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U.S. ARMY CHEMICAL AND BIOLOGICAL DEFENSE COMMAND

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**PREDICTIVE ECOLOGICAL RISK ASSESSMENT
OF BRASS INFRARED WAVELENGTH OBSCURANT
IN A TERRESTRIAL ENVIRONMENT**

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RESEARCH AND TECHNOLOGY DIRECTORATE

March 1998

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13. ABSTRACT (Maximum 200 words) The purpose of this report is to assess and predict the potential for ecological risk due to the use of brass infrared (IR) wavelength obscurant in the field. Although not an ERA tutorial, explanatory information is included to explain concepts involved in predictive ERA. The USEPA ERA guidelines have been applied. This study is a tier-1, screening level, ERA; it uses available environmental toxicity data, material fate and effects data, appropriate environmental fate modeling data, and proposed field scenarios to predict the possibility of impact to the environment under study. These field use scenarios for brass flake obscurant materials are evaluated to predict the environmental impact on terrestrial ecosystems. Ecotoxicological information on brass, existing data gaps, and field scenarios are presented in a fair manner to best assess the potential for ecological risk and help program/risk managers make educated decisions regarding brass usage. This report addresses neither materials other than brass nor the smoke testing and training program in general. A comparable report has been published on the predictive ecological risk assessment for the usage of graphite flake obscurant materials in the terrestrial environment.

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EXECUTIVE SUMMARY

The U.S. Army is currently developing military hardware and methodology to disseminate obscurants that attenuate light in the infrared (IR) wavelengths. Although obscurant testing has been ongoing for several years, more routine and widespread testing for training purposes may occur after the type classification of several currently experimental models. In an effort to predict the potential ecological impact of this testing, and hence reduce costly cleanup later, the Joint Projects Office has sponsored this work to develop methodologies for conducting predictive Ecological Risk Assessments (ERA) for developmental smoke materials. This process follows guidelines recommended by the U.S. Environmental Protection Agency (EPA) for conducting an ERA. ERAs are most often applied to clean-up sites and Base Realignment and Closure (BRAC) procedures but will be adapted here to predict and possibly prevent adverse environmental impact from military obscurant testing.

This ERA is intended to be a screening level or tier-1 assessment. Its purpose is to investigate the body of literature and data available, assess potential impact based on current information, identify data deficiencies, and recommend additional investigations required in making a scientifically sound predictive assessment. This document assumes little or no experience in Ecological Risk Assessment, the format introduces the reader to aspects of how an ERA is intended to function. Therefore this document may contain more explanatory narration than in ERAs written for an experienced audience.

There is presently an adequate amount of data available on the environmental toxicity of brass obscurant materials and its components. Although some studies have been done by non-military organizations, the bulk of the data available has been generated by the US Army and its contractors. Model data is presented on brass concentration and deposition rates from detonation of M76 brass-filled grenades. Several studies are reviewed that assess the toxicity of brass to plants, soil invertebrates, soil biota and laboratory rats. In general these studies indicate that there is a potential for adverse impact to a terrestrial environment under the conditions described, (i.e., the detonation of a single salvo of M76 grenades). The Risk Characterization section of this document quantifies the anticipated risk testing or training with brass material may have on the terrestrial environment and makes recommendations for citing testing or training exercises where brass material will be released and makes recommendations for conducting repetitive testing or training at any single site.

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PREFACE

The work described in this report was authorized under Ex. Order No. 5601553501. This work was started in October 1994 and completed in December 1995.

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PREDICTIVE ECOLOGICAL RISK ASSESSMENT OF BRASS INFRARED WAVELENGTH OBSCURANT IN A TERRESTRIAL ENVIRONMENT

1 INTRODUCTION

For many years, the U.S. Army Edgewood Research, Development and Engineering Center (ERDEC)[(formerly U.S. Army Chemical Research, Development and Engineering Center (CRDEC)] and other locations has been developing field systems to disseminate various specialty obscurant materials¹. Historically, smokes were aimed at attenuating light in the visible wavelength to protect troop and military vehicles from visually-sited weapons. Traditionally, these smokes included phosphorus-based materials, hexachloroethane (HC), and most recently fog oil (FO). With a conscious effort to lessen the impact on human and environmental health effects, fog oil has become the most widely accepted visual screening material at training and development sites.

The advent of more advanced weapons systems containing sophisticated target acquisition and guidance systems spurred the development of smokes that attenuate light in the infrared (IR) and millimeter wavelengths (MMW). The most popular IR smokes are solid materials of brass or graphite flakes. Most MMW smoke systems are still in development and are not considered in this document.

Because personnel training and hardware development often involves environmental release of these smokes/obscurants, it is important to understand the impact these materials may have from a human and environmental health standpoint. Because policy makers and environmental regulators are tightening restrictions on any activities that may adversely affect the environment, an Ecological Risk Assessment (ERA) will help identify any potential problems associated with the activity. Used in this manner, an ERA is a process that evaluates the likelihood that an activity resulting in release or creation of an environmental stressor will result in adverse effects. A risk does not exist unless (1) the stressor has the inherent ability to cause one or more adverse effects, and (2) it co-occurs with or contacts an ecological component (i.e., organism, populations, communities, or ecosystems) long enough and at sufficient intensity to cause an identified adverse effect. An ERA may evaluate the effect of one or more stressors and one or more ecological components. For this ERA a single stressor, "Brass" will be evaluated against several ecological components characteristic of a terrestrial environment. A description of ecological components and approaches used in conducting this assessment will be discussed in the introduction and problem formulation sections.

1.1 Intended Audience.

The use of ERAs is a relatively new practice in the arena of environmental resource or risk management. The majority of ERAs are used by risk managers who are in the process of reviewing damage to the environment caused by some previous activity for the purposes of assessing the amount of remedial actions that are required. This information may also be used as environmental documentation by program managers at testing and training sites, or by a risk manager to have the site placed on a priority list for special cleanup funding, such as a U.S. Environmental Protection Agency (USEPA) National Priorities List (NPL) Superfund site. Program managers in Base Realignment and Closure (BRAC), and risk managers from regulating agencies, USEPA, state EPA and other local regulatory agencies, are familiar with ERAs. This ERA was funded by the Joint Project Office (JPO) and written for program managers who maybe less familiar with an ERA; therefore ample narrative will be contained throughout the document. It is also intended as a predictive assessment. A predictive assessment is designed to help research, development, and environmental program managers make decisions about exercise siting, type, or magnitude. These decisions may prevent inappropriate testing that otherwise may necessitate a costly cleanup or remedial action in the future. The use of predictive ERAs will hopefully prevent the types of environmental contamination that have historically occurred due to a lack of knowledge or regard for the environmental consequences that activities may cause.

An ERA can help identify environmental problems, establish priorities, and provide a scientific basis for regulatory actions. The process can identify existing risks or forecast the potential risk of stressors not yet present in the environment. An ERA can also help program or risk managers decide whether or not the anticipated test or training site is appropriate for the activity. The purpose of this assessment is to predict the likelihood of adverse effects from the dissemination of brass flake obscurants. Ecological risk may be expressed in a variety of ways. Whereas some ecological risk assessments may provide true probabilistic estimates of adverse effects and exposure elements, others may be deterministic or even qualitative in nature. In these cases, the likelihood of adverse effects is expressed through a semiquantitative or qualitative comparison of effects and exposure.

The USEPA has established brief guidelines on methodology for conducting an ERA. The USEPA framework document provides a concise format for an ERA and is used to conduct this ERA, Figure 1². The risk assessment process is based on three major elements: Problem Formulation, Analysis and Risk Characterization. Although characterization of exposure and characterization of ecological effects are most prominent during the Analysis phase, aspects of exposure and effects are considered during Problem Formulation, as illustrated by the arrows in the diagram. The arrows also flow to Risk Characterization, where the exposure and effects elements are integrated to estimate risk.

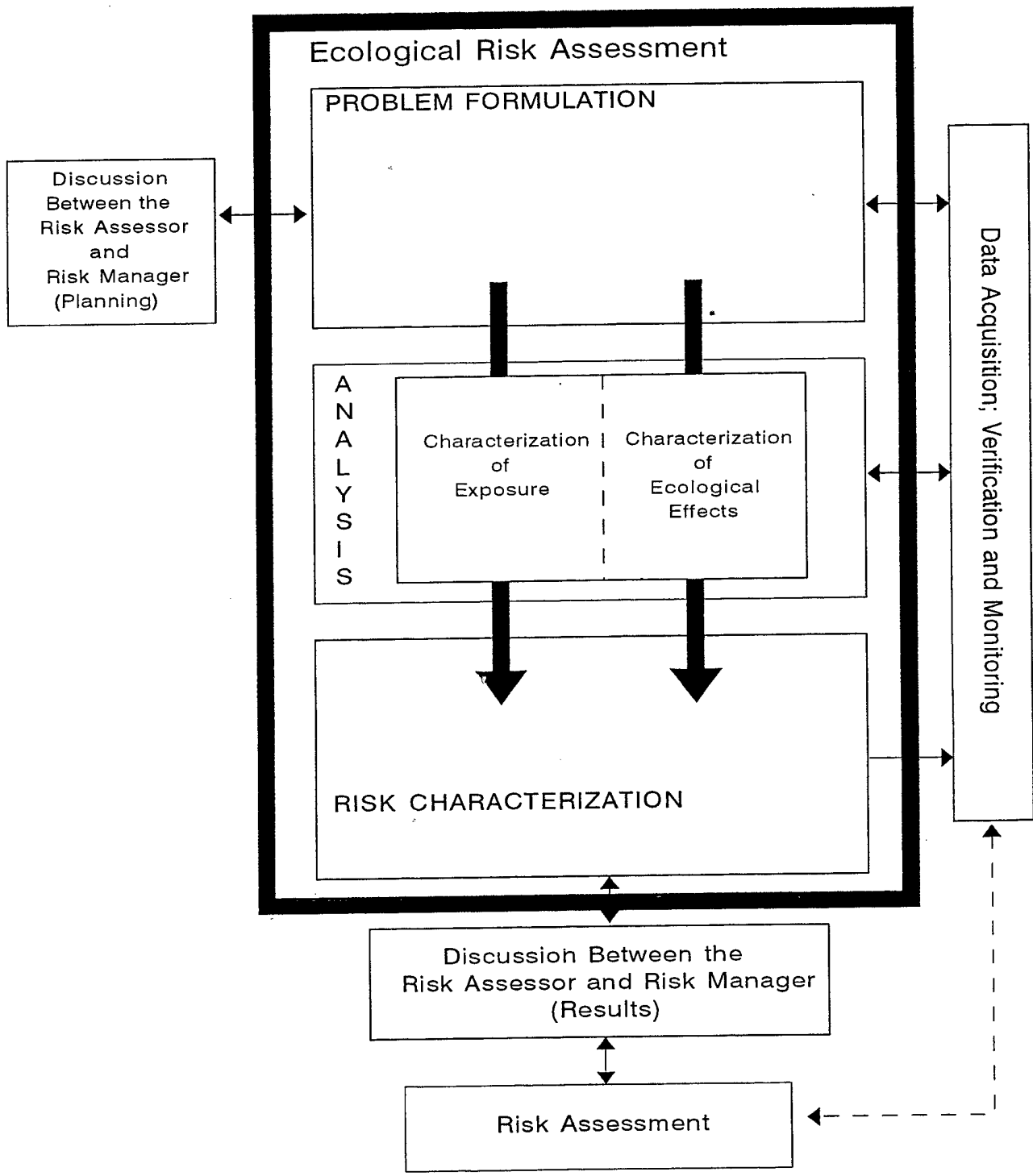


Figure 1. Representation of the Components of an Ecological Risk Assessment as Recommended in the USEPA's Framework for Ecological Risk Assessment Document, February 1992

Problem Formulation, figure 2, includes a preliminary characterization of exposure and effects, as well as examination of scientific data and data needs, policy and regulatory issues, and site-specific factors to define the feasibility, scope, and objectives for the ERA. The level of detail and the information needed to complete the assessment are also determined. Problem Formulation provides an early identification of key factors to be considered, which in turn will produce a more scientifically sound risk assessment.

