conservation and Recovery Act
SERA	Screening Ecological Risk Assessment
SLC	Screening Level Concentration
SVOC	Semivolatile Organic Compound
TRV	Toxicity Reference Value
UF	Uncertainty Factor
USEPA	U.S. Environmental Protection Agency
USFWS	U.S. Fish and Wildlife Service

VDGIF	Virginia Department of Game and Inland Fisheries
VOC	Volatile Organic Compound

Executive Summary

This report presents the ecological risk assessment (ERA) for open burning operations at the Radford Army Ammunition Plant (RAAP) in Radford, Virginia. The RAAP facility, which is government-owned and operated by Alliant Ammunition and Powder Company (AAPC), LLC, has been used primarily for the manufacture of propellants and explosives for use by the United States Government and other commercial applications. Excess or waste propellants and explosives, by-products, and other wastes associated with the manufacturing process that cannot be safely treated in the facility's two incinerators (e.g., materials containing metal particles, rocks, and similar debris that might damage the grinder system used to process the incinerator waste stream) are treated by open burning at the Open Burning Ground. In accordance with Virginia regulatory requirements, a Part B permit application under Subpart X of the Resource Conservation and Recovery Act (RCRA) is being developed for the Open Burning Ground for submittal to the Virginia Department of Environmental Quality (VDEQ) by AAPC.

The methods and approaches used in this ERA, as documented in the final ERA protocol (CH2M HILL 2004a) for the RAAP Open Burning Ground, were developed from applicable U.S. Environmental Protection Agency ERA guidance as well as from the draft ERA combustion guidance per the O*pen Burning/Open Detonation Permitting Guidelines*. The overall objective of the ERA was to evaluate potential risks to ecological receptors associated with the operation of the Open Burning Ground in support of a RCRA Part B, Subpart X permit application for open burning at the site. The ERA evaluated the potential future ecological risks of burning-related chemicals in ecologically relevant media (air, surface water, sediment, and surface soil) as determined by air dispersion and deposition modeling. The characterization of ecological risks involved identifying the potential exposures of ecological receptors and evaluating the potential effects associated with such exposures.

The main focus of the ERA was to quantify potential future risks associated with continued operations of the Open Burning Ground facility. The evaluation of potential future risks from continued operations relied on modeled exposure estimates (i.e., concentrations in relevant media as determined from air dispersion and deposition modeling) for two emission scenarios – propellant burn (short duration) and skid burn (higher non-energetic content burn). The spatial extent of this evaluation encompassed areas within and outside of the Open Burning Ground based upon the results of the air dispersion modeling. The objective of the ERA was to evaluate any potential risks to ecological receptors from continued burning operations so that measures could be taken (if necessary) to reduce any identified risks to acceptable levels through modifications to the design, engineering controls, or other appropriate mechanisms.

1.0 Introduction

This report presents the ecological risk assessment (ERA) for open burning operations at the Radford Army Ammunition Plant (RAAP) in Radford, Virginia. The RAAP facility, which is government-owned and operated by Alliant Ammunition and Powder Company (AAPC), LLC, has been used primarily for the manufacture of propellants and explosives for use by the United States Government and other commercial applications. Excess or waste propellants and explosives, by-products, and other wastes associated with the manufacturing process that cannot be safely treated in the facility's two incinerators (e.g., materials containing metal particles, rocks, and similar debris that might damage the grinder system used to process the incinerator waste stream) are treated by open burning at the Open Burning Ground. In accordance with Virginia regulatory requirements, a Part B permit application under Subpart X of the Resource Conservation and Recovery Act (RCRA) is being developed for the Open Burning Ground for submittal to the Virginia Department of Environmental Quality (VDEQ) by AAPC.

The methods and approaches used in this ERA, as documented in the final ERA protocol (CH2M HILL 2004) for the RAAP Open Burning Ground, were developed from applicable U.S. Environmental Protection Agency (USEPA) ERA guidance (e.g., USEPA 1997a, 1998a) as well as from the draft ERA combustion guidance (USEPA 1999) per the O*pen Burning/ Open Detonation Permitting Guidelines* (USEPA 2002a). However, the draft ERA combustion guidance is designed specifically for the evaluation of hazardous waste combustion facilities (i.e., incinerators, and boilers and industrial furnaces co-firing hazardous waste). The characteristics of the Open Burning Ground (open burning of propellants and explosive wastes) differ substantially from a hazardous waste incinerator. The ERA combustion guidance does not specifically address emissions from open burning operations, such as that at the Open Burning Ground. Thus, not all of the specific components of the ERA combustion guidance are applicable to this ERA. Some components were adapted to address the characteristics of an open burning unit in order to focus on using the most appropriate methods and approaches in the ERA relative to the Open Burning Ground.

As described in USEPA ERA guidance (USEPA 1997a, 1998a, 1999, 2002a), an ERA consists of three main components: (1) problem formulation, (2) analysis, and (3) risk characterization. Problem formulation involves: (1) compiling and reviewing existing information on the habitats and biota potentially present on the site and in the site vicinity, (2) developing exposure scenarios, (3) developing a conceptual model that identifies and evaluates potential source areas, transport pathways, fate and transport mechanisms, exposure media, exposure routes, and receptors, and (4) developing assessment and measurement endpoints for all complete exposure pathways. The problem formulation for the ERA is provided in Section 3.

The two remaining components of an ERA, analysis and risk characterization, are described in Sections 4 and 5, respectively. The analysis portion of the ERA is divided into two main parts, exposure assessment and effects assessment. The exposure assessment involves estimating exposures to potential ecological receptors for the exposure scenarios identified in the problem formulation. The principal activity associated with the exposure assessment is the estimation of chemical concentrations in applicable media to which the receptors might be exposed. Data from air dispersion and deposition modeling are used to estimate ecological exposures for continued operations of the Open Burning Ground (assuming an

additional 40-year active life). Standard models from the literature are used to estimate chemical concentrations in air, surface soil, surface water, sediment, and biological tissues (for use in direct and/or food web exposure modeling) (see Section 4). The principal activity associated with the effects assessment is the development of chemical exposure levels that represent conservative thresholds for adverse ecological effects.

The risk characterization portion of the ERA uses the information generated during the two previous parts of the ERA (problem formulation and analysis) to estimate potential risks to ecological receptors for the exposure scenarios evaluated. Also included is an evaluation of the uncertainties associated with the models, assumptions, and methods used in the ERA, and their potential effects on the conclusions of the assessment.

1.1 Objectives and Overall Approach

The overall objective of the ERA is to evaluate potential risks to ecological receptors associated with the continued operations of the Open Burning Ground in support of a RCRA Part B, Subpart X permit application for open burning at the site. The evaluation of risks from continued operations relies on modeled concentrations in ecologically-relevant media (air, surface soil, sediment, and surface water) as determined from air dispersion and deposition modeling based upon existing facility operating conditions. The characterization of ecological risks involves identifying the potential exposures of ecological receptors at or near the facility and evaluating the potential effects associated with such exposures.

The spatial extent of this evaluation encompasses areas both within and outside of the Open Burning Ground based upon the results of previous investigations at the RAAP facility. The results of the ERA are used to determine potential risks to ecological receptors from continued burning operations at the Open Burning Ground so that measures can be taken (if necessary) to reduce any identified risks to acceptable levels through modifications to the design or other appropriate mechanisms.

1.2 Previous Risk Assessments

A human health risk assessment (FEG 2001a) and a screening-level ecological risk assessment (FEG 2001b) have been conducted for the two RCRA incinerators at the facility, based upon emissions from the Alliant hazardous waste incinerators during trial burn conditions. The screening-level ecological risk assessment was completed in five phases of development and focused on incremental effects from incinerator emissions to ecological receptors. Risk estimates were calculated for each receptor, across all applicable exposure pathways, and summed to obtain an estimate of total risk for each receptor. All risk calculations were found to be below benchmark values for each habitat. Therefore, incremental emissions of selected chemicals of potential concern (COPCs) from incinerator operations were considered unlikely to result in adverse environmental effects.

The human health risk assessment detailed incremental carcinogenic and non-carcinogenic effects from incinerator emissions on individuals (receptors). Risk and hazard estimates were calculated for each receptor, across all applicable exposure pathways, and summed to obtain an estimate of total individual risk and hazard. All hazard and risk calculations were found to be below benchmark values for each exposure scenario. Therefore, incremental emissions of selected COPCs from incinerator operations were considered unlikely to result in adverse carcinogenic or non-carcinogenic effects to human receptors.

A human health risk assessment (HHRA) was also prepared for the Open Burning Ground (CH2M HILL 2005). The purpose of this risk assessment was to evaluate potential risks to human receptors from on-going facility operations so that measures could be taken to reduce identified risks, if needed, to acceptable levels through modifications of burning practices. The evaluation of potential future risks from continued operations was based upon concentrations in relevant media as determined from available emissions estimate information. The HHRA evaluated potential current/future risks for a residential receptor at the off-site location where air dispersion modeling projected that the highest concentrations in air would occur. Two emissions scenarios were evaluated (see the HHRA and Sections 2.4.3 and 4.1.7.1 of this ERA for more information).

2.0 Description of the Facility

The RAAP is a government-owned, contractor-operated facility engaged in the manufacture of propellants and explosives. Production operations first began in 1941 and since 1995, AAPC, LLC has been the facility's contractor. The plant is located approximately 40 miles southwest of Roanoke, Virginia and encompasses about 4,104 acres of land.

The RAAP is located in Pulaski and Montgomery Counties in southwestern Virginia, approximately 7 miles northwest of the City of Radford. The New River separates the two counties and forms the northern boundary, and portions of the eastern and western boundaries, of the facility.

The major products manufactured at the RAAP are solvent and solventless propellants that include single-, double-, and triple-based powders and rocket propellants for rocket systems, numerous types of munitions, and other ordnance-related items. Incineration and open burning are used, as needed, to burn waste pyrotechnics, explosives, and propellants. Wastes which cannot be safety treated in the RAAP incinerator (those that contain stones, metal particles, or other debris in the waste that may damage the grinder system waste geometry) are treated at the Open Burning Ground.

2.1 Description of the Open Burning Ground

The Open Burning Ground is located in the southeastern section of the Horseshoe Area (in the loop of the river) on the northern bank of the New River, and within the 100-year floodplain. The location of the Open Burning Ground in relation to the rest of the RAAP facility is shown on Figure 2-1. Open burning operations are conducted in an area approximately 100 feet by 1,500 feet. Open burning operations are conducted in 6 ft by 18 ft pans situated on raised pads about 250 sq. ft in size. There are eight pads at the Open Burning Ground, each containing two burn pans for a total of 16 pans. A plan-view of the Open Burning Ground is shown on Figure 2-2.

On a routine daily basis, the pans on alternate pads are loaded during the morning hours. The criteria for selecting wastes to be burned are the accumulation start date and theoretical burn rate of the material. The theoretical burn rate is used to ensure that fast burning material is not covered by slower burning material. The waste capacity of each pan is 1,000 pounds. The operator may burn considerably less material to prevent untreated material from landing on the soil.

Some of the wastes received at the Open Burning Ground require an aid to burning. These wastes are placed on wood pallets to allow air circulation under the waste. The pallets are covered with cardboard that is soaked with diesel fuel.

Factors considered in determining whether to burn waste on a specific day include the precipitation forecast and wind speed. If the chance of precipitation is greater than 50 percent, the history of precipitation at the time of ignition is documented. If winds are less than 20 miles per hour and there is no precipitation at the time of ignition, burning operations will commence. Once a pan is loaded with waste, the waste cannot be safely removed from the pan. The Open Burning Ground will not operate during precipitation nor will operators work during a thunderstorm in the local vicinity.

2.2 Waste Characterization

According to the RCRA Part B permit application, the waste materials burned during the incinerator source test are considered to be the same as those that would be burned at the Open Burning Ground. The major products produced at RAAP include single-, double- and triple-base propellants. The principal constituents of these propellants are nitrocellulose, nitroglycerin and 2,4-dinitrotoluene. Waste characterization is based upon information provided in a revised facility Waste Analysis Plan, submitted to VDEQ as part of a revised Part B permit application in 2000. This Waste Analysis Plan identifies and describes 19 different groups of waste that can be treated at the facility.

More information describing the composition, combustion by-products, and combustion residuals of materials treated at the Open Burning Ground can be found in the HHRA for the Open Burning Ground (CH2M HILL 2005).

2.3 Waste Streams Used for Emissions Estimation

Emissions estimates were developed using two sources of information on potential waste streams:

1. As described previously, the same wastes that are treated in the incinerator are also treated at the Open Burning Ground. Information presented in the stack testing report for the incinerator (FEG 2001c) and the HHRA for the incinerator (FEG 2001a) provides the basis for selection of site-specific waste streams used to estimate emissions from the Open Burning Ground. The waste streams selected for combustion modeling to estimate open burning emissions were wastes in Groups 9, 10, and 12. Nitroglycerine and 2,4-dinitrotoluene were identified as the principal organic hazardous constituents (POHCs) in these waste streams. Emissions from open burning were estimated using the POLU13 combustion model.

2. Waste stream information published in the literature (Bjorklund et al. 1998; Mitchell and Suggs 1998) were used as an alternate basis for estimating emissions from the Open Burning Ground. A published database of emission factors applicable to the open burning and open detonation practices had been developed by the Dugway Proving Ground (Mitchell and Suggs 1998). This database includes emissions data from 16 energetic materials that were burned and 23 materials that were detonated in test chamber called a BangBox. Constituents in a propellant type studied in Bangbox testing were included as COPCs if there was a Radford waste group corresponding to that propellant type. The Bangbox emission factors from those same propellant types also

were considered in developing emission estimates from the Radford Open Burning Ground.

More information describing the emission estimates from these waste streams can be found in the HHRA for the Open Burning Ground (CH2M HILL 2005).

2.4 Identification of Compounds of Potential Concern

As described previously, the same wastes that are treated in the incinerator are also treated at the Open Burning Ground. Accordingly, identification of COPCs for the ERA of emissions from the Open Burning Ground incorporates the process used for identifying COPCs for the incinerator SLERA (FEG 2001b). In addition, constituents in a propellant type studied in Bangbox testing were included as COPCs if there was a Radford waste group corresponding to that propellant type.

2.4.1 Comparison to Draft USEPA ERA Combustion Guidance COPC List

The draft ERA combustion guidance (USEPA 1999) contains an extensive discussion of the COPC selection process. However, this guidance document is designed specifically for the evaluation of hazardous waste combustion facilities (i.e., incinerators, and boilers and industrial furnaces co-firing hazardous waste). The characteristics of the Open Burning Ground (open burning of propellants and explosive wastes) differ substantially from a hazardous waste incinerator. The combustion guidance does not specifically address emissions from open burning operations, such as that at the RAAP facility. Thus, not all of the specific components of the ERA combustion guidance, including the selection of COPCs, were applicable to this ERA.