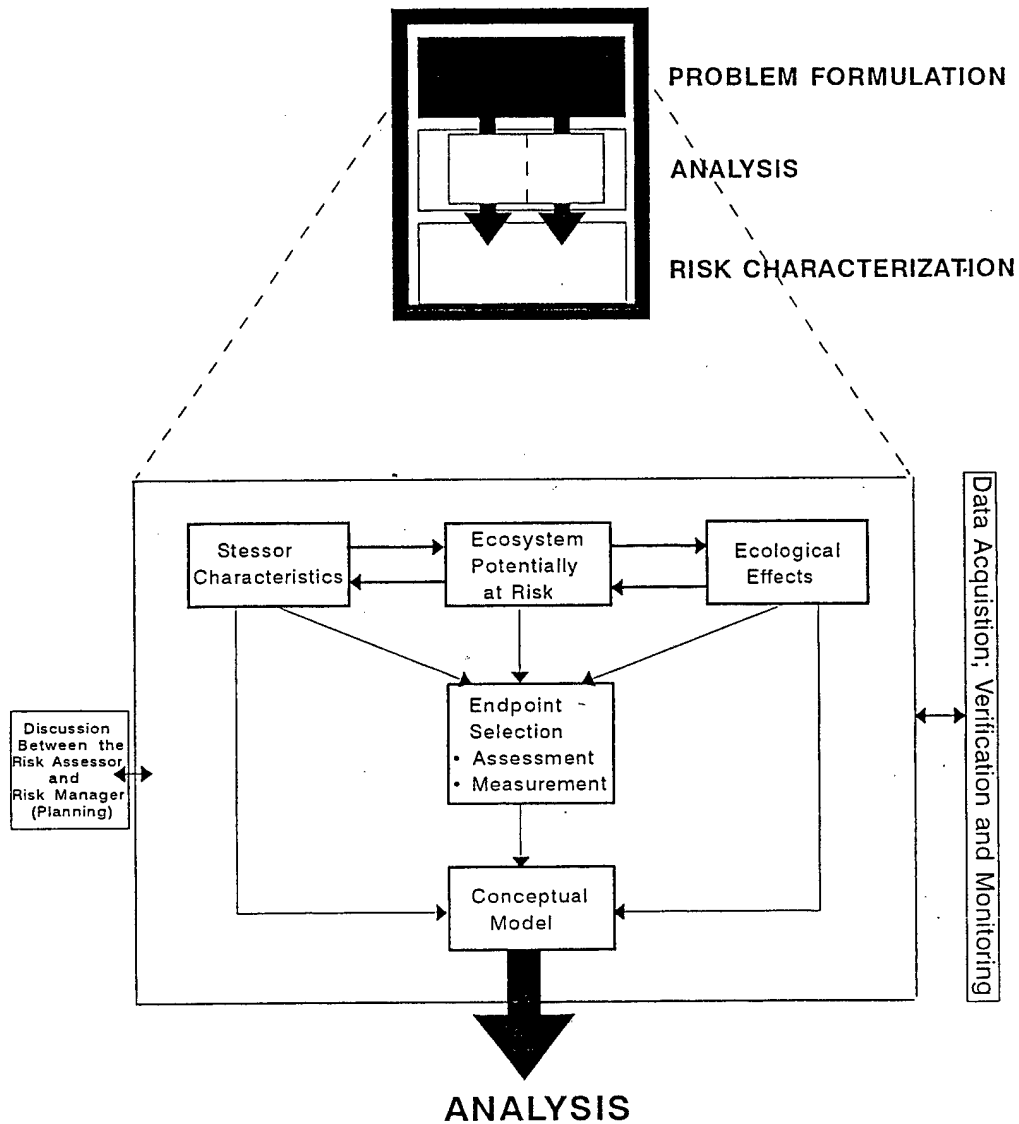


Figure 2 A Representation of the Components of the "Problem Formulation" Phase of an ERA recommended by the USEPA's Framework for Ecological Risk Assessment Document, 1992

The Analysis phase, figure3, of the ERA consists of characterization of exposure and ecological effects. The purpose of characterization of exposure is to predict or measure the spatial and temporal distribution of a stressor and its co-occurrence or contact with the ecological components of concern. The purpose of the characterization of ecological effects is to identify and quantify the adverse effects elicited by a stressor and, to the extent possible, to evaluate cause-and-effect relationships.

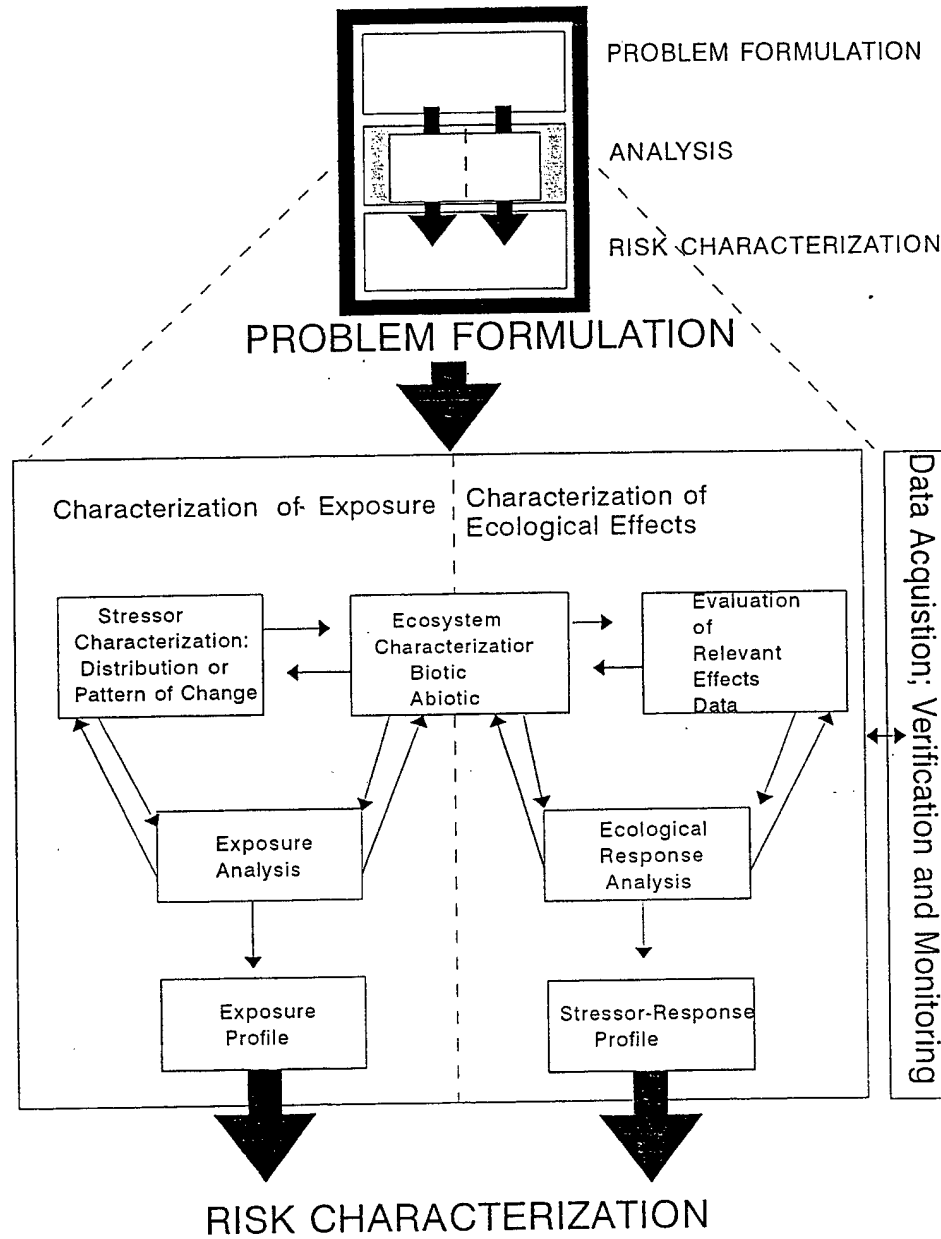


Figure 3. A Representation of the "Analysis" Phase of an ERA Recommended by USEPA's Framework for Ecological Risk Assessment Document, 1992

Risk Characterization, figure 4, uses the results of the exposure and ecological effects analysis to evaluate the likelihood of adverse ecological effects associated with exposure to a stressor. It includes a summary of the assumptions used, the scientific uncertainties, and the strengths and weaknesses of the analysis.

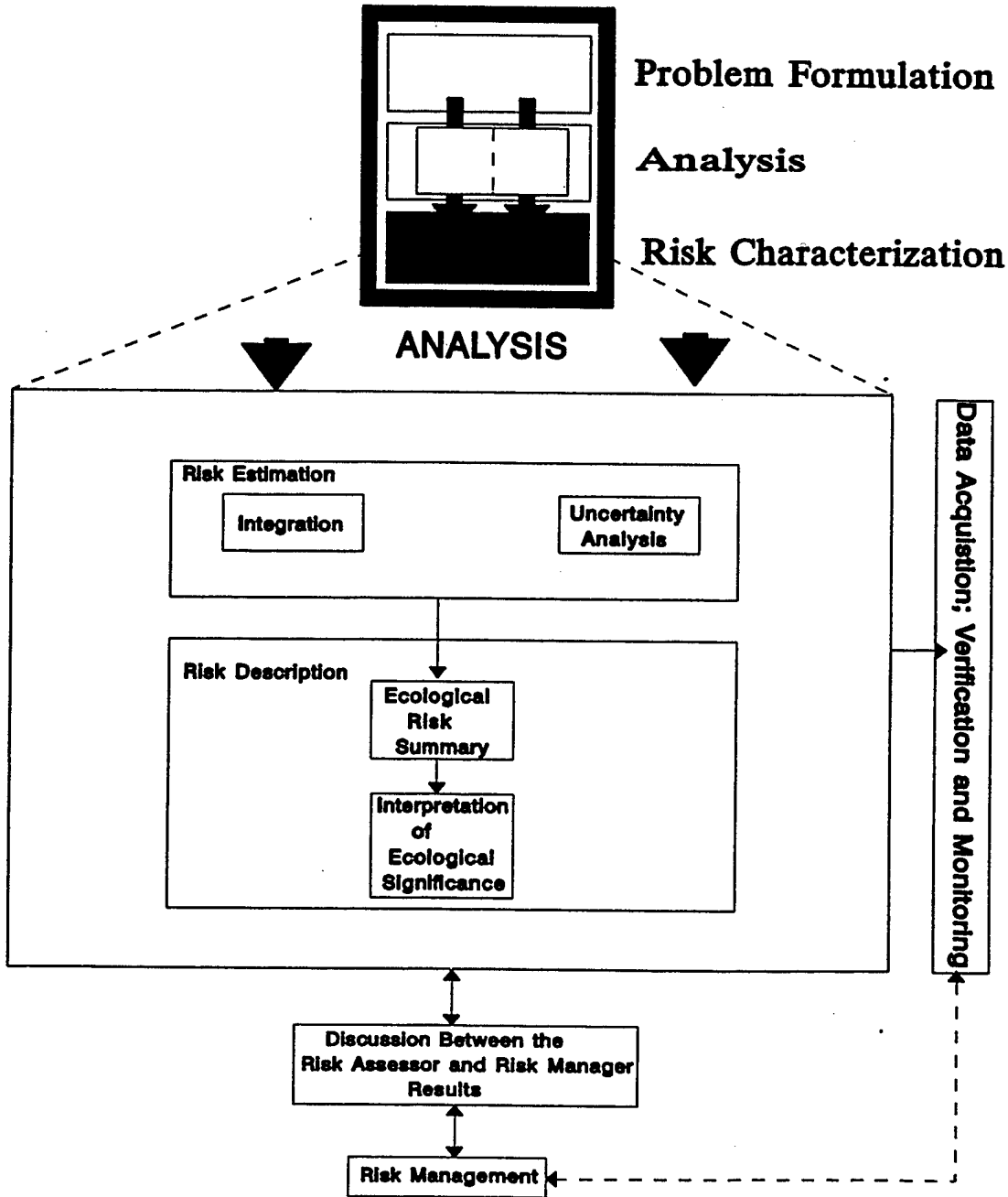


Figure 4. Representation of the "Risk Characterization" Phase of an ERA Recommended by the USEPA's Framework for Ecological Risk Assessment Document, 1992

1.2 Approach.

This Predictive ERA will address the effect testing and training with brass IR smoke may have on a terrestrial environment. This assessment is constructed as a screening level assessment or Tier I of a tiered assessment approach. Site specific conditions, stressors involved, and the ecosystem potentially at risk determines the approach used in conducting an ERA. The intent of a tiered approach is to first investigate the nature and extent of effect a stressor may have had or the effect an anticipated stressor may have on the environment. The first tier assessment may uncover potential problems that may indicate the need for a more in-depth and costly assessment. In the event that a more in-depth ERA is required, the Tier 1 assessment will have already identified problem areas such as data gaps, required literature, potential site surveys, and environmental law and regulations that must be addressed. However, a Tier 1 ERA may indicate that there is little or no anticipated adverse environment effects from the previous or planned activity. If there is sufficient documentation to make a scientifically sound risk characterization and risk management decision, no further work may be required.