The potential COPC list provided in the USEPA (1999) guidance is a "typical" list of compounds or chemical classes that have been identified for evaluation in ERAs at combustion facilities (primarily hazardous waste incinerators). As stated in the ERA combustion guidance (USEPA 1999, Page 2-33), this list of chemicals was compiled based upon professional experience and is not intended to be either limiting or inclusive for a specific facility. While some of the listed chemicals or chemical groups (e.g., dioxin/furans and polycyclic aromatic hydrocarbons [PAHs]) are applicable to the RAAP facility, others (e.g., polychlorinated biphenyls [PCBs]) are not. The ERA combustion guidance (USEPA 1999) identifies the following classes of COPCs for consideration in an ERA:

- **Dioxins and Furans**. USEPA (1999) recommends that the 17 dioxin and furan congeners with chlorine molecules substituted in the 2, 3, 7, and 8 positions always be included in a combustion source ERA. These 17 dioxin and furan congeners were evaluated in this ERA.

- **Polycyclic Aromatic Hydrocarbons (PAHs).** USEPA (1999) recommends that PAHs always be addressed in a combustion source ERA. PAHs were evaluated in this ERA.

- **Polychlorinated Biphenyls (PCBs).** PCBs are not known to be present in the waste stream nor are they likely to be formed as combustion products based upon the materials burned. Thus, PCBs were not applicable to this ERA.

- **Pesticides.** Pesticides or pesticide-contaminated materials are not known to be present in the waste stream nor are they likely to be formed as combustion products based upon the materials burned. Thus, pesticides were not applicable to this ERA.

- **Nitroaromatics.** This chemical class is associated with explosives and other highly nitrogenated hazardous wastes. USEPA (1999) recommends that these chemicals be evaluated if they are present in the waste stream (as is the case at the RAAP facility). COPCs from this class (1,3,5-trinitrobenzene, 1,3-dinitrobenzene, 2,4-dinitrotoluene, 2,4,6-trinitrotoluene, 2,6-dinitrotoluene, and nitrobenzene) were included in the evaluation.

- **Phthalates.** USEPA (1999) recommends that phthalates be considered if the facility burns plastics or materials containing plasticizers. Since such materials might potentially be included in the waste stream at the RAAP facility, COPCs from this class (bis[2-ethylhexyl]phthalate, butylbenzylphthalate, di-n-butylphthalate, di-n-octylphthalate, diethylphthalate, and dimethylphthalate) were included in the evaluation.

- **Hexachlorobenzene (HCB) and Pentachlorophenol (PCP).** USEPA (1999) states that these chemicals should be included as COPCs for facilities burning waste known to contain HCB or PCP, such as wood preservatives and some pesticides. Since this is not the case at the RAAP facility, HCB and PCP were not evaluated.

- **Metals.** USEPA (1999) recommends that the following metals be evaluated in the ERA: aluminum, antimony, arsenic, barium, beryllium, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, thallium, and zinc. Based upon information included in the incinerator SLERA (FEG 2001b), 12 of these metals (aluminum, antimony, arsenic, barium, cadmium, chromium, lead, mercury, nickel, selenium, silver and zinc) were evaluated in this ERA.

- **Volatile Organic Compounds (VOCs).** These are briefly mentioned in the ERA combustion guidance but are not discussed. Numerous VOCs were evaluated in this ERA.

Octanol-water partition coefficient, which correlates with the tendency for a chemical to bioaccumulate, was used as a criteria in identifying COPCs. Typically expressed as log K_{ow}, a value less than 3.5 to 4.0 generally indicates that the chemical will not bioaccumulate to a significant degree (USEPA 1999, 2000a). The guidance presented in USEPA, 2000a regarding identification of bioaccumulative compounds was used as a basis for identifying COPCs for the SLERA. In addition, COPCs based upon published BangBox emissions factors testing were identified. Constituents in a propellant type studied during this Bangbox testing were included as COPCs if there was a Radford waste group corresponding to that propellant type (see Table 2-3 of the Open Burning Ground HHRA). The list of COPCs evaluated in this ERA is presented in Table 2-1.

2.5 Estimation of Emission Rates

Dispersion modeling of the COPCs with the Open Burn/Open Detonation Dispersion Model (OBODM) requires as input emission factors (pound of COPC per pound of waste combusted in a burn pan). The emission factors for open burning of the COPCs were estimated using a combustion model (POLU13) and emissions data collected during the incinerator trial burn. Emission factors obtained from the published literature were also considered. The methodology for calculating emission factors for open burning operations, and the results of those emission factor calculations, are presented in the Open Burning Ground HHRA (CH2M HILL 2005).

The actual burning of propellant waste is performed in 6-foot by 18-foot burn pans on raised pads about 250 feet square in size. There are eight pads in the Open Burning Ground, each consisting of two raised pans, for a total of 16 pans. The waste capacity of each pan is 1,000 pounds, and for estimating purposes, it was assumed that wastes will be burned on eight pans (one pan per pad) each day, 365 days per year. Therefore, the total amount of waste that potentially could be burned annually is 2,920,000 pounds (8,000 pounds per day times 365 days per year).

Some of the wastes received at the Open Burning Ground require an aid to burning. These wastes are placed on a skid (wood pallets) to allow air under the waste. The pallets are covered with cardboard and soaked with diesel fuel. A skid consists of 5 wooden pallets, each weighing 63 pounds (315 pounds of wood), and 3 ounces of cardboard, all treated with 12.5 gallons of on-road diesel fuel. A separate scenario was developed assuming that at least two pans per day would require a skid.

The emission factors used to evaluate these two emissions scenarios (propellant burn and skid burn) are summarized in Table 2-1.

3.0 Problem Formulation

Problem formulation establishes the goals, scope, and focus of the ERA. As part of problem formulation, the environmental setting of a site is characterized in terms of the habitats and biota known or likely to be present, and the types and concentrations of chemicals present in ecologically relevant media. A conceptual model is developed for the site that describes potential sources, potential transport pathways, potential exposure pathways and routes, and potential receptors. Assessment and measurement endpoints are then selected to evaluate those receptors for which complete and potentially significant exposure pathways are likely to exist for the exposure scenarios evaluated. The fate, transport, and toxicological properties of the chemicals present at a site are also considered during this process.

3.1 Environmental Setting

The environmental setting of the assessment area (encompassing the Open Burning Ground, the RAAP, and surrounding areas) is characterized using available information compiled from literature review and existing documents. The characterization of the environmental setting is important in identifying potential receptors (habitats and biota) for the ERA, as well as in identifying potentially complete transport and exposure pathways from source areas to these receptors. The major components of the site characterization are described in the following subsections.

3.1.1 Delineation of the Assessment Area

The ERA combustion guidance document (USEPA 1999; Page 4-2) recommends that the geographical extent of the assessment area be defined as the area surrounding the facility that might be impacted by facility emissions as predicted by air dispersion modeling. The air dispersion model used for the assessment (OBODM) is intended for use in evaluating the potential air quality impacts of open burning and open detonation of obsolete or unsafe munitions and propellants. The results of the air dispersion modeling indicate that dispersion (and subsequent deposition) of burning-related chemicals (e.g., in particulate forms) will be largely confined to an area within 3 km of the Open Burning Ground (see

Section 4.1.7.1 and Figures 4-1 and 4-2). Thus, the assessment area used in the ERA is defined as the area within a 3-km radius of the Open Burning Ground, which is the same size as that used for the RAAP incinerator facility assessment (FEG 2001b).

3.1.2 Physiographic Features

The major physiographic features of the assessment area are described in the following subsections.

3.1.2.1 Climate

Data on the climate of the region were reported from Blacksburg, VA (about 6 miles northeast of RAAP). The weather in this area is characterized by warm summers and cold winters with a fairly even distribution of precipitation throughout the year. The mean annual temperature is approximately 52°F, with an average minimum daily temperature (January) of 20°F and an average daily maximum temperature (July) of 83°F. Average annual precipitation is about 41 inches and average annual snowfall is 20 inches. Prevailing winds are generally from the northwest at an average speed of 8.7 miles/hour.

3.1.2.2 Topography

The entire RAAP facility includes approximately 4,000 acres of complex terrain. The Open Burning Ground is located in the southeastern section of the Horseshoe Area (in the loop of the river) and within the 100-year river floodplain. The area is approximately 100 feet by 1,500 feet and at an elevation of approximately 1,700 feet above mean sea level (amsl). Open burning operations are conducted on raised pads. The area around each pad is slightly depressed to prevent runoff into the New River (Figure 2-2). The portion of the RAAP within the assessment area is relatively flat and ranges in elevation from 1,700 to 1,850 feet amsl. The area immediately adjacent to the RAAP to the south and east is hilly, with elevations of more than 2,000 feet amsl. The areas north and west are relatively flat and level with the RAAP.

3.1.2.3 Geology/Soils

Geologically, the area around the RAAP is composed of mountains and valleys formed by erosion during a long interval of geologic time (USDA 1985b). The RAAP is located in the New River Valley of the Blue Ridge Mountain Foothills (USFWS 2002). The New River drainage is a gently rolling land dissected by shallow drainage ways.

The Open Burning Ground is immediately underlain by Wheeling sandy loam (USDA 1985a). Typically, this soil is level to nearly level, at least 60 inches deep to bedrock, and does not have a seasonal high water table within 6 feet of the surface. The upper 23 inches is dark brown sandy clay loam, and the lower 19 inches is dark brown sandy loam. The substratum is dark brown gravelly sandy loam to a depth of 60 inches or more. The permeability of the Wheeling soil is moderate and surface runoff is slow. The soil is moderately low in organic content.

The soil in the Horseshoe area around the RAAP is generally Braddock-Wheeling in Pulaski County (USDA 1985a) and Unison-Braddock in Montgomery County (USDA 1985b). Braddock-Wheeling soils are deep, nearly level to hilly soils that have a clayey or loamy subsoil, and are formed in alluvium. Unison-Braddock soils are deep, well-drained, gently sloping to moderately steep soils that have a clayey subsoil and have formed in old alluvium on stream terraces and alluvial fans.

3.1.2.4 Hydrology

The predominant hydrologic feature at the Open Burning Ground is the New River, which borders the northern and eastern sides of the facility. The elevation of the river is approximately 1,680 feet amsl and the river flows in a west to east direction in the reach south of the Open Burning Grounds. Average annual volumetric flow calculated for the river is approximately 4.90+07 m^3/yr, based upon USGS data for the New River in Radford, VA (FEG 2001a). Several creeks within the assessment area, including Stroubles Creek, drain into the New River.

Because the RAAP is largely developed, drainage ditches are present that may intermittently hold standing water during and immediately following rain events. In the Open Burning Ground, the area around each burn pad is slightly depressed to prevent runoff into the New River, and a series of drains prevents runoff to the Open Burning Ground from higher elevations (Figure 2-2). Precipitation may pond in the Open Burning Ground until it infiltrates into the ground or is lost through evaporation.

3.1.2.5 Hydrogeology

Groundwater flow throughout the Open Burning Ground is towards the New River.

3.1.3 Habitats

A description of the habitats occurring within or adjacent to the assessment area typically includes, but is not limited to, consideration of those occurring in any terrestrial and/or aquatic environment. The habitat types that occur on or within a 3-km radius of the Open Burning Ground are described in the following subsections.

3.1.3.1 Terrestrial Habitats

Terrestrial habitat types in the Main Unit of the RAAP were identified and described in the Biological Resources Report (VDGIF 1999). The following terrestrial habitat types occur within the assessment area:

- **Natural Upland Forest.** There are a total of 717 acres of Upland Forest habitat at the RAAP. Three distinct vegetative types have been identified:
  - **Dry Calcareous Forest/Woodland**. This community occurs on steep to moderate slopes underlain by limestone. The forest canopy is relatively low and may be thin in rockier sites. The forest is characterized by the presence of *Quercus muhlenbergii,* Chinquapin Oak, in addition to non-oak hardwoods such as *Celtis occidentalis, Ulmus rubra, Acer saccharum/nigrum, Carya* spp., and *Fraxinus americana.* The subcanopy is usually thin and composed of *Ostrya virginiana, Cercis canadensis, Cornus florida,* and saplings of canopy species. Herbaceous cover includes *Bromus pubescens, Festuca subverticillata, Muhlenbergia sobolifera, Sphenopholis nitida, Carex digitalis, Carex laxiflora, Carex platyphylla, Allium cernum, Hypoxis hirsuta, Aquilegia canadensis, Cimicifuga racemosa, Taenidia integerrima, Asclepias quadrifolia, Scutellaria nervos, Galium circaezans, Houstonia longiflora, Erigeron pulchellus,* and *Senecio obovatus.*
  - **Mesic Calcareous Forest (also called Rich Cove/Mesic Slope Forest).** Mesic calcareous forest occurs over limestone and is often transitional to dry calcareous forest/woodland. This habitat type occurs on upland flats, lower slopes, ravines, karst areas, and slopes of various aspects where moisture conditions are moderate.

Except for spicebush (*Lindera benzoin)*, the shrub layer is usually sparse or absent unless invasive exotic species are present. Many hardwood species are present. Drought tolerant species such as *Quercus muhlenbergii* and *Carya* spp. become less frequent whereas *Acer saccharum* increases along with *Juglans nigra, Liriodendron tulipfera, Tilia americana, Aesculus* spp., and *Prunus serotina.* The herb layer is diverse, especially in the spring. Characteristic species include *Deparia acrostichoides, Diplazium pycnocarpon, Poa sylvestris, Carex clanda, Carex communis, Carex copulata, Carex hitchcockiana, Carex oligocarpa, Arisaema triphyllum, Disporum* spp., *Smilacina racemosa, Trillium, grandiflorum, Delphinium tricorne, Caulophyllum thalictoides, Jeffersonia diphylla, Sedum ternatum, Hackelia virginiana,* and *Senecio aureus.*

- **Chestnut Oak Forest (Scarlet Oak Variant).** Chestnut Oak Forest occurs on ridgetops, upper slopes, and lower areas of southeast and southwest slopes. The sites are well-drained and site quality is poor. The forest is characterized by mixed oaks and pines, scattered heaths, and very sparse herb cover. The ground layer is predominantly woody with low shrubs or tree seedlings. Chestnut oak (*Quercus prinus*) and scarlet oak (*Q. coccinea*) dominate the overstory with the following additional species: *Quercus alba, Q. velutina,* and pines (*Pinus strobus, P. virginiana, and P. pungens).* Other frequent tree species are *Myssa sylvatica* and *Acer rubrum* in the overstory and *Amelanchier arborea, Cornus florida,* and *Oxydendron arboreum* in the subcanopy. The shrub layer is principally comprised of *Vaccinium pallidium, V. stamineum,* and *Gaylussacia baccata.* Some characteristic herbs are *Carex pensylvanica, C. digitalis, Cypripedium acaule, Polygala pauciflora,* and *Monotropa hypopithys.*

- **Natural Xeric Calcareous Cliff.** There are a total of 1.7 acres of this community at the RAAP where exposed limestone cliffs occur on steep south- and west-facing bluffs of the New River where erosion-resistant strata outcrop. Cliffs are generally on dry exposures high on the slope but may extend downslope diagonally following the bedding plane of the resistant rock strata. The community is distinguished by the absence of a closed canopy, open exposures of bare rock, and plants being limited to crevices, ledges, soil pockets, and edges. Numerous other smaller cliffs occur under a forest canopy and are not included in this community due to their shaded and more mesic conditions. Scattered trees and shrubs (usually small) may occur around cliff edges and in deeper crevices between outcrops. Typical woody species are *Quercus muhlenbergii, Fraxinus americana, Juniperus virginiana, Celtis occidentalis, Cercis canadensis, Vibernum prunifolium, Toxicodendron radicans, Rhus aromatica,* and *Solidago sphacelata.* Due to the open nature of the habitat and its being prone to disturbance from ice storms (tree fall and broken canopies), this habitat type is often colonized by weedy native taxa in addition to exotics. Common examples are *Chenopdium album, Lepidium virginicum, Euphorbia nutans, Solanum ptycanthum, Bidens bipinnata*, and *Verbesina occidentalis*. The most frequent exotic species are *Marrubium vulgare, Nepeta cataria, Verbascum thapsus, Verbascum phlomoides, Lonicera maackii*, and *Carduus nutans*.

- **Artificial Grassland.** There are a total of 2,500 acres of this community at the RAAP. Trees or shrubs may be present individually or in small groups, but a canopy is lacking. Where shrub invasion has progressed to form larger patches, a shrubland subtype is recognizable. The two dominant species are little bluestem, *Schizachyrium scoparium*, and broomsedge, *Andropogon virginicus*, with other species such as *Tridens flavus, Panicum oligosanthes, Panicum anceps, Eragrostis spectabilis, Setaria glauca, Sorghastrum nutans*, and

Paspalum being frequent. Non-native, cool-season species are also present, such as *Festuca elatior, Poa pratensis, Phleum pratense, Agrostis gigantea, Bromus inermis, Dactylis glomerata,* and *Arrhenatherum elatium*. Principal weed species are *Cirsium arvense, Carduus acanthoides, Carduus nutans, Erechtites hieracifolia, Hypochaeris radicata, Verbascum thapsus, Hieracium pilosella,* and *Datura stramonium*.

- **Artificial Successional Woodland/Forest.** This artificial community is a heterogeneous mixture of woodland and forest. Principal woody species include *Robinia pseudoacacia, Ailanthus altissima, Prunus serotina, Rosa multiflora, Berberis thunbergii, Viburnum prunifolium,* and sometimes *Juglans nigra*. *Poa trivialis, Eupatorium rugosum,* and *Verbesina occidentalis* are herbaceous species somewhat universally present. Common bryophytes are *Thuidium* spp. and *Rhytidium rugosum*.

- **Artificial Pine Plantation.** A total of 357 acres of maturing pine forest occurs within the RAAP. Three species of pines are present, *Pinus strobus* (white pine), *Pinus echinata* (shortleaf pine), and *Pinus taeda* (loblolly pine). Principal shrub species are *Berberis thunbergii, Rubus phoenicolasius, Lonicera japonica, Symphoricarpos orbiculatus, Verbesina occidentalis*, and *Ailanthus altissima.* The most frequent herbaceous species are *Asplenium platyneuron, Diphasiastrum digitatum, Cardamine hirsuta,* and *Satureja vulgaris.*

3.1.3.2 Wetland and Aquatic Habitats

Other than the New River and its associated floodplain, wetland areas are relatively uncommon in the vicinity of the Open Burning Ground. A wetland inventory conducted in 2002 (USFWS 2002) indicated that the combined wetland acreage of the RAAP amounts to two percent of the facility's total land area. The distribution of wetlands from National Wetland Inventory mapping of the area is shown on Figure 2-3. Within the assessment area, 1.1 acres of freshwater emergent wetlands, 1.01 acre of freshwater forested/shrub wetlands, 6.7 acres of freshwater pond, and 287.6 acres of riverine habitat were identified. The following wetland and aquatic habitat types occur within the assessment area:

- **Riparian Forest/Freshwater Forested Wetlands.** A natural Piedmont/Mountain Bottomland forest community type occurs along the New River and Stroubles Creek. This community type is situated on alluvial deposits on floodplains, river banks, and creek banks. Alluvium may be deep and well-drained silt and sand or, closer to the stream level, rocky and seasonally wet. Floodplains vary from a few to many meters wide with the outer edge variously contoured from a high berm to being deeply channeled. The community typically has a mixed hardwood canopy and an open understory with a great diversity of herbaceous species. Characteristic tree species are *Platanus occidentalis* and *Acer saccharinum* on the river bank, and *Acer negundo, Prunus serotina, Celtis occidentalis, Ulmus rubra, Juglans nigra*, and occasionally *Carya cordiformis* on the floodplain. In one small area, *Halesia carolina* grows, a species which is locally common but occurs only along the New River in Virginia. In spring, *Poa trivalis* and *Senecio aureus* dominate the herb layer in some areas. By late in the season, a rank weedy growth reaches head high or more with *Verbesina alternifolia* and *Laportea canadensis* being the principal species. Characteristic herbs are *Bromus latiglumis, Chasmanthium latiflolium, Cinna arundinacea, Elymus riparius, Elymus virginicus, Allium canadense, Urtica gracilis, Chaerophyllum procumbens, Stachys hispida*, and *Silphium perfoliatum* var. *connatum*. There is a relatively low diversity in the herbaceous flora and a great abundance of invasive exotics such as *Microstegium vimineum, Alliaria petiolata*, and *Cardamine hirsuta*.

- **Freshwater Emergent Wetlands.** Small areas of saturated soil conditions bordering springs, streams, and ponds support a wetland flora distinct from the upland vegetation. Groundwater or poor drainage create marshy conditions which support emergent wetland species. Typical species in this habitat type are *Typha latifolida, Sparganium americanum, Glyceria strata, Leersia oryzoides, Carex frankii, Carex lurida, Carex vulpinoidea, Schoenplectus validas, Scirpus atrovirens, Scirpus pendulus, Acorus calamus, Juncus dudleyi, Boehmeria cylindrica, Impatiens capensis, Epilobium coloratum, Lycopus uniflorus, Mimulus ringens, Veronica anagalis-aquatica, Eupatorium perfoliatum,* and *Helenium autumnale*. All of these are wide-ranging species that occur in a variety of wetland habitats.

- **Freshwater Ponds.** Several artificial ponds provide habitat for submersed aquatic plants and certain animal species that might not otherwise be present in the assessment area. The emergent flora of this habitat is essentially identical to that of the emergent wetland community but also includes submersed species such as *Potamogeton crispus, Potamogeton foliosus,* and *Callitiche heterophylla.* This habitat type, however, is generally lacking in species diversity.

- **Open Water.** Riverine habitat (New River) accounts for 287.6 acres within the assessment area. The New River flow rate was calculated at 4.90+07 m^3/yr based upon USGS data for the New River in Radford, VA (FEG 2001a). A current velocity and depth have been estimated at 1.62 meters/second and 4.57 meters, respectively (FEG 2001a). Sand/gravel/mud bare and shore habitat occurs along the New River. The substrate is predominantly coarse to fine-grained alluvium although small bedrock exposures may be present. These habitats are occasionally exposed to intermittent flooding, but late season drawdown produces a diagnostic annual, herb-dominated flora within the river channel on newly exposed substrates. Trees and shrubs are sparse to entirely absent. Waterwillow, *Justicia americana*, occurs almost exclusively as an emergent species in shallows with a substrate of coarse gravel. *Schoenoplectus pungens* and *Schoenoplectus validus* are sparse but typical associates. Characteristic herbs are *Echinochloa muticata, Eragrostis frankii, Eragrostis hypnoides, Panicum capillare, Cyperus bipartitus, Cyperus esculentus, Cyperus flavescens, Cyperus tenuifolius, Eleocharis obtusa, Polygonum hydropiper, Gratiola neglecta, Mollugo verticillata, Chenopodium ambrosioides*, and *Rorippa sylvestris*. Typical native weeds include *Panicum dichotomiflorum, Solanum carolinense*, and *Datura stamonium*. Invasive exotics include *Arthraxon hispidus, Digitaria ischaemum, Microstegium vimineum, Murdannia keisak, Polygonum caespitosum,* and *Euphorbia maculata.*

3.1.3.3 Special Habitats

No wilderness areas, wildlife refuges, and/or wild and scenic rivers occur within the 3-km assessment area radius. However, the perimeter of the Jefferson National Forest is just over 4 km to the north of the assessment area.

3.1.4 Biota

A general description of the biota present on the Open Burning Ground and in surrounding areas was compiled from the incinerator SLERA protocol (FEG 2001b), a biological survey conducted by the Virginia Department of Game and Inland Fisheries (VDGIF 1999), county lists of species provided by the VDGIF, and the scientific literature. The biota known or expected to occur in the site vicinity are discussed by major taxonomic group in the following subsections.

3.1.4.1 Birds

A list of birds known to occur in Montgomery and Pulaski Counties is presented in Table 3-1. Since the assessment area encompasses only a relatively small percentage of these two counties, some of the species listed in Table 3-1 may not occur in the assessment area, including several threatened and endangered species. The biological survey conducted by the VGDIF identified rare, threatened, and endangered species that are known to occur at the RAAP (see Section 3.1.4.6)

3.1.4.2 Mammals

A list of mammals known to occur in Montgomery and Pulaski Counties is presented in Table 3-2. Since the assessment area encompasses only a relatively small percentage of these two counties, some of the species listed in Table 3-2 may not occur in the assessment area, including several threatened and endangered species. The biological survey conducted by the VGDIF identified rare, threatened, and endangered species that are known to occur at the RAAP (see Section 3.1.4.6)

3.1.4.3 Reptiles and Amphibians

A list of reptiles and amphibians known to occur in Montgomery and Pulaski Counties is presented in Table 3-3. Since the assessment area encompasses only a relatively small percentage of these two counties, some of the species listed in Table 3-3 may not occur in the assessment area.

3.1.4.4 Terrestrial Invertebrates

A list of terrestrial invertebrates known to occur in Montgomery and Pulaski Counties is presented in Table 3-4. Since the assessment area encompasses only a relatively small percentage of these two counties, some of the species listed in Table 3-4 may not occur in the assessment area, including some threatened and endangered species. The biological survey conducted by the VGDIF identified rare, threatened, and endangered species that are known to occur at the RAAP (see Section 3.1.4.6).

3.1.4.5 Aquatic Organisms

Fish. A list of fish species known to occur in Montgomery and Pulaski Counties is presented in Table 3-5. Since the assessment area encompasses only a relatively small percentage of these two counties, some of the species listed in Table 3-5 may not occur in the assessment area.

Macroinvertebrates. A list of aquatic macroinvertebrate species known to occur in Montgomery and Pulaski Counties is presented in Table 3-6. Since the assessment area encompasses only a relatively small percentage of these two counties, some of the species listed in Table 3-6 may not occur in the assessment area.

3.1.4.6 Threatened and Endangered Species

The biological survey performed by the VDGIF in May 1999 also including an evaluation of threatened, endangered, and species of concern (VDGIF 1999). This survey was used to determine the possible presence of sensitive receptors for this assessment. Several rare plants were identified on the RAAP. Six species are currently ranked S3 (rare; the lowest of the listing categories), two are ranked S2 (very rare), and three are ranked S1 (extremely rare) (Table 3-7). The regal fritillary (*Speyeria idalia),* a rare butterfly that is declining in much of its range, was also identified on the RAAP. A single population of approximately 20

individuals was observed in the horseshoe area of the New River. None of these species are currently listed as threatened or endangered by either the state (VDGIF) or federal agencies (USFWS). The regal fritillary is listed as a Species of Federal Concern, which is not a legal status.

3.2 Conceptual Model

Figure 3-1 illustrates the ecological conceptual model for the ERA. Important components of the conceptual model are the identification of exposure scenarios, potential source areas, transport pathways, exposure media, potential exposure routes, and potential receptor groups. These components are discussed in the following subsections.

3.2.1 Sources and Exposure Scenarios

The source area addressed in this ERA is emissions from the Open Burning Ground. These emissions were addressed through an evaluation of exposures from continued operations of this facility (Figure 3-1). Source areas related to other activities at the RAAP facility are not directly evaluated.

Two different emissions scenarios were evaluated in the ERA and are described in more detail in Section 4.1.7.1:

- **Propellant Burn.** One scenario represents a burn (lasting approximately 5 minutes) of propellant and other highly energetic material. This scenario assumes a burn rate of 8,000 lbs per day, for 365 days/year.
- **Skid Burn.** A second scenario represents a burn with higher non-energetic content (e.g., wooden skids, diesel oil, non-energetic debris including metal debris, Teflon and HDPE screens). This burning scenario was modeled as a single 12 hour event each day and assumes a burn rate of 2,000 lbs per day, for 365 days/year. The 2,000 lb burn rate was averaged over 12 hours. Much of the waste will be burned within the first hour, though the skids may smolder for several more hours. Modeling the skid burn at a constant emission rate overstates the annual average impacts. Modeled annual averages were adjusted by a ratio of the number of hourly burn events over the total number of hours modeled to provide the annual average values used in the ERA.

3.2.2 Transport Pathways and Exposure Media

A transport pathway describes the mechanisms whereby site-related chemicals, once released, might be transported from a source to ecologically relevant media (such as surface soils) where exposures might occur. These transport pathways are shown on Figure 3-1.

Chemicals (either uncombusted materials or combustion products) released to the air during burning might be transported by prevailing winds to surrounding areas where they might contact receptors directly (inhalation or foliar contact). Site-related chemicals deposited on surface soils might be transported via surface runoff to downgradient surface water bodies or might be deposited directly on the surface water body itself. Site-related chemicals in surface soils might also leach to subsurface soils and groundwater, and then discharge to downgradient water bodies. Chemicals which enter surface water bodies either directly (through deposition from air) or indirectly (via surface runoff or groundwater discharge) might remain suspended in the water column and/or might be transported to sediments. Site-related chemicals in surface soil, sediment, and surface water might be taken

up and accumulated in the tissue of biota, and thus be transported to upper trophic level receptors via food webs.

3.2.3 Exposure Pathways and Routes

An exposure pathway links a source with one or more receptors through exposure via one or more media and exposure routes. Exposure, and thus potential risk, can only occur if complete exposure pathways exist. Figure 3-1 shows the potentially complete and significant exposure pathways to ecological receptors.

An exposure route describes the specific mechanism(s) by which a receptor is exposed to a chemical present in an environmental medium. Terrestrial plants might be exposed through their root surfaces during water and nutrient uptake to chemicals present in surface soils. They might also be exposed to airborne chemicals through gaseous uptake or via deposition to leaf surfaces. Unrooted, floating aquatic plants, and rooted submerged vascular aquatic plants and algae, might be exposed to chemicals directly from the water column or (for rooted plants) from sediments.

Animals might be exposed to chemicals through: (1) the inhalation of gaseous chemicals or of chemicals adhered to airborne particulate matter, (2) the incidental ingestion of contaminated abiotic media (e.g., soil or sediment) during feeding activities, (3) the ingestion of contaminated water, (4) the ingestion of contaminated plant and/or animal tissues for chemicals which have entered food webs, and/or (5) dermal contact with contaminated abiotic media. These exposure routes, where applicable, are depicted on Figure 3-1.