This Tier 1 assessment will address the potential impact that dissemination of a brass IR obscurant material may have on a terrestrial environment. In the Problem Formulation phase, we will address the proposed activity, dissemination of IR material, and the ecological components that may be impacted by this activity. The ecological components used in this assessment and their role and importance in the environment, as well as the IR material and the nature of its source as a possible environmental stressor and its application, will be described. This section will also include a review of environmental laws and regulations that may pertain to the activity of releasing graphite aerosols into the environment.

In the Characterization of Exposure section of the Analysis phase we will present a model that estimates downwind concentration and deposition from detonation of a single salvo of M76 brass-filled smoke grenades. This model presents concentration and deposition data generated under several different meteorological test conditions at points several hundred meters and several kilometers downwind. Data collected under controlled conditions will be presented on the fate of IR material in the environment and its possible availability to environmental components. In the Characterization of Ecological Effects section, data demonstrating a cause/effect relationship between the stressor and the ecological components potentially at risk will be presented. The data presented will be from in-house toxicity studies conducted using indicator organisms and from data identified in the literature that demonstrated this cause/effect relationship.

Finally, the Risk Characterization phase will attempt to quantify the extent of the ecological risk associated with exposure to the stressor. The estimated risks are discussed by considering the types and magnitudes of effects anticipated, the spatial and temporal extent of the effects, and the recovery potential.

Smokes/obscurants (smokes) are designed to hide a specific battlefield vehicle or large area troop and vehicle movements in areas where there would normally be a long line of sight, like large open range or meadow. Because smokes can travel large distances, perhaps up to 40 km³, their effect may reach beyond the anticipated field of utilization. It is therefore reasonable to believe that these materials may also be deposited to or find a way into neighboring agricultural areas.

Disseminated materials have the potential to deposit on and impact any environment downrange from the point of dissemination. For this assessment, those areas of concern include ecosystems that are terrestrial in nature, thus potential deposition sites include plant surfaces and exposed soil. The deposited materials can potentially find their way into the soil, plant tissue, soil invertebrates, and other soil biota. The impact a deposited material may have is also dependant on its reactivity and persistence in the environment. The toxicity and availability to local biota may change over time, depending on the level of incorporation into the particular ecological system. Data available on the level of brass incorporation and any effect brass may have on a terrestrial environment will be examined.

2.1 Stressor Characteristics.

Brass is an alloy of the heavy metal micronutrients, copper (Cu) and zinc (Zn). The exact ratio of the two metals varies slightly. The brass flake material used in previous toxicity studies^{4,5} was reported to have 68.5% Cu, 27.5% Zn, 0.2% Al, 0.1% Pb, 0.1% Sb, 0.5% palmitic acid, and 0.7% stearic acid. The 1.2% acid coating on the particles was reported to be an aid in the milling process used to manufacture brass flakes³.

The flake geometry has the desired property of relative efficiency at attenuating light in the IR wavelength, the wavelength used by sophisticated target acquisition systems. Its large surface/volume ratio and low settling velocity make flakes an obvious choice over materials with a spherical geometry. Descriptions of individual flakes include measurements of major and minor dimensions, where the major dimension is the face of the platelet and the minor dimension is the thickness of the platelet. The milling process does not produce flakes of specific geometry in that, like a snow flake, they are beyond exacting description but do fall within describable ranges. Typically, single flakes employed have a major dimension of 5.0 -10.0 μ and minor dimension of 0.1-0.5 μ ($1\mu +1 \times 10^{-6}$).

Discussions of IR aerosol plumes must include measurement of plume concentrations in milligrams/cubic meter (i.e., mass of particles per unit volume) and extinction coefficient or alpha in $1 M^2/g^{-1}$ (i.e., extinction per gram of material). Characterization of the average or mean size of the particles within the aerosol plume is expressed as an aerodynamic diameter. The aerodynamic diameter (D_a) of a flake is the diameter of a unit density sphere that

settles with the same velocity as the flake. The measurement of the mean particle size of the flake aerosol plume is expressed as Mass Median Aerodynamic Diameter (MMAD). That is the aerodynamic median diameter of the distribution measured on a mass basis as opposed to count or population basis. The spread of the distribution is expressed as Geometric Standard Deviation (GSD).

The flake material used as an obscurant is a flake with an approximate minor dimension of $<0.5\mu$ and a major dimension of 8.0 to 10μ . Brass flakes have been developed as an obscurant in the IR light spectrum. The primary mode of dissemination of brass materials is through detonation of M76 brass-filled smoke grenades. Each grenade contains an explosive charge and 3 lb of brass. The grenades are typically fired from armored vehicles in volleys of 8-12 (36 lb) grenade salvos as countermeasures to target acquisition systems. Brass is also disseminated through large area screening systems like the M56 or modified MA-1A start cart (10-15 lb/min).

2.2 Ecosystem Potentially at Risk.

An ERA must begin with a conceptualization of the environment that will be subject to the effects. For assessments of potential impacts from site construction projects, site remediation, process effluents, or chemical releases, the environment will be an actual place. For generic assessments of technologies or chemicals, it will be a reference environment that is representative of a site where a release would occur. Reference environments can be arrayed on a scale of abstraction. Values can be simply assigned to the parameters of the assessment models that are thought to be representative or even worst case. This approach is appropriate for quickly screening chemicals. The appropriate degree of abstraction of the reference environment depends on the type of assessment to be conducted and the degree to which the characteristics of the likely release sites can be specified⁶.

Principle considerations in environmental description are the boundaries placed on the environment and characterization of the entities and processes occurring within the boundaries. Boundaries may be defined by either a regulatory or equivalent priori definition or properties of the assessment problem. An example of the first type would be the requirements that effluents meet some criterion at the edge of a zone of initial dilution. An example of the second type would be a definition of the boundaries in terms of the area within which the concentration of a chemical is higher than the concentration at which a threshold for toxic effects occurs. Other commonly used approaches include the use of the bounds of applicability of a favored transport model, political boundaries, or a "reasonable" distance such as 1 km⁶.

Because this predictive ecological risk assessment is constructed as a screening or Tier 1 assessment, the environment under consideration here is not a specific location but a generic training/test facility. Smokes are designed to hide a specific battlefield site, vehicle, or even large area vehicle and troop movements on military installations in areas where there

would normally be a long line of sight, like open range, or grassland. Hence, the ecological components described here will be limited to those of a relatively temperate, unforested rangeland. This level of abstraction is appropriate for a screening assessment of this type. Because disseminated smokes can travel large distances, perhaps up to 40 km³ their effect may reach beyond the anticipated field of utilization. Because these materials can carry long distances, their potential range of adverse ecological impacts within the bounds of application of the Gaussian Plume Dispersion Model employed by Driver³ for a single M76 grenade salvo, or 40 km will be assessed.

There are many military test/training sites throughout the U.S. that have the potential to be cited for testing or troop training with brass smokes. The purpose of this Tier 1 assessment is to assess the potential for any negative effects to terrestrial environments(i.e., open range terrestrial environments). Terrestrial ecosystems are areas of potential impact at testing and training sites. Ecological components that will be assessed for potential impact are those that makeup the major components of a typical terrestrial ecosystem and receive direct deposition from environmental release of the IR smoke. These components include the following:

- plant species that can receive direct foliar deposition;
- the effect on plants from uptake of brass through their root systems;
- exposure of soil biota, including invertebrates and microbes;
- incorporation into soil and effect on soil chemistry and physical characteristics.

2.3 Ecological Effects.

Entry into the ecological risk assessment process may be triggered by either an observed ecological effect, such as visible damage to trees, identification of a stressor or activity of concern, or by the manufacturer of a new chemical seeking permit or registry². Past military activities have been known to cause adverse effects, including the use of military battlefield smokes. Solid smoke materials do accumulate and sometimes concentrate in the environment. The U.S. Army Corps of Engineers⁷ has measured elevated levels of IR smoke materials in soils taken at test area C-52A at Eglin Air Force Base, FL. Eglin AFB is the site of the annual "Smoke Week" testing for military countermeasure developmental items.

2.3.1 Ecological Components.

Green plants are the primary producers in the terrestrial ecosystem food chain. Their viability and productivity are direct indicators of the health of the ecosystem. Plants can indicate the presence of several types of stress including effects of temperature, photoperiodicity, moisture, nutrient availability, and toxins in the air, soil, and water. The effect of a contaminant on a terrestrial ecosystem can be quickly observed by its effect from

direct deposition to plant foliar surfaces. Wilting or burning of exposed surfaces can be a very obvious sign of a stressor that has significant environmental toxicity. Effects of contaminant incorporation into the plant tissues from root uptake also indicate presence of stressor in the soil. For these reasons, plants are used as indicators of environmental stress. Plant response may be measured as decreases in productivity and/or fecundity under laboratory and field conditions. Laboratory measurements of ecological effect of a chemical or material on plant indicator species used in an ERA should include an environmental concentration (EC_{50}) that produces a 50% reduction in measured effect (e.g., biomass production, fecundity). To be complete, an ERA for a terrestrial ecosystem should include the measure of plant response to the specific stressor.

Earthworms are key organisms in terrestrial ecological systems because of their role in maintaining the physical characteristics and processes of the soil, such as aeration, water permeability, and breakdown of organic matter. They increase the fertility of soil by increasing the availability of nutrients and are an important link in the food chain. Earthworms are also sensitive bioindicators of environmental stresses. Earthworms have been used to measure the toxicity of stressors in soils through bioassay and avoidance testing⁸. Laboratory toxicity measurements of a chemical or material used in a terrestrial ERA should include an LC_{50} , the concentration that causes 50% mortality in a USEPA standard 14-day earthworm toxicity test, and findings of lowest observable effect level (LOEL).

Soil microbial populations play a critical role in decomposing organic matter and the cycling of important nutrients (nitrogen, phosphorus, sulfur, micronutrients, and some trace metals). Microbial decomposition processes in the soil can also detoxify xenobiotic chemicals. Any physical or chemical perturbation to the soil that impacts the microbial processes also impacts the soil system and vegetation. Measurements of soil microbial activity that should be included in terrestrial ERAs assessing soil bioactivity include soil dehydrogenase activity, a general measure of activity of the soil microbial activity; soil phosphatase, a broad group of enzymes that are important for the mineralization of phosphorus from organic matter; measurement of soil adenosine triphosphate (ATP) levels, a method for measurement of soil microbial biomass; total heterotrophic bacteria; soil microbial diversity; and levels of soil nitrifying bacteria⁹. Laboratory toxicity measurements of soil microbial activity used in a terrestrial ERA should include a determination of and reporting of toxicity values such as EC_{50} , LC_{50} and/or LOEL.

2.3.2 Data Requirements.

Data on the effects of brass on the terrestrial environment employed in this document was generated through research by the U.S. Army and its contractors. This data is considered sufficient for the specific requirements of this Tier 1 predictive ERA. In the event that a site specific ERA is requested, additional information on the toxicology of brass to environmental components of that site may be required.

2.4 Endpoint Selection.

Any ERA must have defined endpoints. Two types of endpoints used in ERAs are assessment and measurement endpoints. An assessment endpoint is a formal expression of the environmental values to be protected, usually referring to characteristics of populations or ecosystems on large scales (e.g., forest or crop production in a geographical area or populations of specific species in a given area). The endpoint selected may vary for each site, and its selection is based on a predetermined requirement for the site. Endpoint selection is normally driven by the intended end use of the site and the resident or transient populations or single species using the site. It is often difficult to quantitatively measure these changes to an assessment endpoint in the field on such a large geographical area. For this reason, measurement endpoints are identified that are measurable ecological characteristics related to assessment endpoints goals. For screening level or Tier 1 assessments, the data often used is available from toxicity tests using indicator species. The indicator species represents a crossover point between the large production of a population or ecosystem to the toxicity data collected in a small scale, controlled laboratory or field research project.

Measurement endpoints are the toxicologist's or field biologist's input into the assessment. The measurement endpoint is a formal, usually quantitative, expression of the results of toxicity testing of an indicator species. They are often expressed in numbers such as a 96-hr LC_{50} , the concentration found to kill 50 percent of the individual organisms over a 96-hr test period. Additional information may be expressed in the form of a concentration response curve, where stressor effect/response can be indicated for various stressor concentrations (e.g., LD, EC, or LC_{1-99}). Measurements used may also be obtained by environmental sampling and laboratory testing⁶.

For a site-specific "Umbrella" ERA and Tier 2 or 3 ERAs, the indicator species employed may be those actually present at the site. For a screening level or Tier 1 assessment such as this, the data employed are that available from previous toxicity testing with more generic indicator species and species representative from specific sites identified through literature investigations, as well as previous in-house toxicity testing. In addition to the species of organism, used as indicators, the medium used for testing (the soil the organisms are tested in) also comes from previously available toxicity studies.

Because this is a Tier 1 level assessment and intended for broad use and not site specific, the assessment endpoints are also nonspecific. Any application of an ERA to a specific site should include more site-specific assessment endpoints. The assessment endpoints for measuring the environmental health and viability for this predictive assessment to a terrestrial ecosystem are: (1) no loss of production in select plant species; (2) no decrease in the viability of selected soil invertebrate and soil microbes; and (3) no avoidance and/or loss of habitat to soil invertebrates.

Measurement endpoints employed will be LC₁₀, LD₁₀, No Observable Effect Level (NOEL), or Lowest Observable Effect Level (LOEL) to: (1) plant production using plant indicator species in 14-day acute toxicity tests; (2) earthworm lethal, sublethal, and avoidance effects in standard 14-day acute toxicity tests; (3) soil microbial dehydrogenase and phosphatase activity, soil microbial ATP levels (indicators of biomass), soil microbial diversity, and levels of soil nitrifying bacteria.

2.5 Indicator Species.

The selection of an indicator species used to represent a specific endpoint is often tied directly to the assessment site. For a specific site, it is important to use a plant species that can be found on the site, that is, a characteristic species of the ecosystem potentially at risk. For example, forest or desert species may constitute the population at risk. In that case, the species selected may be those of most value to man or of ecological dominance to the affected ecosystem.

Often the species used as an indicator may be more generic. When bioassays are conducted using a chemical of particular interest, the researcher may not have a specific application for the toxicity data generated. In those instances, he may select an indicator species that is universally accepted for specific reasons. The plant species selected may be used as a food source or economically important cash crop. Their distribution, abundance, and taxonomic representation may suggest a broad coverage in the plant kingdom. They may be sensitive to many toxic compounds and have been used to some degree in previous bioassays. The use of a scientifically accepted species in various bioassays allows ranking of toxicity based on effect to a common species. The selected species may be compatible with environmental growth conditions or time constraints of the test method. The selected species may germinate easily and quickly or exhibit rapid and uniform growth. The seed may contain no natural inhibitors and require no special pretreatment or release mechanism such as soaking, chilling, light or scarification¹⁰.

In the Environmental Effects Test Guidelines,¹⁰ 10 terrestrial plant species are recommended for the seed germination/root elongation, early seedling growth, and plant uptake test guidelines. Researchers often select species for plant bioassays from this list. Therefore, data on environmental effects often discovered via literature searches and reviews will have been conducted using these species. For Tier 1 and screening level ERAs, the data used most often come from these searches and reviews. Bioassays using site specific indicators are generated during more in-depth site-specific investigations. Toxicity data used in this ERA are of the type found through technical review and literature search.

Data that are available represent primary producers and organisms at the lower levels of the food chain. A description of the plant species, earthworms, and soils used as environmental indicators or media, in appropriate published studies, are provided below.

- Zea mays. Corn, a monocot species selected from the USEPA's listing of sensitive plants.
- Cucumis sativus. Cucumber, a dicot species selected from USEPA's list of sensitive plants.
- Lolium temulentum. Ryegrass, a monocot species selected from USEPA's list of sensitive plants.
- Avena sativa. Clintford oats, a monocot species selected from USEPA's list of sensitive plants.
- Artemisa tridentata, vaseyana. Big Sagebrush, a medium-size perennial shrub found over vast expanses of the arid and semi-arid western states. It grows in relatively harsh environments on alkaline soils and at elevations from sea level to 7000 ft Age: 2-yr old seedlings.
- Pinus ponderosa. Ponderosa Pine, a large coniferous-forest species common to western North America. It grows at a range of elevations and is relatively tolerant to drought. It requires moderate soil fertility. Age: 2-yr old seedlings.
- Pinus echinata. Short-Needle Pine, a coniferous tree indigenous to the southeastern U.S. This variety is used extensively in reforestation. Age: 2-yr old seedlings.
- Festuca elator. Tall Fescue grown from seed, a perennial, cool-season bunchgrass that grows well on dry or wet, alkaline or acidic soils. It has a rather ubiquitous range..
- Phaseolus vulgaris, tendergreen. Bush Bean, grown from seed, an agronomic species that is relatively sensitive to chemical insults.

Data found in literature reviews of brass effects on soil invertebrates are for the earthworm indicator species Eisenia foetida. Eisenia foetida is a species that is widespread throughout the U.S. and is commonly used by researchers as an indicator species for ecotoxicological tests. Because earthworms are constantly in contact with the soil, soil solution, and soil air spaces, they are a good indicator of biological stress. Data retrieved on effects of brass in soil and other military smokes in soil have this species of earthworms in common.

In addition to the indicator species, the media in which environmental toxicity testing is conducted must be considered. The materials selected are subjected to the same type of criteria as a living indicator species. Often the medium, soil for example, has site-specific application but can represent widely diverse soil types. For more generic applications, scientists often use an artificial soil that represents a standard test medium that can be widely employed in various assessments or evaluations and that produces data that are directly

comparable. This allows the rating of some of the toxic effects under standardized testing conditions. Descriptions of media identified from studies which investigated the toxicity of graphite are as follows:

- Sassafras sandy loam. This soil was collected from M-field, a test area at ERDEC, APG, MD. This soil is described as a slightly acidic sandy loam (fine-loamy, siliceous, mesic Typic Hapludult), with low organic matter (OM), and low cation exchange capacity (CEC).

The Sassafras series consists of deep, well-drained, gently sloping to steep soils, dominantly located on undulating uplands, and some short steeper slopes of the coastal Plain. These soils formed on old marine deposits of sandy sediment containing moderate amounts of silt and clay. The soil used in testing from Aberdeen Proving Ground is further described as Sassafras sandy loam, having 2-5% slopes, and moderately eroded. This soil has a profile similar to the general series description, but the surface layer contains more sand, generally a little less clay, and less silt than does the typical Sassafras sandy loam. This soil is well suited to nearly all commonly grown crops. Native vegetation under which the soil was formed was mixed hardwoods, mainly oaks, with Virginia pine invading in places.

- Joppa sandy loam. This soil was collected from an area near Winters Run Stream in Edgewood, MD. This soil is described as a slightly acidic sandy-loam (loamy-skeletal, siliceous, mesic Typic Hapudult) with high OM and relatively high CEC.

The Joppa series consists of deep, well-drained to excessively drained, gently sloping to steep gravelly soils on the coastal plain. These soils formed in thick deposits of sandy and gravelly sediments that contain small amounts of silt and clay. They are generally in hilly areas in the higher parts of the Coastal Plain, close to the juncture with the Piedmont Plateau. The native vegetation under which this soil was formed was drought resistant hardwood, mostly oaks, and some Virginia pine. The specific soil used in soil fate testing described in this ERA is further described as Joppa gravelly sandy loam, having 2 to 5 percent slopes. The soil is cultivatable. The plow layer is grayish brown or dark grayish brown. In areas where the slope is less than 2 percent, the subsoil is red instead of brown. The low water capacity of this soil has more effect on its use and management in farming than the slight hazard of erosion. The soil is better suited to truck crops or early planted crops than to other crops. Joppa soils are easy to work, but pebbles are abrasive to farm implements.

- Artificial soil. The artificial soil mixture is made up of 10% sphagnum peat, 20% kaolinite clay, 69% fine sand, and 1.0% calcium carbonate. This mixture is often used by researchers to represent a generic soil that allows easy comparison of data from soil biota toxicity testing.

2.6 Conceptual Model.

The conceptual model is a hypothesis of what the stressor may be, how and to what extent it enters the environment in question, and speculation on routes of exposure and how environmental stress will be represented. The ERAs that are constructed to assess preexisting contamination to a specific area often speculate on the origination of the environmental stressor. For this predictive assessment, the source of the described stressor is known. Sources for brass particulate releases are testing or training exercises using a Rapid Obscurant System (ROS), or a grenade launcher, mounted on some type of wheeled or tracked tactical vehicle. Brass particles disseminated into the air can travel many kilometers before all the material settles to the ground or other surfaces. Higher concentrations of material will be observed near the generator, with airborne concentrations and surface deposition decreasing with distance traveled away from the source. Any effect on ecological systems is expected to occur from direct deposition to surfaces or from movement of the material into a media like soil or groundwater, etc. Any effect on the environment that the stressor has should be indicated by biological components within the area of brass deposition. Plants may receive direct contact by deposition to leaf surfaces or indirect exposure by root uptake. Stress in plants may be indicated by changes in biomass production, seed or flower formation, or reduced seed germination. Animals in the soil may also be affected from direct deposition of brass or translocation downward into the soil. Indications of stress may be measured by monitoring the activity of soil microbes or invertebrates. Stress in soil invertebrates may be measured by loss of body mass or avoidance of the affected area. Soil microbe stress may be indicated in a number of ways like changes in microbial diversity, total population, soil dehydrogenase activity, and respiration rate.

For a site specific ERA, measurements of these indicators may be made at the site or in lab studies using site-specific biota. For this Tier 1 assessment, we will rely on the indicator species already mentioned to predict possible effects at sites of similar environmental conditions (i.e., an environment loosely described as temperate grassland or previously cleared natural forest area).

2.7 Environmental Toxicity Laws and Regulations.

2.7.1 Air Quality.

Ambient air quality standards for particulates (40 CFR 50.6) are potentially applicable to emission of brass flakes or powder. The primary national ambient air quality standard (NAAQS) for particulate matter is set at $150 \mu\text{g}/\text{m}^3$, based on a 24-h average concentration. Particulate matter is measured as particles with an aerodynamic diameter $\leq 10.0 \mu$. Additional ambient air quality standards for lead and its components are established at $1.5 \mu\text{g}/\text{m}^3$, maximum arithmetic mean averaged over a calendar quarter. However, it is unlikely that brass flakes or powder would remain suspended in the air long enough to meet or exceed these concentration limits.

There are no national emission standards for hazardous air pollutants (NESHAPS) for brass or its primary components (copper, zinc, aluminum, or lead). Antimony and cadmium compounds are listed as hazardous air pollutants under Section 112 (b) of the Clean Air Act amendments of 1990. These compounds are defined as including "any unique chemical substance that contains the named chemical (i.e., antimony, arsenic, etc.) as part of that chemical's infrastructure." Because both antimony and cadmium are only trace elements in the brass flakes, any new NESHAP limits are not likely to apply.

Assuming a single salvo of 12 brass flake grenade rounds, the time-weighted average over 24 h, the NAAQS of $150 \mu\text{g}/\text{m}^3$ would be exceeded at distances within about, 0.1 to 0.5 km of the source, depending on atmospheric conditions³.

2.7.2 Water Quality.

Brass and its primary components (copper, zinc, aluminum, lead, antimony, and cadmium) are not designated as hazardous substances under the Clean Water Act. However, discharge of brass flakes from a point source into the waters of the U.S. could be subject to National Pollution Discharge Elimination Systems (NPDES) permit requirements (40CFR 122).

In addition, the Safe Drinking Water Act's national Primary Drinking Water Regulations would be applicable if the use of flakes would have the potential to impact community or non-community water systems. Contaminant levels of 0.05 mg/L for lead and 0.010 mg/L for cadmium have been established under 40 CFR 141.11³.

Weathering of brass could lead to releases of its elemental components. Copper, zinc, antimony, lead, and cadmium are identified in the regulations of the Comprehensive Response, Compensation, and Liability Act (CERCLA) in 40 CFR 302.4 as hazardous substances subject to reporting requirements if released to the environment in quantities greater than 5,000 lb for copper and antimony, 1,000 lb for zinc, and 10 lb for cadmium.

Copper, zinc, antimony, lead, and cadmium (as wastes) are not listed as hazardous substances under the Resource Conservation Recovery Act (RCRA). However, wastes containing cadmium or lead are characteristic wastes if the waste fails the toxicity characteristic leaching procedure (TCLP). Failure of the TCLP would require waste management procedures consistent with RCRA. Brass flakes should be subjected to this test to ensure they do not become RCRA-regulated waste when used. Palmitic and stearic acids, the coatings on the particles, are not listed as hazardous wastes but could fall under the definition of hazardous wastes if they fail the tests for ignitability, reactivity, and corrosivity as defined in 40 CFR 261 Subpart C.³

Emergency Planning and Community Right to Know Act provisions are

applicable to fumes and dust of copper, zinc, antimony, lead, and cadmium when amounts released are greater than the threshold amount (40 CFR 372.65). The threshold amount for each of these compounds is 10,000 lb.

2.7.3 Transportation.

Brass and its main components are not listed as hazardous materials under the regulation of Hazardous Materials Transportation Act (HMTA) in 49 CFR 171-179. However, fumes or dust of copper, zinc, antimony, lead, and cadmium satisfy the definition of "hazardous substance" in 49 CFR 171.8 if they are transported in quantities in one package that equal or exceed the reportable quantities listed under CERCLA. The transport of these substances must comply with 49 CFR 172.01 if they are shipped in quantities equal to or greater than 5,000 lb for copper and antimony, 1,000 lb for zinc, and 10 lb for cadmium³.