Dermal exposures were not evaluated in the ERA for upper trophic level receptors due to the limitation of available data (USEPA 1999). Based upon the general fate properties (e.g., relatively high adsorption to solids) of the chemicals associated with open burning (e.g., metals, PAHs, and dioxins/furans) and the protection offered by hair or feathers, dermal exposures following deposition for upper trophic level receptor species are not likely to be significant relative to ingestion exposures. Incidental ingestion of soil or sediment during feeding activities was, however, considered in the risk estimates. Direct contact was considered for lower trophic level receptors (e.g., invertebrates). Although available data on inhalation exposures are also limited for many chemicals (USEPA 1999), these exposures were evaluated in the ERA where available data permitted.

3.2.4 Receptor Species

Because of the complexity of natural systems, it is generally not possible to directly assess the potential impacts to all ecological receptors present within an area. Therefore, specific receptor species (e.g., great blue heron) or species groups (e.g., fish) are often selected as surrogates to evaluate potential risks to larger components of the ecological community (guilds, such as piscivorous birds) used to represent the assessment endpoints (e.g., survival and reproduction of piscivorous birds). The receptor species selected for evaluation in the SLERA, and the criteria used to evaluate these species (such as Ambient Water Quality Criteria or the TRVs) are intended to provide conservative representations of the potential ecological risks to the range of guilds that might be present around the Open Burning Ground. Selection criteria typically include those species that:

- Are known to occur, or are likely to occur, in the assessment area

- Have a particular ecological, economic, or aesthetic value
- Are representative of taxonomic groups, life history traits, and/or trophic levels in the habitats present in the assessment area for which complete exposure pathways are likely to exist
- Can, because of toxicological sensitivity or potential exposure magnitude, be expected to represent potentially sensitive populations in the assessment area

The following upper trophic level receptor species were chosen for exposure modeling based upon the criteria listed above, the general guidelines presented in USEPA (1991), and the assessment endpoints discussed in the following subsection:

- Short-tailed shrew (*Blarina brevicauda*) - terrestrial mammalian insectivore
- Meadow vole (*Microtus pennsylvanicus*) - terrestrial mammalian herbivore
- Mink (*Mustela vison*) - semi-aquatic mammalian piscivore
- Red fox (*Vulpes vulpes*) - terrestrial mammalian carnivore
- American robin (*Turdus migratorius*) - terrestrial avian insectivore/omnivore
- Mallard (*Anas platyrhynchos*) - aquatic avian omnivore
- Red-tailed hawk (*Buteo jamaicensis*) - terrestrial avian carnivore
- Great blue heron (*Ardea herodias*) - wetland/aquatic avian piscivore
- Belted kingfisher (*Ceryle alcyon*) - aquatic avian piscivore/insectivore
- Mourning dove (*Zenaida macroura*) - terrestrial avian herbivore

Lower trophic level receptor species were evaluated based upon those taxonomic groupings for which medium-specific toxicity reference values (TRVs) have been developed; these groupings and TRVs are used in most ecological risk assessments. As such, specific species of aquatic biota (e.g., bluegill, mayflies) were not chosen as receptor species; aquatic biota were addressed on a community level via a comparison to surface water and sediment TRVs. Similarly, terrestrial plants and soil invertebrates (earthworms are the standard surrogate) were evaluated using soil TRVs developed specifically for these groups.

Upper trophic level receptor species quantitatively evaluated in the ERA were limited to birds and mammals (as shown in the preceding list), the taxonomic groups with the most available information regarding exposure and toxicological effects. Individual species of amphibians and reptiles were not selected for evaluation because of the general lack of available toxicological information for these taxonomic groups from food web exposures. Potential risks to amphibians and reptiles from exposure via the food web were evaluated using other fauna (birds and mammals) as surrogates. Potential risks to these groups from direct exposures to soil, sediment, and surface water was evaluated using TRVs developed for other taxonomic groups (described above).

Terrestrial and aquatic receptors were evaluated for both emission scenarios. As discussed in Section 3.1.4.6, no known occurrences of threatened or endangered species occur within the boundaries of the Open Burning Ground or in close proximity.

3.2.5 Assessment and Measurement Endpoints

The conclusion of the problem formulation includes the selection of ecological endpoints, which are based upon the conceptual model. Two types of endpoints, assessment endpoints and measurement endpoints, are defined as part of the ERA process (USEPA 1992, 1997a, 1998a). An assessment endpoint is an explicit expression of the environmental component or value that is to be protected. A measurement endpoint is a measurable ecological characteristic that is related to the component or value chosen as the assessment endpoint. The considerations for selecting assessment and measurement endpoints are summarized in USEPA (1992, 1997a) and discussed in detail in Suter (1989, 1990, 1993).

Endpoints in the ERA define ecological attributes that are to be protected (assessment endpoints) and a measurable characteristic of those attributes (measurement endpoints) that can be used to gauge the degree of impact that has or might occur. Assessment endpoints most often relate to attributes of biological populations or communities, and are intended to focus the ERA on particular components of the ecosystem that could be adversely affected by chemicals attributable to the site (USEPA 1997a). Assessment endpoints contain an entity (e.g., mink population) and an attribute of that entity (e.g., survival rate). Individual assessment endpoints usually encompass a group of species or populations (the receptor) with some common characteristic, such as specific exposure route or contaminant sensitivity, with the receptor then used to represent the assessment endpoint in the risk evaluation.

Assessment and measurement endpoints might involve ecological components from any level of biological organization, from individual organisms to the ecosystem itself (USEPA 1992). Effects on individuals are important for some receptors, such as threatened and/or endangered species; population- and community-level effects are typically more relevant to ecosystems. Population- and community-level effects are usually difficult to evaluate directly without long-term and extensive study. However, measurement endpoint evaluations at the individual level, such as an evaluation of the effects of chemical exposure on reproduction, can be used to predict effects on an assessment endpoint at the population or community level. In addition, use of criteria values designed to protect the majority (e.g., 95 percent) of the components of a community (e.g., Ambient Water Quality Criteria for the Protection of Aquatic Life) can be useful in evaluating potential community- and/or population-level effects.

Table 3-8 summarizes the assessment and measurement endpoints selected for the ERA.

4.0 Analysis

The analysis portion of an ERA is divided into two main parts, exposure assessment and effects assessment. Exposure assessment involves estimating exposures of ecological receptors to site-related chemical constituents for the emission scenarios identified in the problem formulation. In the effects assessment, chemical-specific TRVs are developed (as part of the measurement endpoints used to evaluate each assessment endpoint).

4.1 Exposure Assessment

The principal activity associated with the exposure assessment is the estimation of chemical concentrations in applicable media to which the receptors might be exposed. Results from

the air dispersion modeling (OBODM) and deposition modeling were used to estimate ecological exposures for continued (future) operations of the Open Burning Ground (assuming an additional 40-year active life). Standard models from the literature were used to estimate chemical concentrations in air, surface soil, surface water, sediment, and biological tissues (for use in direct and/or food web exposure modeling). These methods and models are described in Sections 4.1.7 and 4.1.8.

4.1.1 Emission Scenarios

The main focus of the ERA is to quantify potential future risks associated with continued operations of the Open Burning Ground. The evaluation of potential future risks from continued operations relies upon modeled exposure estimates (i.e., concentrations in relevant media as determined from dispersion and deposition modeling; see below). The spatial extent of this evaluation encompassed areas both within and outside of the Open Burning Ground based upon the results of the air dispersion modeling. For this ERA, the assessment area was the area within a 3-km radius of the Open Burning Ground (see Section 3.1.1).

Consistent with applicable USEPA ERA guidance (USEPA 1997a, 1998a, 1999, 2002a), potential ecological risks were initially evaluated in a screening-level ERA (SLERA) that corresponds to Steps 1 and 2 of the ERA process (as described in USEPA 1997a). The SLERA was conducted using intentionally conservative assumptions, approaches, and parameter values. Its purpose was to provide an upper-bound estimate of potential ecological risks. The conservative assumptions applied included:

- **Estimation of Exposure Point Concentrations.** The SLERA uses very conservative (i.e., "worst-case") estimates for exposure point concentrations. Potential ecological risks for terrestrial habitat types were evaluated at the predicted points of maximum impact for ground-level air and total deposition based upon the results of air dispersion and deposition modeling (using worst-case assumptions). For the river, it was considered overly conservative to assume that the entire river could occur at the maximum point of deposition (due to its large size and significant flow), so location-specific deposition estimates were calculated for the portion of the river located within the assessment area. Location-specific deposition estimates were also calculated for two additional water bodies, an emergent wetland located near the estimated point of maximum deposition, and a pond, which was located outside of the facility boundary.

- **Exposure Parameters.** The SLERA also included the use of very conservative (i.e., maximum or high-end) estimates for parameters, such as bioaccumulation factors and receptor ingestion rates, used to estimate initial (screening) exposure doses.

If the screening risk estimates suggested potential risk, more realistic exposure estimates were considered in a second (baseline) tier of evaluation (Step 3 of the ERA process). The baseline problem formulation (Step 3) entails refining media concentration and exposure estimates using more realistic assumptions and approaches relative to those used in the screening tier, which is intended to be an extremely conservative assessment. These more realistic assumptions and approaches include:

- Reevaluating conservative model assumptions (such as soil mixing depth).

- Using central tendency estimates (rather than maximums or minimums) for exposure parameters such as bioaccumulation factors, receptor ingestion rates, and receptor body weights. The use of central tendency values for these parameters provides a more representative estimate of potential exposures and risks to receptor populations (the focus of the selected assessment endpoints).

The dispersion model estimates the 1-hour, 8-hour, 24-hour, and annual average concentrations at selected receptor locations. The ERA utilizes the annual average concentration estimates when calculating exposures because these estimates are most applicable to chronic exposures.

4.1.2 Selection of Chemicals for Evaluation

The selection of COPCs is discussed in Section 2.4.

4.1.3 Fate and Transport Mechanisms

The transport and partitioning of chemicals into particular environmental compartments, and their ultimate fate in those compartments, can be predicted from key physico-chemical characteristics. The physico-chemical characteristics that are most relevant for deposition and exposure modeling in this ERA include molecular weight, melting point temperature, volatility, water solubility, diffusivity in air and water, adsorption to solids, octanol-water partitioning, and degradability. Chemical-specific values for the COPCs were obtained from USEPA (1998b, 1999) and other relevant scientific literature and are presented in Table 4-1.

Molecular weight (g/mole) is defined as the sum of all atomic weights for all atoms in the compound's molecule. The melting point temperature (T_m) is defined as the temperature (in °K) at which the solid state of a compound undergoes a phase change to a liquid form.

Volatility describes how readily a chemical will evaporate into the air from water, sediment, or surface soil. Volatilization of a chemical from water to air is dependent upon its physical properties but can be approximated by Henry's Law Constant (H), which is calculated by dividing the vapor pressure (V_p; in atmospheres) by the water solubility (in moles/m^3). Chemicals with H values greater than 1×10^{-3} can be expected to volatilize rapidly from water, while those chemicals with H values less than 1×10^{-3} volatilize less readily (Howard 1991). Chemicals with H values less than 1×10^{-7} volatilize less readily than water so that the chemical concentration in water can increase as the water evaporates at a higher rate than the chemical (Howard 1991). Volatility from soil or sediment is usually expressed qualitatively (e.g., low, moderate, rapid) (Howard 1991).

Water solubility (S; mg/L) is defined as the saturated concentration of a compound in water at a given temperature and pressure (USEPA 1999). The water solubility influences how a chemical will behave in aqueous media. Highly water soluble chemicals tend to remain dissolved in the water column rather than partitioning to sediment (Howard 1991). Also, chemicals with high water solubility generally exhibit a lower tendency to bioconcentrate in aquatic organisms and a greater likelihood of biodegradation (Howard 1991). Diffusivity in air (D_a) and water (D_w) is used to calculate the liquid or gas phase transfer of a chemical into a water body (USEPA 1999).

Adsorption is a measure of a chemical's affinity for binding to solids, such as soil (Kd_s), suspended sediment (Kd_{sw}), and bottom sediment (Kd_{bs}). Adsorption is expressed in terms of partitioning, either K_d (adsorption coefficient; a unitless expression of the equilibrium

concentration in the solid phase versus the water phase) or as K_{oc} (K_d normalized to the organic carbon content of the solid phase; again unitless) (Howard 1991). The higher the K_{oc} or K_d value, the greater the tendency for the chemical to adhere strongly to soil or sediment particles. K_{oc} values can be measured directly or can be estimated from either water solubility or the octanol-water partitioning coefficient using one of several available regression equations (Howard 1991).

Octanol-water partitioning can be used to approximate the degree to which a chemical is hydrophilic or hydrophobic. The octanol-water partitioning coefficient (K_{ow}) expresses the relative partitioning of a chemical between octanol (lipids) and water. A high affinity for lipids equates to a high K_{ow} and vice versa. K_{ow} has been shown to correlate well with bioconcentration factors in aquatic organisms, adsorption to soil or sediment particles, and the potential to bioaccumulate in the food chain (Howard 1991). Typically expressed as log K_{ow}, a value less than 3.5 to 4.0 generally indicates that the chemical will not bioaccumulate to a significant degree (USEPA 1999, 2000a). For aquatic species (the receptor group with the most available data), log BCF (bioconcentration factor) can be related to log K_{ow} (for values less than 6) using the following formula (USEPA 1995a):

$$log\ BCF = (0.79)\ (log\ K_{ow}) - 0.40$$

Thus, a log K_{ow} of 3.5 equates to a BCF value of approximately 250.

Degradability is an important factor in determining whether there will be significant loss of mass or change in the form of a chemical over time in the environment. The half-life of a compound is typically used to describe losses from either degradation (biological or abiotic) or from transfer from one compartment to another (e.g., volatilization from surface soil to air). The half-life is the time required for one-half of the mass of a chemical to undergo the loss or degradation process. For the deposition models used in this ERA, degradation is used to estimate the parameter ksg, the soil loss constant due to degradation.

4.1.4 Transport Pathways and Exposure Media

A transport pathway describes the mechanisms whereby site-related chemicals, once released, might be transported from a source to ecologically relevant media (such as surface soils) where exposures might occur. As discussed in Section 3.2, the primary mechanisms for chemical transport from the source area (Open Burning Ground) include:

- Transport via prevailing winds for chemicals released to the air during burning, followed by deposition to terrestrial, wetland, and aquatic habitats
- Leaching of deposited chemicals from the soil by precipitation and transport by surface runoff to surface water bodies
- Leaching of deposited chemicals from the soil by infiltrating precipitation and transport to surface water bodies via groundwater
- Uptake by biota from surface soil, sediment, and/or surface water and trophic transfer to upper trophic level receptors

4.1.5 Exposure Pathways and Routes

Exposure pathways and routes are discussed in Section 3.2.3.

4.1.6 Receptors

Receptors used in the ERA are discussed in Section 3.2.4.

4.1.7 Exposure Point Concentrations

Concentrations in ground-level ambient air, surface soil, surface water, and sediment were estimated at the point of maximum air concentrations and maximum total deposition, as well as at receptor-specific locations (for aquatic water bodies), based upon the results of the air dispersion and deposition modeling using the methods described in the following subsections. Concentrations in the tissue of biota (prey items) were then estimated from these media concentrations as described in Section 4.1.7.5.

4.1.7.1 Modeling and Air Deposition Model

Air dispersion modeling (OBODM) was used to characterize potential air quality impacts of open burning at the Open Burning Ground. A detailed description of the model selection, model inputs, meteorological data selection, and receptor grid is presented in *Air Modeling Protocol for the Open Burning Ground* (CH2M HILL 2003), which had been approved by the VDEQ, and the Open Burning Ground HHRA (CH2M HILL 2005).

Burning operations at Radford were characterized by two burning scenarios: (1) propellant burn, and (2) skid burn. These two burning scenarios reflect the range of combustion conditions that could be encountered at the Open Burning Ground.

It was assumed that eight of the 16 burn pans present at the Open Burning Ground are simultaneously operating at capacity, or 1000 pounds each. For the purposes of selecting meteorological data for modeling, it was assumed that Open Burning Ground operations occur only during the daylight hours from one half hour after dawn to one half hour before dusk (i.e., between 0800 and 1700). It was anticipated that the most significant emissions will be associated with the short-duration (propellant) burns. Based on this consideration, the worst-case emission scenario was modeled using the following initial set of assumptions for the propellant burn:

- A maximum of one burn event per day
- 1,000 pounds of material per pan per burn event; 8 burn pans operating per event
- Initially, the burn duration was assumed to be 5 minutes for propellant wastes. This is based upon site-specific information indicating that typical burn durations are 5 minutes, with a typical waste load of 400-500 pounds per pan. It is assumed that a maximum waste load of 1,000 pounds per pan would have a similar burn duration.

The skid burn was modeled as a single 12 hour event each day. The 2,000 lb burn rate was averaged over 12 hours. Much of the waste will be burned within the first hour, though the skids may smolder for several more hours. Modeling the skid burn at a constant emission rate overstates the annual average impacts. Modeled annual averages were adjusted by a ratio of the number of hourly burn events over the total number of hours modeled to provide the annual average values used in the HHRA. The waste composition used in modeling reflected the higher content of non-energetic materials in a skid burn.

For the ERA, the modeling results for the annual average concentrations of the COPCs resulting from emissions from the Open Burning Ground were used. For the propellant

burn, the model calculated an average value assuming that a burn occurs during all the daylight hours occurring between 0800 and 1700 over the period of a year. This value was then adjusted to reflect the actual annual burn rate. The modeled annual average concentrations were divided by the theoretical burn quantity (e.g., the sum of the quantity burned during all daylight hours between 0800 and 1700 in a year) and then multiplied by the theoretical maximum annual burn quantity of 2,920,000 lbs (365 days times 8,000 lbs per day).

Similarly, for the annual average concentration of a skid burn, the model calculated an average value assuming that a burn occurs during all the daylight hours occurring between 0800 and 1700 over the period of a year. This value was then adjusted to reflect the actual annual burn rate. The modeled annual average concentrations were divided by the theoretical burn quantity and then multiplied by the theoretical maximum annual burn quantity of 730,000 lbs (365 days times 2,000 lbs per day).

Emissions from combustion activities occur either in the vapor or particle phase. Estimating the potential magnitude of ecological exposure through indirect exposure pathways requires evaluation of the deposition of COPCs. Deposition modeling results were used to evaluate the rate at which COPCs enter a given medium (i.e., soil or surface water). These results were combined with indirect pathway equations in order to calculate concentrations in environmental media such as soil, surface water, sediment and biota.

The equations and input assumptions used to estimate media concentrations were generally consistent with the incinerator SLERA (FEG 2001b). However, the incinerator SLERA used the Industrial Source Complex – Short Term, Version 3 (ISCST3) dispersion model to simulate indirect impacts from wet and dry deposition of emissions to air. ISCST3 has not been identified as a suitable model for modeling emissions from open burning operations (USACE 2001).

While OBODM is specifically designed to model emissions from open burning operations, it is not designed to simulate wet and dry deposition of particulate emissions. Therefore, for purposes of the ERA, an approach was developed to estimate particle deposition that provided a conservative evaluation of indirect pathway exposure within the capabilities of OBODM. More information describing this model and this methodology is presented in the Open Burning Ground HHRA (CH2M HILL 2005) and Attachment 1.

A total of 2,500 coarse, rectangular grid receptors, placed on 200-meter spacings with the Open Burning Ground at the center of the grid, were used to locate the maximum concentrations resulting from open burning emissions under both scenarios. The initial, or coarse, receptor grid extends outward to a distance of 10 km from the Open Burning Ground. Receptor elevations were obtained from the USGS 1-degree Digital Elevation Model (DEM) data (USGS/EROS website, http://edc.usgs.gov/geodata). A fine receptor grid using 100 meter spacings was used to provide further resolution of the maximum impact identified in the coarse grid runs.

Area-average concentrations were calculated over the coarse receptor grid over a 6 km by 6 km grid for use in calculating concentrations in soil that could runoff into the New River. Discrete receptors were placed on the New River at 1-km intervals, 6 km upstream and 6 km downstream from the Open Burning Ground. For lentic waterbodies (see Section 4.1.7.4), area-average concentrations were calculated using the fine receptor grid over the waterbody and a watershed estimated from topographic mapping using a Geographical Information

System (see Section 4.1.7.4). Attachment 1 provides the deposition model inputs and deposition equations used in the ERA.

The coarse grid receptor locations, used to calculate area-average concentrations in air and used to help locate the maximum deposition locations, are presented in the Open Burning Ground HHRA (CH2M HILL 2005). Concentration isopleths (annual averages) for particulates for the propellant and skid burn scenarios are shown on Figures 4-1 and 4-2, respectively. The air dispersion modeling results for each burn scenario are shown in Table 4-2.

Except for the criteria pollutants (CO, PM_{10}, NO_x, and SO_2) and hydrogen chloride (HCl), all of the COPCs with emission estimates were evaluated for inhalation exposures in the ERA (Table 4-3). Non-volatile chemicals were also evaluated in surface soil, surface water, and sediment based upon estimated deposition. Significant deposition and accumulation of volatile chemicals is unlikely due to their:

- High volatility, as indicated by vapor pressure and Henry's Law Constant values (Table 4-1)
- Short half-lives in surface soil and surface water
- Low bioaccumulation potential (USEPA 200a), as indicated by low log K_{ow} values (Table 4-1)

Thus, the inhalation route was the only potential exposure route likely to be potentially significant and the only one evaluated in the ERA for volatile chemicals. See Section 4.1.7.5 for a discussion of the chemicals evaluated for exposures via food webs.

4.1.7.2 Air Concentrations

As part of the air modeling, chemical-specific emission rates and a maximum annual average dispersion factor were generated. Ground-level ambient air concentrations (annual average) were calculated for each chemical by multiplying the emission rate by the dispersion factor. As discussed previously, the risk estimates were based upon the maximum estimated air concentration at the predicted point of maximum impact.

4.1.7.3 Surface Soil Concentrations

Emissions from open burning will result in the deposition of chemicals onto surface soils in areas on, and adjacent to, the Open Burning Ground. The soil concentrations resulting from the deposition of airborne chemicals were estimated based upon the total deposition rate, average soil density, soil mixing depth, and the duration of emissions. The total deposition rate was derived from the deposition model. A deposition velocity of 1 cm/s, a soil mixing depth of 1 cm (USEPA 1999), a soil bulk density of 1.50 g/cm^3 (USEPA 1999), and an emission duration of 40 years were used.

Surface soil concentrations were conservatively estimated at the point of maximum total deposition. These concentrations were then adjusted by the application of a soil loss constant, which considers losses due to leaching, erosion, surface runoff, degradation (both abiotic and biotic), and volatilization (USEPA 1999; Attachment 1).

4.1.7.4 Surface Water and Sediment Concentrations

Chemical constituents emitted during open burning might also reach surrounding water bodies (e.g., the New River) via direct deposition onto the surface water and from runoff/ erosion of chemicals deposited within the watershed.

Direct deposition onto the surface water and surface runoff from the watershed were modeled for three water bodies:

- The portion of the New River within a 3-km radius of the Open Burning Ground (Figure 2-3)
- A freshwater emergent wetland located approximately 2,000 feet south of the Open Burning Ground (Figure 2-3)
- A freshwater pond located approximately 6,000 feet south of the Open Burning Ground and outside of the facility boundary (Figure 2-3)

The wetland represents the nearest lentic water body of any significant size to the Open Burning Ground that may provide habitat for aquatic receptors and be impacted by burning emissions under the propellant and skid burn scenarios (Figures 4-1 and 4-2, respectively). The pond represents the nearest off-site lentic water body of any significant size that may provide habitat for aquatic receptors. The all three water bodies were modeled (for both direct deposition and deposition within the watershed, that is, cumulative loading) based upon location-specific estimates.

The deposition model estimates the mass balance between chemicals entering the water body and the amounts that are dissolved in the water column, adhered to suspended particles in the water column, and/or deposited to bottom sediments. The model also considers losses from such factors as benthic burial and volatilization from the water column (USEPA 1999; Attachment 1).

The model requires some water body-specific inputs for certain parameters including (listed with potential source of such parameters):

- Surface area (m^2) - Value for the river (2.90E+05 m^2) from FEG (2001a), and the value for the wetland and pond estimated from available mapping (1.94E+03 m^2 and 3.89E+03 m^2, respectively)
- Watershed area (m^2) - Value for the river (2.70E+07 m^2) from FEG (2001a), and the value for the wetland and pond estimated from topographic mapping using a Geographical Information System (GIS) (3.68E+05 m^2 and 6.74E+05 m^2, respectively)
- Current velocity (m/s) - Value for the river (1.62 m/s) from FEG (2001a). Current velocity for the wetland and pond were assumed to be zero.
- Flow rate (m^3/year) - calculated for the river (4.90+07 m^3/yr) based upon USGS data for the New River in Radford, VA (FEG 2001a). For the wetland and pond (2.96E+02 m^3/yr and 5.92E+02 m^3/yr, respectively), flow rate was calculated by multiplying the water depth by the surface area, that is, total turn-over once each year was assumed.
- Depth of the water column (m) - Value for the river (4.57 m) from FEG (2001a), and for the wetland (0.15 m) based upon data collected by the USFWS for the RAAP Wetlands

Inventory Report (USFWS 2002). Because depth data were not available for the pond, the wetland value (0.15 m) was used, which is likely to be a conservative estimate.

- Depth of the sediment layer (cm) - Assumed to be 3 cm for all three water bodies, the default value in USEPA (1999)

4.1.7.5 Tissue Concentrations

Dietary items for which tissue concentrations were modeled included terrestrial and aquatic plants, soil invertebrates (earthworms), small mammals, benthic invertebrates, and fish. The methods used for calculating these tissue calculations are outlined below.

Only those chemicals with the potential to bioaccumulate to a significant extent were considered for estimation of tissue concentrations and subsequent food web modeling. Table 4-2 in USEPA (2000a) provides a list of bioaccumulating chemicals, which was developed based upon a set of criteria that included persistence (estimated half-life), toxicity (fish), and bioaccumulation potential (based upon BCF and log K_{ow} values). Of the metal COPCs listed in Table 4-3, all but aluminum, antimony, and barium are on the list of bioaccumulative chemicals. Of the organics listed in Table 4-3, only the higher molecular weight PAHs, dioxins/furans, and hexachloroethane are considered bioaccumulative and were evaluated for food web exposures.

Terrestrial Plants. Tissue concentrations in the above-ground vegetative portion of terrestrial plants were estimated by calculating and summing uptake from three primary mechanisms: (1) direct deposition of particulates to leaf surfaces, (2) air (vapor) transfer, and (3) root uptake. The models used for each of these mechanisms are outlined in USEPA (1999). Default factors (USEPA 1999) were used for four model parameters required to estimate total concentrations in plants:

- Interception fraction of the edible portion of the plant (R_p) - 0.50 (unitless)
- Plant surface loss coefficient (k_p) - 18 ($year^{-1}$)
- Length of plant exposure (T_p) - 0.12 (year)
- Yield or standing crop biomass (Y_p) - 0.24 (kg/m^2)

Total concentrations in plants were estimated on a dry-weight basis (conversions to dry weight were made using an estimated solids content of 12 percent [USEPA 1999]). The air-to-plant and soil-to-plant biotransfer factors used in the food web models are shown in Table 4-4.

Earthworms. Tissue concentrations in soil invertebrates (earthworms) were estimated by multiplying the modeled surface soil concentration for each chemical by chemical-specific bioaccumulation factors (BAFs) obtained from the literature. BAFs consider both direct exposure to soil and exposure via the diet. BAFs based on depurated analyses (soil was purged from the gut of the earthworm prior to analysis) were selecting because direct ingestion of soil was accounted for separately in the food web model.

The BAF values were based upon the ratio between dry-weight soil and dry-weight earthworm tissue. For chemicals without available measured BAFs, an earthworm BAF was estimated using data for similar chemicals or a BAF of 1.0 was assumed (Table 4-5).

Small Mammals. Whole-body tissue concentrations in small mammals (shrews, voles, and mice) were estimated using one of two methodologies. For chemicals with literature-based soil-to-small mammal BAFs (Table 4-6), the small mammal tissue concentration was calculated by multiplying the measured or estimated surface soil concentration for each chemical by the chemical-specific soil-to-small mammal BAF obtained from the literature. The BAF values used were based upon the ratio between dry-weight soil and whole-body dry-weight tissue. BAFs for shrews were those reported in Sample et al. (1998b) for insectivores, for voles are those reported for herbivores, and for mice are those reported for omnivores.

For chemicals without soil-to-small mammal BAF values, an alternate approach was used to estimate whole-body tissue concentrations. Because most chemical exposure for these small mammals is via the diet, it was assumed that the concentration of each chemical in the small mammal's tissues was equal to the chemical concentration in its diet, that is, a diet to whole-body BAF (wet-weight basis) of one was assumed. The use of a diet to whole-body BAF of one is likely to result in a conservative estimate of chemical concentrations for chemicals that are not known to biomagnify in terrestrial food webs (e.g., PAHs) based upon reported literature values for chemicals that are known to biomagnify in food webs. For example, a maximum BAF (wet weight) value of 1.0 was reported by Simmons and McKee (1992) for PCBs based upon laboratory studies with white-footed mice. Menzie et al. (1992) reported BAF values (wet-weight) for DDT of 0.3 for voles and 0.2 for short-tailed shrews. Reported BAF (wet-weight) values for dioxin were only slightly above one (1.4) for the deer mouse (USEPA 1990).

Aquatic Plants. Tissue concentrations in the above-ground vegetative portion of rooted aquatic plants were estimated only for root uptake using the same methodologies as described above for terrestrial plants except that sediment (not soil) concentrations were used in the calculation.

Benthic Invertebrates. Tissue concentrations in benthic invertebrates were estimated by multiplying the estimated sediment concentration for each chemical by chemical-specific sediment-to-invertebrate BAFs obtained from the literature. The BAF values used were based upon the ratio between dry-weight sediment and dry-weight invertebrate tissue. BAFs based upon depurated analyses (sediment was purged from the gut of the organism prior to analysis) were selected because direct ingestion of sediment was accounted for separately in the food web model. For chemicals without available measured BAFs, a BAF was estimated using data for similar chemicals or a BAF of 1.0 was assumed (Table 4-7).