2.7.4 State Regulations.

State regulations may differ from federal regulations and should be consulted in locations where activities involving this material take place.

3 Analysis.

3.1 Characterization of Exposure.

3.2 Stressor Characterization.

Brass is an alloy of copper (Cu) and zinc (Zn). The exact ratio of the two metals varies slightly. The brass flake material used in studies by Thomson et al.⁴ and Haley et al.⁵ were reported to have 68.5% Cu, 27.5% Zn, 0.2% Al, 0.1% Pb, 0.1% Sb, 0.5% palmitic acid, and 0.7% stearic acid. The 1.2% acid coating on the particles was reported to be an aid in the milling process used to manufacture brass flakes.³

The flake geometry has the desired property of relative efficiency at attenuating light in the IR wavelength, the wavelength used by sophisticated target acquisition systems. Its large surface/volume ratio and low settling velocity make flakes an obvious choice over materials with a spherical geometry. Descriptions of individual flakes include measurements of its major and minor dimensions, where the major dimension is the face of the platelet and the minor dimension is the thickness of the platelet. The milling process does not produce flakes of specific geometry in that, like a snowflake, they are beyond exacting description but do fall within describable ranges. Typically single flakes employed have a major dimension of 5.0 - 10.0 μ and minor dimension of 0.1-0.5 μ .

Discussions of IR aerosol plumes must include measurement of plume

concentrations in mg/m^3 , (i.e., mass of particles per unit volume) and extinction coefficient or α in M^2/g^{-1} , (i.e., extinction per gram of material). Characterization of the average or mean size of the particles within the aerosol plume are expressed as an aerodynamic diameter. The aerodynamic diameter (D_p) of a flake is the diameter of a unit density sphere that settles with the same velocity as the flake. The measurement of the mean particle size of the flake aerosol plume is expressed as Mass Median Aerodynamic Diameter (AMMAD). That is the aerodynamic median diameter of the distribution measured on a mass basis as opposed to count or population basis. The spread of the distribution is expressed as Geometric Standard Deviation (GSD).

The flake material used as an obscurant is a flake with an approximate minor dimension of $<0.5\mu$ and a major dimension of 8.0 to 10 μ . Brass flakes have been developed as an obscurant in the IR light spectrum. The primary mode of dissemination of brass materials is through detonation of M76 brass-filled smoke grenades. Each grenade contains an explosive charge and 3 lb of brass. The grenades are typically fired from armored vehicles in volleys of 8-12 (36 lb) grenade salvos as countermeasures to target acquisition systems. Brass is also disseminated through large area screening systems like an M56 or modified MA-1A start cart (10-15 lb/min).

3.3 Exposure Analysis.

While brass obscurant material can be disseminated through large area screening systems like the M56, the primary mode of dissemination for training purposes is through the M76 grenade. The M76 is designed for point source obscuration and target acquisition countermeasures. As mentioned, the grenades are routinely discharged from tanks or other armored vehicles in volleys or salvos of 8-12 grenades with an average material instantaneous dissemination of about 30 lb of material. Studies to measure downrange deposition of brass material have been conducted by Bowers et al.¹¹ and Cataldo et al.⁹. Actual field measurement and characterization of material deposition are difficult due to the unpredictable nature of obscurant plumes and constantly changing meteorological conditions at test sites.

Ideally, smoke testing conditions for obscurant materials fall into a rather narrow range of operation. Most smoke dissemination testing is done under rather low wind conditions and moderate amounts of atmospheric turbulence to facilitate effective cloud formation and downwind dispersion. Under milder wind conditions and low turbulence, surface deposition in the area of dissemination can be expected to be much greater than under more energetic conditions.

3.4 Exposure Profile.

Bowers et al.⁹ conducted deposition studies at Dugway Proving Ground (DPG), Utah, where brass samples were collected from a single M76 grenade salvo up to 600 m

downrange. A Volume Surface Diffusion Model (VSDM) was also used to predict deposition within the area of actual measurement for comparison with observed deposition. Figure 5 shows actual brass deposition along the centerline of the sampling grid and compares with predicted deposition using the VSDM.

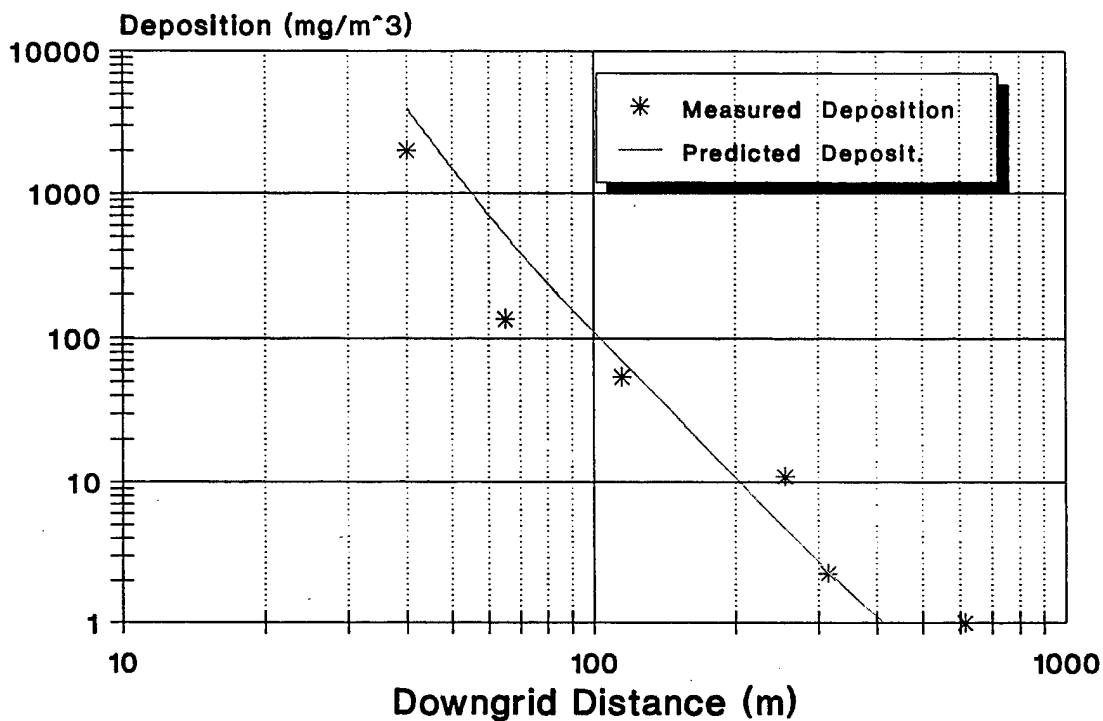


Figure 5. IR Deposition from a Single M76 Grenade Salvo Measured along a Centerline and Calculated by Bowers Using the VSDM Model

For the purposes of training troops in equipment operations and maneuvers, ideal smoke dissemination conditions may not necessarily be required for each exercise. Therefore, smoke materials may be disseminated under less than ideal conditions.

A Gaussian plume dispersion model employed by Driver³ been used to predict downwind aerial concentrations (Fig. 6) and ground deposition of brass material (Fig. 7)(table 2) disseminated from a single M76 salvo beyond several hundred meters downwind. Several site conditions accounted for in the model include wind velocity and turbulence, degree of insolation, height an position of grenade discharge, particle settling velocity and other parameters. Driver³ developed data for six scenarios that would cover the range of possible field conditions resulting in the possible minimis and maximus material deposition. Plume disseminations used to determine brass deposition for cases 1 through 6 are listed in Table 1. Parameters that were varied include the atmospheric stability category (ASC) defined in Table

1, plume dispersion height (H), mean wind velocity (u), and material deposition velocity (V_d). Other parameters listed in Table 1 include material dissemination rate (Q_p) and period of dissemination (t).

Table 1. Test Case Parameters for Estimating Brass Flake Aerosol Plume Dispersal in the Atmosphere and Deposition to Ground Surfaces.

Case	Parameter	Q_p (g/s)	H (m)	u (m/s)	ASC	V_d (cm/s)	t (s)
1	ASC	5450	5	2	A	0.17	2
2	ASC	5450	5	2	C	0.17	2
3	ASC	5450	5	5	D	0.50	2
4	ASC	5450	5	2	F	0.17	2
5	u	5450	5	5	C	0.50	2
6	H	5450	10	2	C	0.17	2

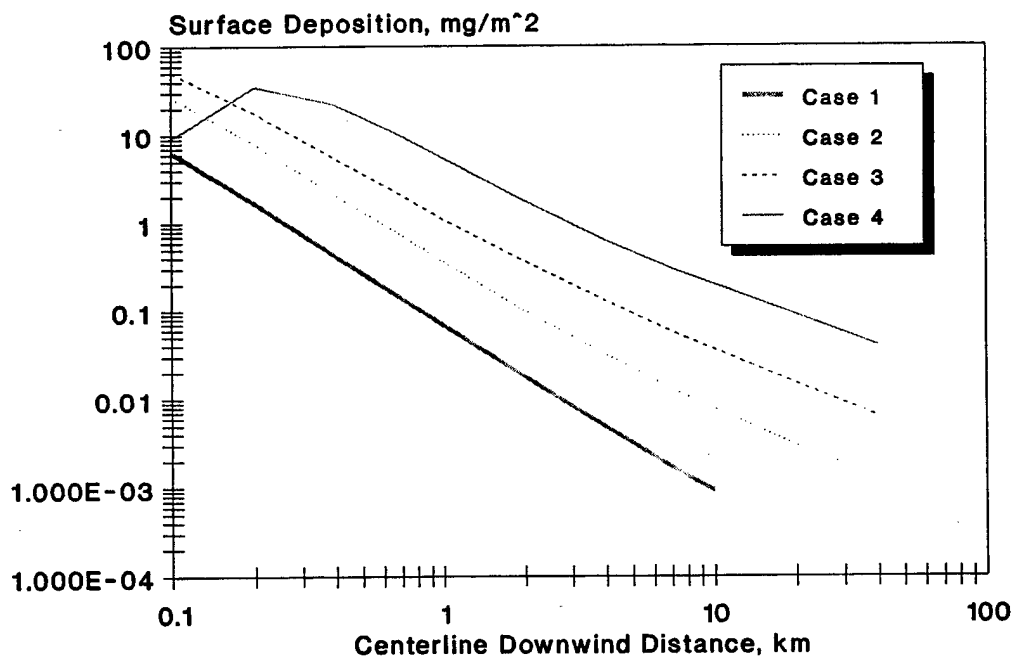


Figure 6. Surface Deposition of Brass Flakes From a Single M76 Grenade Salvo, Surface Deposition Calculated Using the Gaussian Plume Dispersion Model.

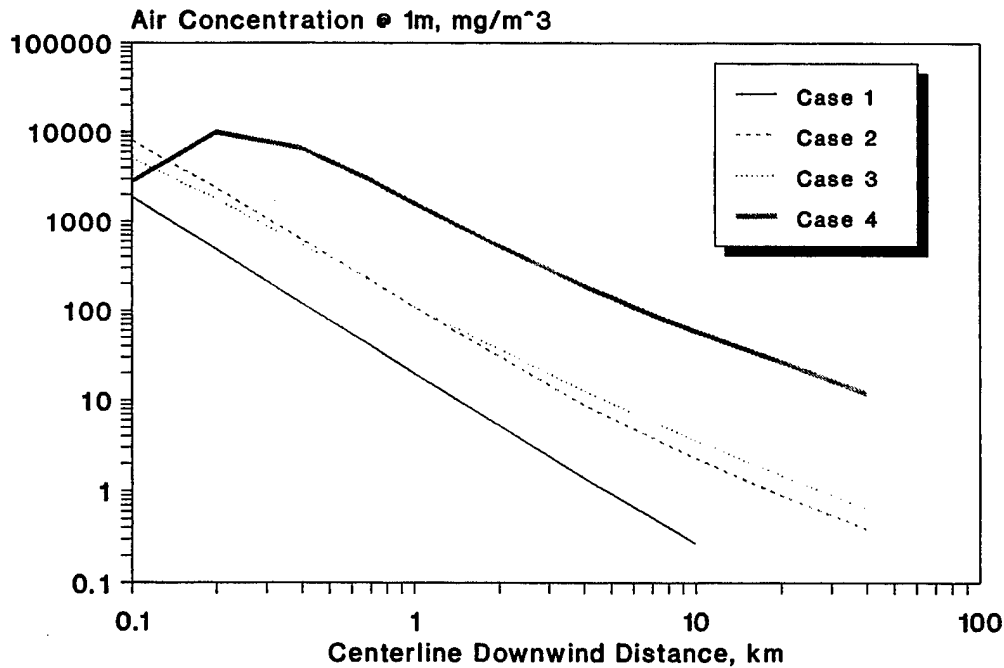


Figure 7. Brass Aerosol Concentration Estimated Using the Gaussian Plume Dispersion Model. Concentration Estimate Shown Is for Expected Concentration at 1 Meter above Ground.