Fish. Except for dioxin, tissue concentrations in whole-body fish was estimated using water-to-fish BCFs. BCF values were converted to BAF values by multiplying the BCF by a food chain multiplier (USEPA 1995b, 1999). Food chain multipliers for organic chemicals were calculated using chemical-specific log K_{ow} values and were based upon the consumption of trophic level 3 fish. Trophic level 3 was used because the piscivorous receptors (belted kingfisher, great blue heron, and mink) used in the ERA consume fish from this trophic level. A food chain multiplier of one was applied to all metals.

Resulting BAF values were converted to a dry-weight basis by dividing the wet-weight BAF by the estimated solids content for fish (25 percent [0.25]; USEPA 1993). For chemicals without available measured BCFs or BAFs, a BAF was estimated using data for similar chemicals (Table 4-8).

For dioxin, tissue concentrations in whole-body fish were estimated by multiplying the sediment concentration by a sediment-to-fish BAF obtained from the literature. The BAF value used was based upon the ratio between dry-weight sediment and dry-weight fish tissue. Literature values based upon the ratio between dry-weight sediment and wet-weight fish tissue were converted to a dry-weight basis by dividing the wet-weight BAF by the estimated solids content for fish (25 percent [0.25]; USEPA 1993). The sediment-to-fish BAF used for dioxin in the ERA is shown in Table 4-8.

4.1.8 Dietary Intakes

Upper trophic level receptor exposures (via the food web) to chemicals in surface soil, surface water, and sediment were determined by estimating the chemical concentrations in each relevant dietary component for each receptor. Incidental ingestion of soil or sediment, and ingestion of drinking water, were included when calculating the total exposure. As previously mentioned, not all chemicals were modeled for food web exposures. Only those chemicals with the potential to bioaccumulate to a significant extent were evaluated (non-volatile COPCs listed in Table 4-2 of USEPA 2000a that are also listed in Table 4-3).

Dietary intakes for each upper trophic level receptor species were calculated using the following formula (modified from USEPA [1993]):

$$DI_x = \frac{[[\sum_i (FIR)(FC_{xi})(PDF_i)] + [(FIR)(SC_x)(PDS)] + [(WIR)(WC_x)]]}{BW}$$

where:
- DI_x = Dietary intake for chemical x (mg chemical/kg body weight/day)
- FIR = Food ingestion rate (kg/day, dry-weight)
- FC_{xi} = Concentration of chemical x in food item i (mg/kg, dry-weight)
- PDF_i = Proportion of diet composed of food item i (dry-weight basis)
- SC_x = Concentration of chemical x in soil/sediment (mg/kg, dry-weight)
- PDS = Proportion of diet composed of soil/sediment (dry-weight basis)
- WIR = Water ingestion rate (L/day)
- WC_x = Concentration of chemical x in water (mg/L)
- BW = Body weight (kg, wet weight)

Note that soil/sediment ingestion is modeled as a dietary component (rather than using a separate soil ingestion rate). A sample calculation in Attachment 2 compares this approach with the calculation of the daily dose of COPC ingested using ingestion rates presented in USEPA (1999). The difference between estimated dietary intakes (Di_x) using the different approaches is negligible.

The conservative (i.e., high-end) receptor-specific values that were used as inputs to this equation for the screening risk estimates were obtained from relevant scientific literature (Table 4-9 - high-end). Consistent with the conservative approach used in a SLERA, the minimum body weight and maximum food and water ingestion rates from the scientific literature were used for each receptor. In addition, exclusive diets (i.e., all intake was assumed to be from a single prey item for each receptor, plus any applicable soil, sediment, and water ingestion) were used when calculating screening risk estimates per USEPA (1999). The use of exclusive diets, by definition, resulted in maximum exposures and thus

conservative estimates of risk. If the receptor is assumed to consume a diet composed exclusively of the most contaminated prey item, this will result in the highest possible exposure (and thus risk) estimate. Actual diets are more representative of potential exposures while exclusive diets provide the most conservative exposure estimate. Baseline risk estimates based upon actual diets (as determined from the literature for each receptor) were calculated if risks were identified based upon exposure estimates using the exclusive diet.

For the screening risk estimates, it was assumed that chemicals were 100 percent bioavailable to the receptor and it was assumed that each receptor spends 100 percent of its time in the water body or at the dispersion model grid location evaluated (i.e., an area use factor [AUF] of 1.0 was assumed).

4.2 Effects Assessment

The principal activity associated with the effects assessment is the development of chemical exposure levels (TRVs) that represent conservative thresholds for adverse ecological effects. These chemical-specific TRVs are included as part of the measurement endpoints developed to evaluate each of the assessment endpoints.

4.2.1 Uncertainty Factors

The TRVs used in the ERA were based upon chronic no-effect levels. When chronic No Observed Effect Concentration (NOEC) or No Observed Adverse Effect Level (NOAEL) toxicity values were not available, estimates were derived or extrapolated from subchronic NOEC/NOAEL values, chronic or subchronic Lowest Observed Effect Concentration (LOEC)/Lowest Observed Adverse Effect Level (LOAEL) values, or acute values as follows (USEPA 1999):

- A chronic LOAEL (or LOEC) was multiplied by an uncertainty factor (UF) of 0.1 to convert it to a chronic NOAEL (or NOEC)
- A subchronic NOAEL (or NOEC) was multiplied by a UF of 0.1 to convert it to a chronic NOAEL (or NOEC)
- An acute lethal value (LC_{50} or LD_{50}) was multiplied by a UF of 0.01 to convert it to a chronic NOAEL (or NOEC)

Exposure duration was defined as follows (USEPA 1999; Sample et al. 1996):

- Fish, mammals, and birds:
  - Chronic is >90 days or during a critical life stage
  - Subchronic is 14 to 90 days
  - Acute is <14 days
- Plants and invertebrates:
  - Chronic is >20 days or during a critical life stage
  - Subchronic is 3 to 20 days

– Acute is <3 days

4.2.2 Medium-Specific TRVs

Chemical-specific TRVs were developed for air, surface soil, surface water, and sediment. As discussed in Sections 3.2.4 and 3.2.5, these TRVs are intended to evaluate receptor groups (communities) and not individual organisms or species.

Medium-specific TRVs were developed based upon regulatory criteria, such as Ambient Water Quality Criteria (AWQC), or on values described in the literature. When a specific chemical lacked an available TRV for a particular medium, data from other chemicals with similar chemical structure and mode of action were considered. TRVs, or the data used to calculate them, were selected using best professional judgement considering such factors as study design, study methodology, study duration, study endpoint, exposure route, life stage, and test species (USEPA 1999).

4.2.2.1 Air

TRVs for inhalation exposures to animals (e.g., birds and mammals) of gaseous chemicals or chemicals adhered to airborne particulates were developed where available data allowed. Most of the available data is from inhalation exposures to mammals (such as mice) under laboratory conditions and many chemicals lack useable data on which to develop TRVs. Table 4-10 lists the inhalation-based TRVs for the applicable chemicals listed in Table 4-3.

4.2.2.2 Surface Water

Surface water TRVs for several divalent metals required site-specific adjustment based upon water hardness. Because site-specific hardness data were not available, adjustments to these TRVs were made using a default hardness of 100 mg $CaCO_3$/L (USEPA 1999, 2002b).

For chemicals known to bioaccumulate in aquatic food webs, TRVs were based upon the final chronic value (rather than the final residue value) as per USEPA (1996b) and Suter and Tsao (1996). The use of final chronic values is intended to protect ecological receptors from direct exposures to chemicals in surface water, rather than from exposure via the food chain. Potential risks to upper trophic level receptors from food chain exposures (tissue residues) were evaluated separately (see Section 4.2.3). Table 4-11 lists the surface water TRVs for the applicable chemicals listed in Table 4-3.

4.2.2.3 Sediment

Sediment TRVs for inorganics were typically based upon studies that correlate chemical concentrations in sediments with some measure of benthic community impairment; this approach is known as the Screening Level Concentration (SLC) approach. SLC-based TRVs cannot be adjusted to account for site-specific bioavailability. Since these TRVs correlate adverse effects observed in a particular sample to each individual chemical present, without attempting to discern which chemical or group of chemicals is actually responsible for the observed effects, their use tends to result in a very conservative estimate of risk. However, approaches such as equilibrium partitioning are not yet considered applicable for deriving sediment TRVs for inorganic chemicals.

Sediment TRVs for organic chemicals were obtained from OME (1993), USEPA (1996b), and Jones et al. (1997). Sediment TRVs for most organic chemicals were based upon the

equilibrium partitioning approach (USEPA 1996b, USEPA 1999), calculated using the following formula:

$$TRV = (f_{oc})\,(K_{oc})\,(FCV)$$

where:

TRV	=	Toxicity Reference Value (µg/kg)
f_{oc}	=	Total organic carbon content (percent, as a fraction)
K_{oc}	=	Normalized adsorption coefficient (L/kg)
FCV	=	Chronic AWQC or its equivalent (µg/L)

To be consistent with deposition modeling, the default value of four percent (USEPA 1999) was used in this equation for total organic carbon. The K_{oc} values used in this equation were derived from the literature and are listed in Table 4-1. The equilibrium partitioning approach is the recommended approach in USEPA (1996b, 1999) for deriving sediment TRVs for non-polar organic chemicals. The equilibrium partitioning approach was applied to polar organic chemicals (e.g., o-cresol), although adsorption mechanisms other than hydrophobicity may significantly increase the fraction of the chemical sorbed to the sediment particles (Suter and Tsao 1996). Therefore, this approach is likely to overestimate the bioavailable chemical concentration and the benchmarks provided are considered conservative. Table 4-12 provides the sediment TRVs for the applicable chemicals listed in Table 4-3.

4.2.2.4 Surface Soil

Widely accepted and comprehensive TRVs for surface soils are currently limited. While many sources have identified "safe" contaminant levels in surface soils from a human health perspective, only a few, such as Efroymson et al. (1997a, 1997b), MHSPE (1994), and USEPA (2000b), have developed soil TRVs with protection of ecological receptors as a goal.

TRVs are most widely available for terrestrial plants and soil invertebrates (earthworms). Table 4-13 lists the soil-based TRVs that were used in the ERA for the applicable chemicals listed in Table 4-3. The TRV for aluminum is based on USEPA's Ecological Soil Screening Level documentation (USEPA, 2003).

4.2.3 Ingestion TRVs

Ingestion-based TRVs for dietary exposures were derived for each avian and mammalian receptor species (Section 3.2.4) and bioaccumulative chemical (Section 4.1.8) evaluated in the ERA. Toxicological information from the literature for wildlife species most closely related to the receptor species was used, where available, but was be supplemented by laboratory studies of non-wildlife species (e.g., laboratory mice) where necessary. The ingestion-based TRVs are expressed as milligrams of the chemical per kilogram body weight of the receptor per day (mg/kg-BW/day).

Growth and reproduction were emphasized as assessment endpoints because they are the most relevant, ecologically, to maintaining viable populations and because they are generally the most studied chronic toxicological endpoints for ecological receptors. If several chronic toxicity studies were available from the literature, the most appropriate study was selected for each receptor species based upon study design, study methodology, study duration, study endpoint, and test species. Ingestion-based TRVs for mammals and birds are summarized in Tables 4-14 and 4-15, respectively, for the applicable chemicals listed in Table 4-3.

5.0 Risk Characterization

The risk characterization portion of the ERA uses the information generated during the two previous parts of the ERA (problem formulation and analysis) to estimate potential risks to ecological receptors for the exposure scenarios evaluated. Also included is an evaluation of the uncertainties associated with the models, assumptions, and methods used in the ERA, and their potential effects on the conclusions of the assessment.

As part of risk characterization, the exposure concentrations (abiotic media) or exposure doses (upper trophic level receptor species) are compared with the corresponding TRVs to derive risk estimates using the hazard quotient (HQ) method. HQs are calculated by dividing the chemical concentration in the medium being evaluated by the corresponding medium-specific TRV or by dividing the exposure dose by the corresponding ingestion-based TRV.

HQs equaling or exceeding one indicate the potential for unacceptable risk since the chemical concentration or dose (exposure) equals or exceeds the TRV (effect). However, TRVs and screening exposure estimates were derived using intentionally conservative assumptions such that HQs greater than or equal to one do not necessarily indicate that risks are present or impacts are occurring. Rather, it identifies chemical-pathway-receptor combinations requiring further evaluation using more realistic exposure scenarios and assumptions. Following the same reasoning, HQs less than one indicate that risks are unlikely, enabling a conclusion of negligible risk to be reached with high confidence.

USEPA ERA combustion guidance (USEPA 1999) also suggests calculating Hazard Indices (HIs); a HI is the sum of the HQs for a particular set of chemicals for a particular exposure pathway. In this ERA, the calculation of HIs was considered for specific chemical groups with similar modes of action where sufficient information was available to document additive effects. Dioxins and furans were evaluated as a single group using the toxicity equivalency quotient (TEQ) approach and the toxicity equivalency factors (TEFs) listed in Table 5-1 (from van der Berg et al. [1998]).

5.1 Risk Calculation

Risk calculation compares the modeled exposure concentrations in air, surface soil, surface water, and sediment with the corresponding TRVs to derive risk estimates using the HQ method. These comparisons are conducted for the chemicals selected in Section 4.1.2 and listed in Table 4-3.

5.1.1 Ground-Level Air

5.1.1.1 Propellant Burn

Concentrations in ground-level air (based upon modeled annual average concentrations at the estimated point of maximum impact near the Open Burning Ground) are compared to inhalation-based TRVs in Table 5-2. None of the COPCs exceeded an inhalation-based TRV, although many (67 of 108) of the COPCs lacked inhalation-based TRVs.

5.1.1.2 Skid Burn

Concentrations in ground-level air (based upon modeled annual average concentrations at the estimated point of maximum impact at the Open Burning Ground) are compared to

inhalation-based TRVs in Table 5-2. None of the COPCs exceeded an inhalation-based TRV, although many (67 of 108) of the COPCs lacked inhalation-based TRVs.

5.1.2 Terrestrial Habitats (Surface Soil)

5.1.2.1 Propellant Burn

The comparison of chemical concentrations in surface soil (at the estimated point of maximum deposition) with TRVs is presented in Table 5-3. Comparisons were based upon soil concentrations estimated using the most conservative soil mixing depth (1 cm). The 1-cm soil mixing depth was used to provide a very conservative bounding estimate since natural mixing of soil by plant roots and soil fauna will occur to much deeper depths, especially over the 40-year period of deposition used in the modeling (see Attachment 3 and Section 6).

None of the COPCs exceeded a TRV at the maximum point (Table 5-3). The comparison for aluminum was based upon measured pH in six soil samples collected from various depths within the RAAP. The values measured in site soils ranged from 6.2 to 8.1 (source: " Site Screening Report for Solid Waste Management Units 13, 37, 38 46, 57, 68, 69 and Areas of Concern A, F and Q. Draft", September 2004). Fourteen organic chemicals lacked TRVs for both flora and soil fauna.

Screening exposure dose estimates (at the maximum point of deposition) for each terrestrial upper trophic level receptor species are compared to ingestion TRVs in Table 5-4. Example calculations are provided in Attachment 2. Based upon these conservative screening estimates, HQs did not exceed one for any terrestrial receptor.