Cases 2 and 3 are thought to represent the most typical condition for test conditions. Case 1 represents extremely unstable atmospheric conditions during which tactical release of brass flake aerosols may be least effective because of rapid plume dispersion but during which time the lowest environmental risk may be expected due to reduced deposition levels. Case 4 represents moderately stable conditions that are not common at most sites and represents a worst-case condition along the mean wind vector. Cases 5 and 6 were selected to demonstrate the predicted impact of wind speed and plume height, respectively. Both cases were assigned ASC category C and each differs by a single parameter from Case 2. Case 2 and Case 3 represent the most likely testing scenario, where wind conditions are low with moderate atmospheric turbulence.

Pasquill-type atmospheric stability categories (ASCs) are described as: A) extremely unstable, B) moderately unstable, C) slightly unstable, D) neutral, E) slightly stable, and F) moderately stable. Each of these categories are also influenced by wind speed and insolation, see Driver ³.

This model, while useful for this study, may not be completely applicable for specific sites with well defined conditions. Other models available include the "Industrial Source Complex Dispersion Model" and "Real-Time Volume Source Dispersion Model" Bowers and

White¹². The model employed for specific sites should be evaluated on a case-by-case basis.

Table 2. Downwind Surface Deposition Concentrations For 6 Dissemination Scenarios

Distance Downwind (km)	Material Deposited (mg/m ²)					
	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
0.1	6.4	27.0	51.0	9.3	32.0	15.0
0.2	1.7	8.0	18.0	35.0	9.4	6.9
0.4	0.42	2.1	5.4	22.0	2.5	2.1
0.7	0.14	0.73	2.1	9.8	0.85	0.72
1.0	0.069	0.37	1.1	5.5	0.43	0.37
2.0	0.018	0.10	0.37	1.8	0.12	0.10
4.0	0.0048	0.032	0.13	0.63	0.037	0.032
7.0	0.0017	0.013	0.058	0.30	0.015	0.013
10.0	0.00092	0.0077	0.036	0.20	0.0093	0.0078
20.0	0.0030	0.015	0.090	0.0035	0.0030	
40.0	0.0013	0.0063	0.040	0.0015	0.0013	

3.5 Fate of Brass in Soils

The form of the brass in the soils has a great effect on its bioavailability. The most significant effects are caused by differences in the soil CEC, pH, and organic matter (OM). Brass in soil usually speciates into several forms: inorganically bound, organically bound, and exchangeable and pooled residual. Of these, the exchangeable is the form most bioavailable¹³. In the work done by Wentzel and Guelta¹³ and Cataldo et al.⁹ on soil chemistry, all agree that CEC, pH and OM affect the toxicity of brass to various soil organisms. For example, Cataldo et al.⁹ showed that at the concentrations tested up to 2500 $\mu\text{g/g}$, brass forms reach an equilibrium between 100 and 450 days after amendment. The level of exchangeable brass available at different weathering states is dependent on the specific soil chemistry.

The movement of brass downward through the soil is also dependant on the same soil conditions. Wentsel et al.¹³ found that after 8 mo, brass migrated to a depth of 5 cm in soil with low pH, OM, and CEC. But, migration was less for the soil with higher pH, CEC, and OM. In the studies by Cataldo et al.⁹, labeled brass only penetrated approximately 1 cm into the soils.

The fate and effects of brass flakes deposited on soil surfaces depend strongly on the properties of the soil. To have effect on soil invertebrates and be available to the plant root zone, the material must penetrate below the soil surface. To date, testing on the transport of brass into the soil root zone is limited to the studies listed above. For the purposes of this screening level assessment, brass concentrations in the soil will be calculated assuming two major factors; 1) that the brass material will penetrate to 5.0 cm below the soil surface, and 2) the brass concentration is uniform throughout this 5.0 cm depth. Because actual soil penetration and brass concentration gradients would be determined by site-specific conditions and soil chemistry, these assumptions will be made for easy application to the generic testing environment. The assumption of a soil penetration of 5.0 cm is taken from Wentsel and Guelta¹³ where penetration was demonstrated using a worst-case nutrient limited sandy soil. This depth may be a conservative approach; however, for this ERA, for toxicological reasons, brass availability to plant root zones and soil invertebrates must be shown. In the Risk Characterization section, this exposure scenario and use of the more conservative toxicity data from the nutrient-limited sandy type soils like Sassafras and Burbank sandy loams from the Wentsel et al.^{8,14,15,16}, and Cataldo et al.⁹ studies will be used.

Calculation of soil concentration will be done using measured surface deposition data from Bowers et al.¹¹ and modeled deposition data from Cataldo et al.⁹. Surface deposition quantities expressed as milligrams per square meter (mg/M^2) are converted to a volumetric concentration in micrograms per cubic centimeter ($\mu\text{g}/\text{cm}^3$). The surface deposition is then assumed equally dispersed to a depth of 5.0 cm, in a soil volume of 5.0 cm^3 . Concentration is then converted to micrograms per gram ($\mu\text{g}/\text{g}$) assuming an average soil density of $1.45 \text{ g}/\text{cm}^3$.

During testing by Bowers et al.¹¹, the highest single deposition sample was $2300 \text{ mg}/\text{M}^2$, 65 M downwind.

$$\begin{aligned} \text{convert weight milligrams to } \textit{micrograms} & \quad 2,300.0 \text{ mg}/\text{M}^2 \times 1000 \text{ } \mu\text{g}/1 \text{ mg} \\ & = 2,300,000.0 \text{ } \mu\text{g}/\text{M}^2 \end{aligned}$$

$$\begin{aligned} \text{convert area to centimeters squared} & \quad 2,300,000.0 \text{ } \mu\text{g}/\text{M}^2 \times 1\text{M}^2/10,000 \text{ cm}^2 \\ & = 230.0 \text{ } \mu\text{g}/\text{cm}^2 \end{aligned}$$

assuming even distribution

of 230 μg to a depth of
 5.0 cm = 230.0 $\mu\text{g}/5 \text{ cm}^3$

weight per centimeter cubed = 46.0 $\mu\text{g}/\text{cm}^3$

convert to micrograms per gram = 46.0 $\mu\text{g}/\text{cm}^3 \times 1 \text{ cm}^3/1.45 \text{ g}$

= 31.7 $\mu\text{g}/\text{g}$

Table 3. Plume Centerline Brass Surface Deposition Data and Calculated Soil Concentration from Samples Collected from Dissemination of a Single M76 Grenade Salvo from Bowers et al¹². Brass Soil Concentrations Calculated from Bowers Soil Surface Deposition Data.

Distance Downwind Meters (M)	Brass Surface Deposition mg/ M ²	Brass Concentration in Soil $\mu\text{g}/\text{g}$
40	2000	3.20E+01
65	135	2.16E+00
115	54	8.64E-01
115	56	8.96E-01
255	11	1.18E+00
315	4	6.40E-02
315	1	1.60E-02
615	1	1.60E-02

Table 4. Brass Surface Deposition and Soil Concentration Data Calculated by Cataldo et. al⁹ Using a Modified Gaussian Plume Dispersion Model. Data from Table 2, Case 3. Brass Soil Concentration Calculated Using Cataldo's Case 3 Dissemination Scenario.

Distance downwind Meters (M)	Brass Surface Deposition mg/M ²	Brass Concentration in Soil ug/g
100	5.10E+01	7.03E-01
200	1.80E+01	2.48E-01
400	5.40E+00	7.45E-02
700	2.10E+00	2.89E-02
1000	1.10E+00	1.52E-02
2000	3.70E-01	5.10E-03
4000	1.30E-01	1.79E-03
7000	5.80E-02	8.00E-04
10000	3.60E-02	4.96E-04

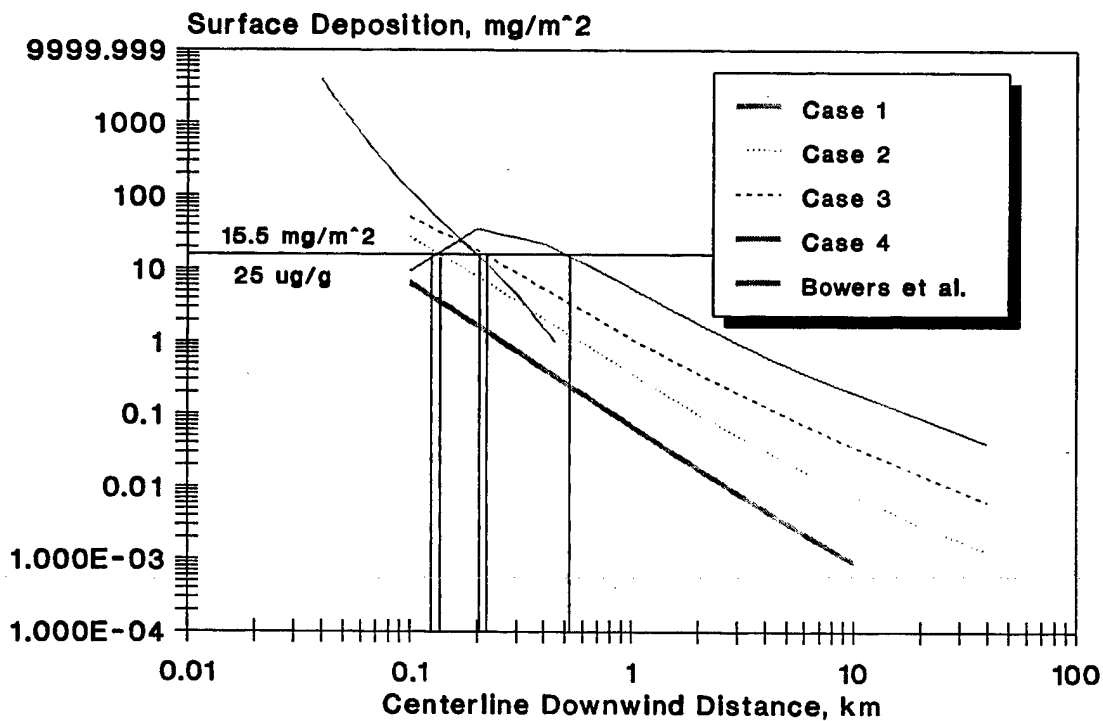


Figure 8. Surface Deposition Data From the Combined Testing of Bowers et al.¹¹ and Modeled Data from Cataldo et al.⁹.

4 CHARACTERIZATION OF ECOLOGICAL EFFECTS

4.1 Terrestrial Effects.

Brass flakes used as obscurants in training and testing activities will be deposited on soil and vegetative surfaces in varying amounts. Although brass is composed of copper, zinc, and trace amounts of aluminum, antimony, and lead, only the addition of copper and zinc to terrestrial systems is expected to be of concern at deposition rates expected for obscurant release.

There are many reports of recognizable copper, zinc, and even brass contamination and their effect on the environment, but few deal with the release of obscurant materials in the form used as the obscuring material or at rates and times of exposure that can be documented. The data available for direct effect of obscurant release on terrestrial environments are in the forms of two distinct scenarios. The first is the effect of obscuring material introduced directly into the soil, and second is the effect of material deposited to soil and foliar surfaces.

Other than the amount of material deposited, one of the most important factors controlling obscurant toxicity is the soil type and chemistry. The work of several leading researchers, Wentzel and Guelta^{13,14}, and Cataldo et al.⁹, on the topic is discussed. Their work stresses the importance of soils and soil chemistry in determining toxic effects. Soil type used for gathering toxicity data and at the site of application will also be an important factor for those attempting to utilize this Risk Assessment. It is therefore important to describe the soils used in these toxicity studies.

- Burbank: Burbank Sandy Loam (sandy, skeletal, mixed, xeric, Torriorthent), a soil representing the desert areas of Washington, Oregon, and Idaho and having a low cation-exchange capacity (CEC), low organic matter (OM) and neutral pH.
- Cinebar: Cinebar clay loam, Washington Forest soil; high OM and CEC and slightly acidic pH.
- Palouse: Palouse silt loam (fine-silty, mixed, mesic); soil typical of agricultural soil of eastern Washington with moderate OM and CEC, pH of 5.4.
- Palouse + OM: Palouse silt loam soil amended with 0.22% (W/W) dried alfalfa.
- Sassafras: Sassafras sandy loam; typical of eastern tidal agricultural soil, with low pH, OM and CEC.
- Joppa: Joppa sandy loam; sandy soil with high OM, and CEC, with moderately low pH.

Table 5 lists selected properties of the soils used for conducting brass fate and effect studies described in this document.

Table 5. Selected Properties of Soils Used in the Toxicity Studies of Brass Flakes

Soil Property	1. Burbank Sandy Loam	2. Palouse Silt Loam	3. Cinebar Clay Loam	4. Sassafras Sandy Loam	5. Joppa Sandy Loam
% Sand	45.1	1.1	35.2	32.0	50.0
% Silt	51.4	77.5	51.4	50.0	36.0
% Clay	4.0	21.4	13.4	18.0	14.0
pH	7.4	5.4	5.6	4.5	5.1
Organic Carbon	0.5	1.7	7.2	1.0	7.2
CEC(meq/100g)	5.5	23.8	38.2	3.6	8.3
P ₂ O *	4.8	5.8	26.0	3.0	13.0

% P expressed as P₂O

4.2 Soil Microbial Activity.

The impact of brass on soil microbial activity was measured by changes to dehydrogenase and phosphatase activity, soil ATP content, soil microbial-species diversity, and the effects on nitrifying bacteria and total heterotrophic bacteria. Soil microbial activity data is available for soils 1-4 above.

Soil dehydrogenase activity is a measure of general activity of the soil microbial activity. Dehydrogenase activities were severely impacted by brass amendment. At the lowest amendment level, 25 $\mu\text{g/g}$, soil dehydrogenase activity declined by as much as 75% of that in control soils (soils of the same type receiving no brass treatment). Of the soils, Burbank (1) was most susceptible and showed little recovery after 420 days while activity in Cinebar (3) soil was less pronounced and had a somewhat better recovery. For the four soils tested calculated average EcD₅₀ values were 79 $\mu\text{g/g}$. Negative impact of brass flakes on dehydrogenase activity for the soils is ranked Burbank > Palouse+OM > Palouse > Cinebar, based on their 420-day EcD₅₀ values of 24, 113, 189, and 1082 $\mu\text{g/g}$, respectively. Microbial populations in the soils with greater CEC and OM content were better able to tolerate greater depositions of brass.

Soil phosphatase testing measured the activity of soil enzymes that are important for the mineralization of phosphorus from organic matter to forms available to plants. Soil phosphatase activity was affected most in the Burbank soil. LOEL was 25 $\mu\text{g/g}$ for Burbank,

although no observable effect was noted at the 500 $\mu\text{g/g}$ level in the other three soils. All soils were affected at 2500 $\mu\text{g/g}$.

Measuring soil microbial biomass levels after the addition of a compound can indicate how well the soil microbial population will survive. Changes in soil microbial biomass can influence nutrient cycling, decomposition processes, and other important biotic functions that contribute to a stable ecosystem. Measuring ATP from the soil microbial biomass is an easy way to measure the soil microbial biomass. Soil microbial biomass decreased at 7 days to approximately 30% of control in Burbank soil at 500 and 2500 $\mu\text{g/g}$. In the three other soils only the highest level of brass amendment caused ATP levels to drop. After 7 days of incubation the EcD_{50} 's were 375, 1468, 3166, and 2442 $\mu\text{g/g}$ for Burbank (1), Cinebar (3), Palouse (2), and Palouse+OM, respectively.

Microbial diversity may be a useful parameter for assessing the effects of stress on the soil microbial community. The stability of the microbial community requires a certain amount of diversity. A widely used measure of species diversity is the Shannon-Weaver index of species diversity, which is a general diversity index sensitive to species richness and relative species abundance. The effect of brass flake amendment to soil microbial diversity appears to be slight. At 100 $\mu\text{g/g}$, a small enhancement was observed for Cinebar and Palouse+OM soil between 28 and 270 days of incubation. At 2500 $\mu\text{g/g}$ inhibition was noted in Burbank, Cinebar, and Palouse soil at 420 days.

Nitrogen is the nutrient most limiting in agriculture and arid land ecosystems for plant and soil microbial growth and function. Conversion of organic matter is a two step process accomplished by two different nitrifying bacteria, Nitrosomonas sp. and Nitrobacter sp. Nitrosomonas sp. in Burbank was the only soil to show an effect after 2 days at brass concentrations of 500 $\mu\text{g/g}$. Nitrosomonas sp. decreased at the 2500 $\mu\text{g/g}$ level in all soils at the 2 day incubation. Nitrosomonas sp. recovered and increased over controls after an incubation time of 420 days. Nitrobacter sp. was only affected at the 2500 $\mu\text{g/g}$ level in soils after the first 2 days of incubation. Nitrobacter sp. also recovered in all soils over time.

4.3 Effect on Soil Invertebrates .

Wentzel and Guelta⁸ conducted microcosm studies using the earthworm Lumbricus terrestris in a uniformly mixed exposure medium of brass in sandy loam soil, in a standard USEPA 14-day earthworm toxicity test. Testing was also conducted using the same soil contaminated with brass during smoke tests conducted 12-18 mos before exposure testing. Fourteen-day LC_{50} values of 190 $\mu\text{g/g}$ of brass, with 95 % fiducial limits of 56 and 220 $\mu\text{g/g}$ were determined for laboratory contaminated soil. Soil contaminated during field testing showed less toxicity with a 14-day LC_{50} of 340 $\mu\text{g/g}$ brass, with 95 % fiducial limits of 258 and 414 $\mu\text{g/g}$. Data indicated that the toxicity of brass exposed to the environment may be reduced over

time or upon complexing in the soil. Sublethal effects demonstrated in changes in earthworm body weight were noted, with a highest NOEL of 83 $\mu\text{g/g}$.

Wentsel and Guelta¹⁶ also demonstrated the avoidance of earthworms to soils contaminated with brass at concentrations as low as 60 $\mu\text{g/g}$. However, when organic matter (which increases soil CEC) was added to the same soil, earthworm avoidance was less significant with a LOEL of 125 $\mu\text{g/g}$.

Cataldo et al.⁹ conducted testing with the earthworm *Eisenia foetida* in which brass was allowed to be deposited on the surface of microcosms with artificial soil. A LOEL of 445.5 $\mu\text{g/cm}^2$ for 14-day tests, where brass was not mixed with the soil but merely deposited on the soil surface, indicated that earthworms can tolerate high brass surface deposition when conditions prevent brass incorporation into the soil.

4.4 Effects on Plants through Soil Amendment.

The effects of brass flakes on seedling germination and growth have been demonstrated by Wentsel et al.¹⁵. Testing was conducted in the following three soils. a Sassafras sandy loam, collected from "M" field, Edgewood area of Aberdeen Proving Ground, MD represents an acidic soil with low organic matter. This soil, with no pre-existing brass contamination, was used as a control soil and as a base for the M-field brass spiked soil (MS). The same soil type as soil 1, collected from a contaminated area of M-field, M-field contaminated (MC), that had previously been contaminated during open air obscurant testing 12 to 18 mos before initiation of plant toxicity testing. The MC soil was used to indicate persistence of brass toxicity. An acidic Joppa Sandy-loam with high organic matter collected from an area near Winters Run stream Harford County, MD, was used as a control and a base for brass spiked soil (WR). In spiked soils 1 and 3, the brass added was mixed uniformly within the soil. In contaminated soil 2, the soil was thoroughly mixed for a homogeneous brass concentration. Dilutions of contaminated soil 2 were made by adding unspiked soil 1.

Wentsel et al.¹⁵ evaluated germination and seedling growth in the three soils described above over a range of brass concentrations using oat, corn, soybean, and tomato as indicator species selected from EPA's list of sensitive monocotyledons and dicotyledons. Toxicity to plants was evaluated based on seedling germination, plant height and biomass. Seedling germination was shown to have a LOEL of 50 $\mu\text{g/g}$ soil using M-field spiked (MS) soil while Winters Run (WR) soil showed a NOEL of 700 $\mu\text{g/g}$. M-field contaminated (MC) soils showed no significant effect on seedling germination at brass concentrations of 2700 $\mu\text{g/g}$.

Plant growth studies showed significant plant stunting occurred at a LOEL of 50 $\mu\text{g/g}$ in MS soil, while LOEL for WR soil was 370 $\mu\text{g/g}$. For MC soil type, LOEL for seedling stunting was 230 $\mu\text{g/g}$. These results demonstrate the greater buffering capacity a soil (WR)

with high OM and CEC has over the nutrient poorer (MS) soil. The results also show the ability of even a nutrient poor soil (MC) to mitigate to a degree the toxicity of brass once the brass has had time to weather and complex into the soil. This is demonstrated in the difference in the LOEL between MS and MC soils.

Cataldo et al.⁹ conducted seedling germination testing using bush bean, Alfalfa and tall fescue in soils 1-3, Table 5 . Germination was tested 0 and 450 days after amendment at brass levels of 0, 25, 100, 500, and 2500 $\mu\text{g/g}$. No effect of brass amendment on seedling germination was noted at any brass concentration for time 0 or 450 days after amendment.

Cataldo et al.⁹ also investigated effects on plants to soils amended with brass and aged for 160 prior to testing. The plant biomass was used as the indicator of plant stress to brass. Plant dry weight was taken from plants allowed to grow for 470 days after seeding in brass-amended soil 160 days after amendment. Significant biomass reduction was noted for bush bean at brass concentrations of 500 $\mu\text{g/g}$ in Burbank and Palouse soils and 2500 $\mu\text{g/g}$ in Cinebar and Palouse+OM soils. Tall fescue was significantly affected at 500 $\mu\text{g/g}$ in Burbank, Palouse and Palouse+OM while only affected in Cinebar soil at the 2500 $\mu\text{g/g}$ concentration. Again, higher soil CEC and OM content allowed greater buffering of brass toxicity to plants. Plants grown on low-CEC soil, namely Burbank and Palouse, consistently show greater toxic effect than the high-CEC soil, Cinebar. The overall dry-matter accumulation by plants corresponds to soil CEC, with Cinebar > Palouse+OM > Palouse > Burbank.

4.5 Effects on Plants via Foliar Deposition.

Using a wind tunnel at wind velocities of 0.9 to 4.5 m/s, Cataldo⁹ simulated aerial deposition to foliar surfaces of bush bean, sagebrush, Ponderosa pine, short needle pine, and tall fescue. Deposition to plant surfaces varied with specific foliar deposition velocities (see Table 6). Cataldo summarized that leaf structure and geometry played a role in surface deposition as well as material resuspension at different wind velocities.

Contact toxicity of brass to foliar surfaces was evaluated by observations of plant wilting, leaf curl, and leaf dropping over a 30-day period. The metabolic response of the plants was assessed by measuring net photosynthesis and dark respiration of tall fescue and Ponderosa pine for up to 21 days following exposure. Finally, plant biomass production in tall fescue was measured 30 and 60 days post-exposure.

With the exception of sagebrush at the 4.5 m/s wind speed, no damage to plant tissue was observed. Plant photosynthetic rate for 0.9 and 1.8 m/s tests was reduced slightly after exposure while metabolic rates for the 4.5 m/s test decreased for several days after exposure. Initial losses of metabolic activity were possibly related to thigmotropic response to the force of the wind itself or to the shading of leaf surfaces by deposited brass. It was noted that although a substantial portion of brass remained on leaf surfaces, photosynthetic activity returned to normal levels after several days

Table 6. Foliar Mass Loading of Brass Flakes to Vegetation During Wind Tunnel Testing.

Species	Wind Speed (m/s)	Foliar Mass Loading ($\mu\text{g}/\text{cm}^2$ sd, n=6)
Bush Bean	0.9	84.30 \pm 14.40
	1.8	149.72 \pm 37.05
	2.7	305.80 \pm 105.47
	4.5	443.94 \pm 72.04
Sagebrush	0.9	193.71 \pm 31.54
	1.8	444.07 \pm 44.28
	2.7	650.70 \pm 81.84
	4.5	1095.40 \pm 302.06
Ponderosa Pine	0.9	243.86 \pm 50.93
	1.8	622.49 \pm 133.16
	2.7	443.25 \pm 64.08
	4.5	237.01 \pm 58.55
Short-Needle Pine	0.9	283.78 \pm 45.76
	1.8	694.11 \pm 164.83
	2.7	546.51 \pm 129.92
	4.5	400.94 \pm 153.79
Tall Fescue	0.9	79.83 \pm 7.90
	1.8	238.68 \pm 15.44
	2.7	240.39 \pm 38.40
	4.5	291.85 \pm 72.34

Brass deposited to leaf surfaces did produce a significant but small decrease in biomass production over the first 30 days after exposure. Biomass production at higher deposition levels from 2.7 and 4.5 m/s wind speed tests were 12 to 18 % below control plant production.

5. RISK CHARACTERIZATION

Risk characterization is the final phase of risk assessment. During this phase, the likelihood of adverse effects occurring as a result of exposure to stress is evaluated. Risk Characterization has two major steps which are risk estimation and risk description. The stressor-response profile from the analysis phase serves as input to risk estimation. The uncertainties identified during all phases of the risk assessment are analyzed and summarized.