5.1.2.2 Skid Burn

The comparison of chemical concentrations in surface soil (at the estimated point of maximum deposition) with TRVs is presented in Table 5-5. Comparisons were based upon soil concentrations estimated using the most conservative soil mixing depth (1 cm). The 1-cm soil mixing depth was used to provide a very conservative bounding estimate since natural mixing of soil by plant roots and soil fauna will occur to much deeper depths, especially over the 40-year period of deposition used in the modeling (see Attachment 3 and Section 6).

The comparison for aluminum was based upon measured pH in six soil samples collected from various depths within the RAAP (values ranged from 6.2 to 8.1). Fourteen organic chemicals lacked TRVs for both flora and soil fauna.

Estimated lead concentrations exceeded plant TRVs (HQ of 1.33) based upon conservative estimates. Estimated chromium concentrations exceeded soil fauna TRVs (HQ of 1.81) based upon conservative estimates.

Screening exposure dose estimates (at the maximum point of deposition at the Open Burning Ground) for each terrestrial upper trophic level receptor species are compared to ingestion TRVs in Table 5-6. Example calculations are provided in Attachment 2. Based upon these conservative screening estimates, NOAEL-based ingestion TRVs were exceeded by the screening exposure doses for the following:

- Lead for the short-tailed shrew (HQ of 1.72), American robin (HQ of 2.08), and mourning dove (HQ of 5.63)

- Mercury for the short-tailed shrew (HQ of 1.66) and American robin (HQ of 1.26)
- Dioxin/furans for the short-tailed shrew (HQ of 162), meadow vole (HQ of 3.40), red fox (HQ of 6.25), and American robin (HQ of 14.7)

LOAEL-based ingestion TRVs were exceeded by the screening exposure doses for the following:

- Dioxin/furans for the short-tailed shrew (HQ of 16.2) and American robin (HQ of 1.47)

Because the screening exposure estimates indicated potential risks, risk estimates using more realistic exposure estimates were considered in a second (baseline) tier of evaluation (Step 3 of the ERA process). The baseline estimates used average rather than maximum ingestion rates and minimum body weights but were still conservatively calculated at the maximum point of deposition. NOAEL-based ingestion TRVs were exceeded by the baseline exposure doses for the following:

- Lead for the mourning dove (HQ of 3.96)
- Dioxin/furans for the short-tailed shrew (HQ of 36.2), meadow vole (HQ of 2.05), red fox (HQ of 2.19), and American robin (HQ of 2.42)

LOAEL-based ingestion TRVs were exceeded by the baseline exposure doses for the following:

- Dioxin/furans for the short-tailed shrew (HQ of 3.62)

Because the exposure estimates were based upon the maximum point of deposition (which will encompass a very small area based upon the dispersion modeling), and the few and low magnitude LOAEL-based exceedances, any potential impacts to ecological receptors would be very localized and would unlikely adversely impact species populations.

5.1.3 Aquatic Habitats (Surface Water and Sediment)

As discussed in Section 4.1.7.4, potential ecological risks were evaluated for three water bodies located near the Open Burning Ground. Because the deposition model considers surface runoff within the watershed when deriving the estimates of chemical concentrations in surface water and sediment, the concentrations in these two media were calculated using the most conservative (1 cm) soil mixing depth (but see Attachment 3 and Section 6).

5.1.3.1 Propellant Burn

New River. The comparison of chemical concentrations in New River surface water with TRVs is presented in Table 5-8. There were no exceedances of surface water TRVs.

The comparison of chemical concentrations in New River sediment with TRVs is presented in Table 5-9. There were no exceedances of sediment TRVs.

Screening exposure dose estimates for each wetland/aquatic upper trophic level receptor species are compared to ingestion TRVs in Table 5-10. There were no exceedances based upon the screening estimates.

Wetland. The comparison of chemical concentrations in wetland surface water with TRVs is presented in Table 5-8. Low-magnitude exceedances of surface water TRVs were observed for total (HQ of 1.88) and dissolved (HQ of 2.36) lead.

The comparison of chemical concentrations in wetland sediment with TRVs is presented in Table 5-9. There were no exceedances of sediment TRVs.

Screening exposure dose estimates for each wetland/aquatic upper trophic level receptor species are compared to ingestion TRVs in Table 5-11. There were no exceedances based upon the screening estimates.

Pond. The comparison of chemical concentrations in pond surface water with TRVs is presented in Table 5-8. There were no exceedances of surface water TRVs.

The comparison of chemical concentrations in pond sediment with TRVs is presented in Table 5-9. There were no exceedances of sediment TRVs.

Screening exposure dose estimates for each wetland/aquatic upper trophic level receptor species are compared to ingestion TRVs in Table 5-12. There were no exceedances based upon the screening estimates.

5.1.3.2 Skid Burn

New River. The comparison of chemical concentrations in New River surface water with TRVs is presented in Table 5-13. There were no exceedances of surface water TRVs.

The comparison of chemical concentrations in New River sediment with TRVs is presented in Table 5-14. There were no exceedances of sediment TRVs.

Screening exposure dose estimates for each wetland/aquatic upper trophic level receptor species are compared to ingestion TRVs in Table 5-15. There were no exceedances based upon the screening estimates.

Wetland. The comparison of chemical concentrations in New River surface water with TRVs is presented in Table 5-13. There were no exceedances of surface water TRVs.

The comparison of chemical concentrations in New River sediment with TRVs is presented in Table 5-14. There were no exceedances of sediment TRVs.

Screening exposure dose estimates for each wetland/aquatic upper trophic level receptor species are compared to ingestion TRVs in Table 5-16. There were no exceedances based upon the screening estimates.

Pond. The comparison of chemical concentrations in New River surface water with TRVs is presented in Table 5-13. There were no exceedances of surface water TRVs.

The comparison of chemical concentrations in New River sediment with TRVs is presented in Table 5-14. There were no exceedances of sediment TRVs.

Screening exposure dose estimates for each wetland/aquatic upper trophic level receptor species are compared to ingestion TRVs in Table 5-17. There were no exceedances based upon the screening estimates.

5.2 Risk Evaluation

5.2.1 Terrestrial Habitats

There were no exceedances of inhalation-based TRVs from exposure to facility-related chemicals in ground-level air for both the propellant burn and skid burn scenarios. There

were also no exceedances of soil TRVs or ingestion TRVs even using the most conservative exposure assumptions (e.g., 1-cm soil mixing depth, maximum point of deposition, and screening inputs) for the propellant burn scenario.

Using the most conservative exposure assumptions (e.g., 1-cm soil mixing depth, maximum point of deposition, and screening inputs), exceedances were observed for plants (lead; HQ of 1.33), soil fauna (chromium; HQ of 1.81), short-tailed shrew (lead, mercury, and dioxin/furans), American robin (lead, mercury, and dioxin/furans), mourning dove (lead), meadow vole (dioxin/furans), and the red fox (dioxin/furans) for the skid burn scenario. Using baseline exposure estimates for the upper trophic level receptors, the only LOAEL-based exceedance (at the maximum point of deposition) was for dioxin/furans (short-tailed shrew; HQ of 3.62). Because the exposure estimates were based upon the maximum point of deposition (which will encompass a very small area based upon the dispersion modeling), and the few and low magnitude LOAEL-based exceedances, any potential impacts to ecological receptors would be very localized and would unlikely adversely impact species populations.

A soil mixing depth of 1 cm was used in the ERA to derive the risk estimates. Although deposition will occur only on the soil surface, natural mechanisms (such as the activity of plant roots and soil fauna) will result in mixing to depths deeper than 1 cm over the period of time evaluated by the model (40 years). In typical surface soils, the biologically active upper layer is likely to be in the top 4 to 8 inches (10 to 20 cm), according to ORNL ERA guidance (Suter 1995; Suter et al. 1995). Most species of earthworms will burrow in the top 4-6 inches, but some species (anecic-type earthworms) have burrows that may penetrate as deep as 2.5 m (10 feet) under some conditions (Edwards and Bohlen 1996; Edwards 1998; Lee 1985). The bulk of the plant root biomass for both woody and herbaceous plant species in temperate regions is located within the top 12 to 16 inches (30 to 40 cm) of the soil column, with the highest root densities in the upper 8 inches (20 cm), as based upon available data for individual plant species (e.g., Burns and Honkala 1990; Bell 1992).

Based upon these data, a soil mixing depth of 6 inches (15 cm) is a more reasonable estimate of the depth of bioturbation over the 40-year life of the facility. As such, risk estimates based upon a soil mixing depth of 15 cm are also included as Attachment 3 for the chemicals and receptors for which HQs exceeded one based upon a mixing depth of 1 cm.

Using a 15-cm mixing depth, there are no exceedances of plant or soil fauna TRVs for the skid burn scenario (Attachment 3, Table 1). Ingestion-based TRVs are exceeded for the mourning dove (lead), short-tailed shrew (dioxin/furans), and meadow vole (dioxin/furans) using screening exposure estimates and NOAELs (Attachment 3, Table 2). Using baseline exposure estimates, there are low magnitude exceedances of NOAELs for dioxin/furans and the short-tailed shrew (HQ of 2.54) and meadow vole (HQ of 1.54) (Attachment 3, Table 3). There are no exceedances based upon LOAELs.

5.2.2 Wetland and Aquatic Habitats

The evaluation of the New River, wetland, and pond indicated negligible risks to aquatic receptors for the skid burn scenario. For the propellant burn scenario, low magnitude exceedances of surface water TRVs were observed in the wetland for total (HQ of 1.88) and dissolved (HQ of 2.36) lead for the most conservative scenario modeled (e.g., 1-cm soil mixing depth). Based upon a more realistic soil mixing depth of 15 cm (see Section 5.2.1), there are no exceedances of surface water TRVs (Attachment 3, Table 4).

There were no exceedances of sediment-based TRVs using the most conservative exposure assumptions for all three water bodies and both burn scenarios. There were also no exceedances of ingestion-based TRVs based upon the screening exposure dose estimates for each wetland/aquatic upper trophic level receptor species using the most conservative exposure assumptions for all three water bodies and both burn scenarios.

5.3 Cumulative Risk Assessment

At the request of VDEQ, a cumulative risk assessment that combines the results of the RAAP incinerator SLERA with the results of this SLERA for the Open Burning Ground is included. The results are summarized in Tables 5-18 (aquatic habitats) and 5-19 (terrestrial habitats). For ease of comparison, the cumulative assessment is based upon the sum of the hazard quotients from each assessment. In general, the incinerator contributions to the total risk are small relative to the Open Burning Ground.

The cumulative assessment should be interpreted with caution because the Total ESQ calculated in the Incinerator SLERA and the Sum of Hazard Quotients (Sum HQ) calculated in this SLERA are not equivalent. The differences include:

- Total ESQs do not include dioxin/furan TEQs, whereas the Sum HQs include TEQs.
- Total ESQs were calculated for maximum impact points in three types of terrestrial habitat. The Sum HQ is based upon a single maximum impact for all terrestrial habitats. The Total ESQ for each terrestrial habitat was added to the Sum HQ.
- Sum HQs were calculated for two separate burn scenarios (skid and propellant). The Total ESQ is for all incinerator emissions. The Total ESQ was added to the Sum HQ for each burn scenario.
- Several dietary compositions were evaluated for each upper-level trophic receptor in the Incinerator SLERA. A single dietary composition per receptor was evaluated in the OBG SLERA. The Sum HQ was added to the Total HQ that was based upon the most closely matched diet.
- Only the New River was evaluated in the Incinerator SLERA. The OBG SLERA evaluated three water bodies, including the New River. Therefore, only River Sum HQs were added to aquatic Total ESQs. Other water bodies evaluated in the OBG SLERA were not included in the cumulative assessment (Note: water and sediment ESQs are presented for both terrestrial and aquatic habitats, but the derivation of these values is not clear, and were therefore not used in the cumulative assessment).
- In the freshwater habitats, several surface water Total ESQ values are presented. The maximum (herbivorous fish) of the fish or water column invertebrate Total ESQs was added to the surface water Sum HQ for the cumulative assessment.
- Aquatic wildlife were not evaluated in the Incinerator SLERA. Total ESQs based upon the closest receptor/diet combinations were selected for the cumulative assessment. For the mink and great blue heron, a carnivorous mammal/bird diet based only upon fish was not evaluated in the Incinerator SLERA. Therefore, the total ESQ based upon the carnivorous EQ diet (all possible food items equally represented in the diet) was used.

5.4 Risk Conclusions

Based upon the evaluation contained in this ERA using conservative and more realistic exposure assumptions, risks to ecological receptors inhabiting the habitats surrounding the Open Burning Ground are expected to be minor and spatially limited under both the propellant and skid burn scenarios. In general, the incinerator contributions to cumulative risk estimates are small relative to the Open Burning Ground. Performance standards are developed in Section 7 to address the potential risks identified in this ERA.

6.0 Uncertainties

Uncertainties are present in all risk assessments because of the limitations of the available data and the need to make certain assumptions and extrapolations based on incomplete information. Uncertainties associated with the waste characterization, estimation of emission factors, and air dispersion modeling are presented in the Open Burning Ground HHRA (CH2M HILL 2005). The uncertainty in this ERA is mainly attributable to the following factors:

- **Dispersion Modeling** - While the most applicable dispersion model (OBODM) and best available input data were used in the dispersion modeling, the resulting outputs of relevance to the ERA (e.g., chemical concentrations in air, dispersion factors used in deposition modeling, and the identification of the points of maximum impact) must be considered best estimates.

- **Deposition Modelin**g - Exposure point concentrations in surface soil, surface water, and sediment were estimated using models and parameter values from the literature (primarily USEPA [1999, 1998b]). Although site-specific input parameter values were used in these models when available, the use of default values for many parameters introduces some uncertainty into the deposition estimates. Because most default values are selected to be conservative estimates, this tends to result in overestimating exposure concentrations and thus risks. One example is the default soil mixing depth of 1-cm for untilled soils. Although deposition will occur only on the soil surface, natural mechanisms (such as the activity of plant roots and soil fauna) will result in mixing to much deeper depths than 1-cm over the period of time evaluated by the model (40 years). For this reason, a more realistic soil mixing depth of 15 cm (Attachment 3) was also evaluated when potential risks were identified under the more conservative assumptions.

  For simplicity, the deposition model applied individual point estimates (e.g., the point of maximum deposition) to much larger areas. This results in overestimating deposition (as does the use of a 1-cm soil mixing depth).

  While OBODM is the best available dispersion model for open burning operations, OBODM is not specifically designed to simulate wet and dry deposition of particulate emissions. The deposition component associated with the OBODM media concentration estimates in surface soil, surface water, and sediment was based on deposition equations adapted from USEPA combustion guidance (USEPA 1999; 1998b) to fit the OBODM model output.

- **Food Web Exposure Modeling** - Chemical concentrations in terrestrial and aquatic food items (plants, soil invertebrates, small mammals, benthic invertebrates, and fish) were modeled from modeled media concentrations and were not directly measured. The use of generic, literature-derived exposure models and bioaccumulation factors introduces some uncertainty into the resulting estimates. The values selected and methodology employed were intended to provide a conservative (screening) estimate of potential food web exposure concentrations.

  Another source of uncertainty is the use of default assumptions for exposure parameters such as bioconcentration and bioaccumulation factors (BCFs/BAFs). Although BCFs or BAFs for many bioaccumulative chemicals were readily available from the literature and were used in the ERA, the use of a default factor of 1 to estimate the concentration of some chemicals in receptor prey items is a source of uncertainty.

  Area use factors were assumed to equal one. This is a conservative assumption because a significant percentage of each upper trophic level receptor species' time could be spent foraging in unimpacted areas or areas where chemical concentrations are expected to be significantly lower.

- **Exposure Assumptions** - The use of default exposure assumptions such as chemicals being 100 percent bioavailable and 100 percent absorbed from food overestimates potential exposures.

- **Chemicals Without Medium-Specific TRVs** - A number of chemicals lacked medium-specific TRVs, particularly for air and to a lesser extent soil. This introduces some uncertainty to the assessment because these chemicals could not be quantitatively evaluated for all potentially significant exposure pathways. It should be noted, however, that the lack of a TRV for a particular chemical in a particular medium does not necessarily mean that an unacceptable risk exists, just that a quantitative evaluation could not be accomplished. When possible, data for similar chemicals were used to qualitatively evaluate potential risks associated with these chemicals.

- **Ingestion Screening Values** - Data on the toxicity of many chemicals to the receptor species were sparse or lacking, requiring the extrapolation of data from other wildlife species or from laboratory studies with non-wildlife species. This is a typical limitation and extrapolation for ecological risk assessments because so few wildlife species have been tested directly for most chemicals. The uncertainties associated with toxicity extrapolation were minimized through the selection of the most appropriate test species for which suitable toxicity data were available. The factors considered in selecting a test species to represent a receptor species included taxonomic relatedness, trophic level, foraging method, and similarity of diet.

  A second source of uncertainty relates to the derivation of ingestion screening values for metals. Most of the toxicological studies on which the ingestion screening values for metals were based used forms of the metal (such as salts) that have high water solubility and high bioavailability to receptors. Because the analytical samples on which site-specific exposure estimates were based measured total metal, regardless of form, and these highly bioavailable forms are expected to compose only a fraction of the total metal concentration, this is likely to result in an overestimation of potential risks for these chemicals.

A third source of uncertainty associated with the derivation of ingestion screening values concerns the use of uncertainty factors. For example, NOAELs were extrapolated to LOAELs using an uncertainty factor of ten. This approach is likely to be conservative because Dourson and Stara (1983) determined that 96 percent of the chemicals included in a data review had LOAEL to NOAEL ratios of five or less. The use of an uncertainty factor of 10, although potentially conservative, also serves to counter some of the uncertainty associated with interspecies extrapolations, for which a specific uncertainty factor was not used.

- **Chemical Mixtures** - Information on the ecotoxicological effects of chemical interactions is lacking for most chemicals, which generally required (as is standard for ecological risk assessments) that the chemicals be evaluated on a compound-by-compound basis during the comparison to TRVs. This approach could result in an underestimation of risk (if there are additive or synergistic effects among chemicals) or an overestimation of risks (if there are antagonistic effects among chemicals). Although the use of HIs is one possible way to account for potential additive effects, it does not account for antagonistic effects. Similarly, HIs are only appropriate for chemicals with the same mode of action. With the exception of PAHs and dioxins/furans, there are no obvious chemical groupings with similar modes of action among those evaluated. Individual dioxin and furan congeners were evaluated as a group using the toxicity equivalency approach due to the general lack of toxicological data for most congeners other than 2,3,7,8-TCDD.

- **Receptor Species Selection** - Reptiles and amphibians were selected as receptors in the ERA but were not evaluated quantitatively. Reptiles and amphibians were evaluated using other fauna as surrogates due to the general lack of taxon-specific toxicological data. This represents an uncertainty in the risk assessment.

  It was also assumed that any reptiles and amphibians present in the assessment area were not exposed to significantly higher concentrations of COPCs and were not more sensitive to COPCs than other receptor species evaluated in the ERA. This assumption was a source of uncertainty. In addition, there is some uncertainty associated with the use of specific receptor species to represent larger groups of organisms (e.g., guilds).

7.0 Evaluation of Burning Limits

The results of the SLERA have been used to evaluate possible burning limits that would achieve health risks corresponding to the risk management threshold of an Ecological Hazard Quotient of 1.0 (USEPA, 2002a). Risks were higher than the risk management threshold are shown in Table 7-1.

Performance standards for burning wastes at the Open Burning Grounds have been proposed, based on the estimated risks for these emissions constituents. Ratios of the estimated risks to the risk management threshold were calculated and applied to the waste quantities assessed in the SLERA to develop the performance standards. In certain cases, these ratios were applied to the waste constituents that would be analyzed in the waste streams.

In certain cases, the performance standard is a limitation on waste feed constituents. The rationale for the waste feed constituents is discussed below in this section.

These proposed performance standards are presented in Table 7-2, and are discussed below in further detail.

Propellant burn scenario:

- Performance standard for all terrestrial receptors is the limit originally assessed in the SLERA, 8,000 lbs/day, 365 days/year, for all waste streams burned at the Open Burning Ground.
- Performance standard for aquatic receptors (in surface water) is 3,400 lbs/day, 365 days/year only for wastes from Waste Groups 7 and 12 that contain greater than 870 mg/kg. The lead concentration assessed in the SLERA was 2,060 mg/kg (corresponding to an emission factor of 0.00206 g/g – see Table 2-1). That lead concentration corresponded to a EHQ of 2.36 for aquatic organisms in surface water. A lead concentration of 870 mg/kg in the waste would correspondingly achieve an EHQ of 1.

Skid burn scenario:

- The performance standards for terrestrial fauna is 1,100 lbs/day, 365 days/year, for waste streams treated by skid burns that contain greater than 7 mg/kg chromium. For waste streams with less than 7 mg/kg chromium, the skid burn limit is 2,000 lbs/day, 365 days/year, the burn rate assessed in the SLERA.
- The performance standards for terrestrial foodweb receptors is a waste feed limit of 1% total chlorine. As shown in the SLERA, the estimated risks are driven by emissions of dioxins/furans. The rationale for the 1% total chlorine limit is described in Section 9.1. Waste stream testing data collected by Radford indicates that these waste groups, which contain chlorides or perchlorate salts, are likely to have elevated chlorine contents, which could serve as a precursor to dioxin/furan formation, when burned. The performance standard for lots of waste with less than 1% total chlorine) is 2,000 lbs/year, 365 days/year.
- The performance standard for terrestrial foodweb receptors is 500 lbs/day, 365 days/year for lots of waste with >520 mg/kg lead. For waste streams with less than 520 mg/kg lead, the skid burn limit is 2,000 lbs/day, 365 days/year, the burn rate assessed in the SLERA.

7.1 Total Chlorine Waste Feed Performance Standard

As described in the HHRA (Section 9.1), dioxin/furan emissions from open burning of propellants at the Radford Army Ammunition Plant Open Burning Ground represent a significant contribution to total hypothetical health and screening ecological risks. Dioxins and furans represent combustion byproducts, and therefore are not constituents that can be tested in waste streams to determine their potential for dioxin/furan emissions. There are several organic precursors to dioxin/furan formation, however, all of these require the presence of total chlorine. Therefore, total chlorine can be a reasonable indicator of the potential for a waste stream to produce dioxins and furans when combusted.

Bench-scale studies of incineration have indicated a relationship between dioxin/furan formation and the level of chlorine in the waste feed (USEPA, 2003, page 2-22 http://www.epa.gov/ncea/pdfs/dioxin/nas-

review/pdfs/part1_vol1/dioxin_pt1_vol1_ch02_dec2003.pdf). In a Swedish study using municipal waste streams with chlorine contents ranging from 0.5 to 1.7 percent, the highest emissions of dioxins/furans were formed at the highest chlorine content; no correlation between chlorine content and dioxin/furan emissions was found with chlorine contents below 0.5 percent. It was concluded from these results that Swedish municipal solid wastes were below a threshold value of 1.0 percent chlorine associated with a general increase in dioxin and furan formation in the post-combustion region (USEPA, 2003, page 2-23). For commercial-scale incinerators, chlorine content is not always a reliable predictor of dioxin/furan emissions. However, USEPA concludes that "[f]or uncontrolled combustion, such as open burning of household waste, chlorine content of wastes may play a more significant role in affecting levels of CDD/CDF emissions than observed in commercial scale combustors." (USEPA, 2003, page 2-32).

One source of emission factors has been testing from the "BangBox" (Mitchell and Suggs, 1998). One of the few waste streams associated with significant dioxin/furan emissions in the BangBox testing was a synthetic manufacturer's waste from aluminized ammonium perchlorate production. The composition of this waste stream is described as follows by Mitchell and Suggs, 1998 (page 40):

This surrogate waste was supposed to simulate the mix of AP-contaminated plastic gloves, cotton rags, Kimwipes, wood towel rods and similar materials that result from the clean-up of the vessels used to manufacture AP-based propellants. These materials are usually disposed of by open burning in pans or by incineration. The original plan was to bring an actual AP-based manufacturing waste to DPG (note: Dugway Proving Ground) for the experiment, however, this was prohibited because DPG did not have a permit for destroying this type of waste. In hindsight, the surrogate waste burned was not truly representative of a real manufacturing waste. The chemical composition was appropriate, i.e., 65% aluminized AP (69% AP, 19% aluminum), 20% plastic material (polyethylene gloves), 11% paper/wood/cloth and 4% diesel fuel; the problem lies with the manner in which the propellant was placed in contact with the combustible materials. That is, 1-in. cubes randomly dispersed on top of the combustible materials. In an actual waste, the propellant would be dispersed on the combustible materials as a fine powder. . . .

These results are consistent with a combination deflagration (AP) and incineration type burn (melting of polyvinyl gloves and charring of the wood dowel sticks by the heat released from the deflagration). This environment would have provided the conditions which favor the formation of SVOCs and dioxins and furans. These conditions are : low temperature (250-400 C), long residence time (seconds), presence of Cl and organic materials and a metal that could serve as a catalyst.

The emission factors from this waste stream were used to estimate dioxin/furan emissions and risks for the Radford skid burn scenario. The Radford skid burn actually consists of wet nitrocellulose with bits of tramp metal and debris (which would damage the grinder in the incinerator, requiring the waste to be open burned), with dunnage (wood pallets and cardboard) and diesel as donor fuels. Note that the chloride content of the waste stream in the BangBox was approximately 18%:

- Aluminized ammonium perchlorate = 28% chloride (chloride = 35.5 g/mole; Al-AP = 126.5 g/mole; 35.5/126.5 = 0.28)
- Al-AP is 65% in the waste stream, 0.28 x 0.65 = 0.18, or 18%

This provides an indication of the significance of that waste stream as a chlorine source. Use of the Al-AP waste for dioxin/furan emission factors considerably overstates the potential for dioxin/furan emissions from the skid burn, and at the same time reinforces the role of chlorine as a precursor for dioxin/furan formations.

Conclusions:

1. Chlorine content in the waste stream is a suitable indicator for evaluating waste streams for potential to emit dioxin/furans when burned; total chlorine content can also be feasibly tested.
2. A total chlorine content of 1% (10,000 ppm) represents a threshold level for minimizing dioxin/furan emissions during combustion, based on the available literature.
3. The waste stream used to provide dioxin/furan emissions estimates for the skid burn at the Radford Open Burning Ground, not only provided a conservative estimate of dioxin/furan emissions and risks, but represented a significant source of chlorine during combustion (18%). This waste stream is not representative of what Radford burns during skid burns.

7.2 Proposed Mitigated Skid Burn Pan

Current methods for disposing of propellant manufacturing wastes and dunnage involve open burning using diesel fuel as a donor fuel with an initiator such as black powder. This method is characterized by a large but short duration, high temperature 'flare-up' of the powder and diesel fuel followed by a lengthy, low temperature burning of the wastes. These wastes are frequently wetted with water for increased safety during handling and the water tends to prevent rapid, high temperature combustion during disposal. The majority of the diesel fuel and black powder are burned during the short duration 'flare-up' while the ignited propellant wastes and dunnage slowly burn and simultaneously volatize the water used for stabilization of these wastes. The low temperature combustion following the consumption of the diesel fuel provides conditions conducive to the formation of dioxins and furans as products of incomplete combustion.

An alternative approach is to use a continuous supply of propane or natural gas as the donor fuel and a remotely actuated spark ignitor as the ignition source. With this approach, the donor fuel is delivered and combusted as needed and higher combustion temperatures are maintained throughout the burn. The physical structure of this approach uses a gas burner system and combustion air introduction system below the wastes with a piezeoelectric ignition system (similar to those found in modern 'pilotless' furnaces and stoves). A schematic is presented in the attached figure. Perforated metal trays or metal pallets replace the wooden pallets currently used to hold the wastes. The burners and metal pallets are restrained by high temperature cabling to prevent creation of projectiles in the event that a detonation or deflagration occurs. The net result of this approach will be more complete combustion with reduced potential for the formation of combustion products such as dioxins and furans, reduced opacity, and shorter duration burns. The use of the diesel fuel and black powder would be eliminated and replaced with the use of propane or natural gas. Clean wooden pallets would no longer be burned as dunnage with this approach. An example of this type of burn pan is depicted in the HHRA, Figure 9-1.

For purposes of evaluating performance standards associated with the mitigated skid burn scenario, the following assumptions regard emissions were made:

- PAHs were assumed to not be emitted, since diesel and dunnage would not be used with this skid burn design (as described previously in Section 2, PAH emissions were assumed to be associated with combustion of wood used for dunnage).
- Dioxin and furans emissions were assumed to be lower, because of more favorable combustion conditions. For purposes of evaluating potential performance standards, dioxin emissions were assumed to be similar to those that would be achieved during a propellant burn.

The performance standards proposed for a mitigated skid burn scenario are shown in Table 7-2.

8.0 References

Agency for Toxic Substances and Disease Registry (ATSDR). 1989. *Toxicological profile for 1,2-dichloropropane.*

Agency for Toxic Substances and Disease Registry (ATSDR). 1990b. *Toxicological profile for 1,1-dichloroethane.*

Agency for Toxic Substances and Disease Registry (ATSDR). 1990c. *Toxicological profile for chlorobenzene.*

Agency for Toxic Substances and Disease Registry (ATSDR). 1990d. *Toxicological profile for nitrobenzene.*

Agency for Toxic Substances and Disease Registry (ATSDR). 1992a. *Toxicological profile for antimony.*

Agency for Toxic Substances and Disease Registry (ATSDR). 1992b. *Toxicological profile for barium.*

Agency for Toxic Substances and Disease Registry (ATSDR). 1992c. *Toxicological profile for 1,3-butadiene.*

Agency for Toxic Substances and Disease Registry (ATSDR). 1992d. *Toxicological profile for 4-nitrophenol.*

Agency for Toxic Substances and Disease Registry (ATSDR). 1992e. *Toxicological profile for bromomethane.*

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Tables

Figures

Attachment 1
Deposition Modeling

Attachment 2
Example Calculations

Attachment 3
15-cm Soil Depth Modeling Results