Supporting information in the form of a weight-of-evidence discussion is also presented during this step².

Risk description has two primary elements. The first is the ecological risk summary, which summarizes the results of the risk estimation and uncertainty analysis and assesses confidence in the risk estimation through a discussion of the weight-of-evidence. The second element is interpretation of ecological significance, which describes the magnitude of the identified risks to the assessment endpoint².

To predict the impact that testing with the M76 will have on the terrestrial environment, a scenario for dissemination conditions and the soil types that will be exposed to the brass deposition has been chosen. Several types of soils have been discussed along with their associated levels of toxicity when exposed to or amended with brass. Where toxicity values are a function of soil type (e.g., earthworm or plant toxicity using amended soil, brass soil penetration studies), the toxicity data discussed will be that generated from tests using the Sassafras sandy loam collected from the M-field area of Aberdeen Proving Ground, MD, and the Burbank sandy loam used by Cataldo et al.⁹ in brass acute toxicity testing. In keeping with accepted risk assessment practices, the position of assuming worst case scenarios in calculating possible environmental exposure and environmental impact is taken.

The Sassafras and Burbank sandy loam are relatively nutrient poor soils. The high sand content with low CEC and OM content may be similar to the soils found in the southeastern U.S. where there are several troop training and test sites. Of the soil types studied, the sandy loam is the soil in which brass contamination will have its highest rate of bioavailability, thus representing an environmentally conservative toxicological scenario.

The aerial deposition scenario employed is that of relatively calm wind with moderate atmospheric mixing. The amount of material released is that equal to the payload of a single salvo of 12 M76 grenades. This scenario is used since it is consistent with the deposition numbers reported by Bowers et al.¹¹, and Driver et al.³ Case 3 scenario.

5.1 **Risk Estimation.**

To be a risk to any assessment endpoints or environmental components, a stressor must be demonstrated to co-exist, be available to, or be in contact with the components of the environment at risk. We have described the environment at risk as a generic terrestrial environment consisting of grasslands or meadow. The components of the ecosystem at risk have also been described as green plants, soil invertebrates, and various soil microbiota. When brass obscurant material is disseminated during training or testing exercises, two basic things happen to the disseminated material. First, the plume is carried with the ambient wind currents. The plume expands as it mixes with the air and becomes less dense as it travels downwind. Second, as the plume moves, material is lost or deposited to any surrounding stationary surfaces that the plume encounters. Of most interest are those surfaces that are or can affect local environmental

media, like soils, plants and/or animals.

5.1.1 **Integration of Stressor-Response and Exposure Profiles.**

Three general approaches to demonstrate the integration of the stressor-response and exposure profiles are as follows:

- comparing single effect and exposure values
- comparing distributions of effects and exposure
- conducting simulation modeling.

Because these are areas of active research, particularly in the assessment community and landscape-level perturbations, additional integration approaches are likely to be available in the future. The final choice as to which approach will be selected depends on the original purpose of the assessment as well as time and data constraints². In this assessment, the comparison of single effect and exposure values will be used. This method is also referred to as the "Quotient Method" and will be discussed later in this section.

5.1.1.1 **Exposure Profile.**

The characterization of exposure section has presented modeled data from Cataldo et al.⁹ and deposition data collected from actual field testing by Bowers et al.¹¹ for brass plume concentrations and deposition rates for several wind conditions and atmospheric stability scenarios. These data are very useful in determining the availability of brass material to the environmental components. The characterization of exposure section also presented data for movement of brass into the soil to a depth of as much as 5.0 cm. Data from Cataldo et al.⁹ indicated that brass only mixed into the top 1.0 cm of the soil.

The value of 5.0 cm has been chosen for this assessment for several reasons. The first is that to demonstrate any toxicity the stressor must be in contact with the environmental components. The root zone for many annual grasses and other non-woody plant species is generally accepted to be the top 6 (15.5 cm) of soil. The use of 5.0 cm penetration point would put the brass stressor into the top portion of the plant root zone. In the calculation of ecological risk to an environment, it is appropriate to use conservative approaches to evaluating risk, especially in the Tier 1 investigation. That is the approach that tends to show greater chances of toxic effects,(i.e., to assume the worst). The use of the 5.0 cm penetration will therefore demonstrate availability to a larger portion of the soil and plant environment. Secondly, although this may be a trade-off that results in lower soil brass concentrations due to a dilution effect. during training exercises the tracked vehicle that would normally be equipped with a Rapid Obscuration System (ROS) would easily disturb the top several centimeters of soil as it travels through an area of brass deposition, causing incorporation of brass into the soil.

Deposition quantities measured by Bowers et al.¹¹, and models employed by Cataldo et al.⁹ presented in the exposure analysis section, are again presented below. The modeled Case 3 scenario from Cataldo et al.⁹, that of low wind conditions and moderate atmospheric mixing, has been used in calculating deposition and soil concentrations. This represents the greatest chance for environmental impact and most closely represents meteorological conditions that existed during the testing conducted by Bowers et al.¹².

Table 7. Plume Centerline Brass Surface Deposition Data and Calculated Soil Concentration From Samples Collected from Dissemination of a Single M76 Grenade Salvo from Bowers et al.¹¹ Brass Soil Concentrations Calculated from Bowers Soil Surface Deposition Data.

Distance Downwind Meters (M)	Brass Surface Deposition mg/M ²	Brass Soil Concentration ug/g
40	2000	2.76E+01
65	135	1.86E+00
115	54	7.40E-01
115	56	7.70E-01
255	11	1.50E-01
315	4	5.50E-02
315	1	1.38E-02
615	1	1.38E-02

Table 8 Brass Surface Deposition and Soil Concentration Data Calculated By Cataldo et. al.⁹ Using a Modified Gaussian Plume Dispersion Model. Data from Table 2, Case 3. Brass Soil Concentration Calculated Using Cataldo's Case 3 Dissemination Scenario.

Distance downwind Meters (M)	Brass Surface Deposition mg/M ²	Brass Concentration in Soil ug/g
100	5.10E+01	7.03E-01
200	1.80E+01	2.48E-01
400	5.40E+00	7.45E-02
700	2.10E+00	2.89E-02
1000	1.10E+00	1.52E-02
2000	3.70E-01	5.10E-03
4000	1.30E-01	1.79E-03
7000	5.80E-02	8.00E-04
10000	3.60E-02	4.96E-04

5.1.1.2 Dose-Response Profile.

The dose-response profile is a summary of the data available from existing laboratory toxicity testing. As mentioned earlier, the test organisms employed in these tests are indicator species used routinely in laboratory testing to represent species that may be common to many natural environments. Indicator species used may also come from USEPA's list of sensitive indicator species. For a site specific Tier 1 ERA, actual species known to be present on site may be substituted for indicator species.

From the conceptual model in the problem formulation section, exposure was described as from two possible routes: (1) direct exposure from surface deposition and (2) exposure from material deposited to the soil surface and incorporated into the soil chemical/nutrient system, made biologically available to the plants root systems, soil invertebrates and soil microbiota. Direct exposure from surface deposition is discussed first.

In plant foliar deposition studies conducted by Cataldo et. al.⁹, NOEL was established in wind tunnel testing. Foliar deposition as high as 650.7 $\mu\text{g}/\text{cm}^2$ for sagebrush, 443.9 $\mu\text{g}/\text{cm}^2$ for bush bean, 622.5 $\mu\text{g}/\text{cm}^2$ for Ponderosa pine, 649.1 $\mu\text{g}/\text{cm}^2$ for short needle pine, and 291.8 $\mu\text{g}/\text{cm}^2$ for tall fescue produced no contact phytotoxicity. Although some reduction in net plant photosynthesis and respiration was observed, this was attributed to leaf shading by deposited material and not due to any toxic effect. Cataldo et al.⁹ also observed that any gentle agitation and normal rainfall removed brass deposits from the leaf surfaces, therefore, in a natural setting, brass deposition would not be expected to persist. Shortly after brass removal, plant photosynthesis and respiration returned to normal levels.

Toxic effects from brass deposition to soil surfaces has also not been clearly established. This may be due in part to avoidance to surface contamination by earthworms. Wentzel and Guelta¹⁶, demonstrated earthworm avoidance to brass contaminated at brass soil concentrations as low as 60 $\mu\text{g}/\text{g}$. Cataldo et al.⁹, noted no earthworm fatalities in testing effect of brass deposition to soil at brass soil surface deposition levels of 445 $\mu\text{g}/\text{cm}^2$. Cataldo noted that some deleterious effect was observed as loss of responsiveness to handling at 14 days post-exposure. This sublethal effect is considered unrealistic in the natural setting, because testing was done in shallow exposure chambers (25 mm) where earthworms were perhaps unable to avoid contact with surface depositions. Although no lethal effects to earthworms were demonstrated, the effect of earthworm avoidance to the area of contamination represents a loss of habitat for the earthworm and potential reduction in beneficial soil parameters enhanced by the presence of earthworms.

Presently, data are limited on the effect of surface deposition of brass material to soil microbial activity. Data for soil microbial response are available from Cataldo et al.⁹, however, this testing used mixtures of brass and fog oil (FO) deposited to the soil surface.

Because it is proposed that FO added to brass may have a beneficial synergistic effect, the estimated values of brass deposition are higher than expected for the proposed deposition scenario, and the data available are inappropriate for determining single stressor, dose-response effects.

Data are available for the toxic effects of brass mixed in soil to plants, earthworms, and soil microbiota. The effects of brass-amended soil have been presented in the Characterization of Ecological Effects section of this ERA. Detrimental effects to plant seed germination, seedling growth, and overall plant productivity are indicated by decreases in total plant biomass. The effect on plants was shown to be more significant in the nutrient-limited soils, (Sassafras and Burbank sandy loams), than in the more fertile soils tested. As mentioned earlier, the estimation of negative impact will be based on tests using the more nutrient limited soils. Wentsel et al.¹⁵ reported an LOEL for seed germination and seedling growth in plant indicator species at a brass soil concentration of 50.0 $\mu\text{g/g}$. This effect was demonstrated shortly after soil was amended with brass smoke. Other studies by Cataldo et al.⁹ demonstrated a soil buffering potential. Amended soil aged for 160 days before plant toxicity testing showed lower toxic effects than newly spiked soil. Brass speciation studies showed that the bioavailability of brass material in the soil decreased with time. These studies also demonstrated different abilities to buffer brass contamination based on soil CEC, pH, and OM. The sandy loam soils tested showed the lowest buffering ability.

The quantification of the initial brass toxicity in soil to plants does not consider the buffering effect a soil may have on plant toxicity over time. Because the timing of brass deposition to the soil may coincide with a critical plant life stage, the LOEL value observed immediately after soil amendment will be used. For any indication of possible negative impact from brass in soil, the LOEL employed will be 50.0 $\mu\text{g/g}$. The potential for recovery due to soil buffering abilities will be discussed later in this section.

The toxicity of brass-amended soil to earthworms has also been documented. Studies by Wentsel and Guelta^{8,16} evaluated toxic effects, including lethal and sublethal effects and earthworm avoidance to brass-amended Sassafras sandy loam soil. Of the earthworm responses to tests discussed thus far, the earthworm avoidance of brass contamination is the most sensitive indicator of stress to soil invertebrates. Unlike plants and soil microbiota, the mobility of the earthworm allows avoidance and evacuation of contaminated soils when the stressor is present in sufficient concentrations. Earthworms play an overall role in maintaining soil fertility, and the abandonment of brass-contaminated areas represents an overall decline in environmental quality for the abandoned portion of a terrestrial environment. The intent of any ERA is to quantify impact to the environment, including loss of habitat. In this ERA, the LOEL for invertebrates will be the earthworm avoidance level reported by Wentsel and Guelta¹⁶ as 60.0 $\mu\text{g/g}$ using Sassafras sandy loam soil.

5.1.1.3 Hazard Quotient Index.

As mentioned earlier, the risk characterization section of an ERA brings together the exposure and response information in a manner that quantifies the risk to the environment under consideration. The three general approaches to this quantifying risk are (1) comparing single effect and exposure values; (2) comparing distributions of effects and exposure; and (3) conducting simulation modeling. The nature of the stressor or stressors, and the increasing level of sophistication of the ERA from, Tier 1 to Tier 2 or Tier 3, help determine the quantifying approach in assessing possible hazard levels¹⁸. The intent of this ERA is that of a predictive, Tier 1 assessment. The level of abstractness and Tier 1 approach used in this ERA combine to give the results of information in broad application. The fact that this ERA is not site-specific dictates the level of abstraction and contributes to the selected method of evaluation. When an ERA is used for BRAC, the ERA is very site-specific, often with multiple stressors. This ERA addresses only the single predicted stressor, brass smoke material. The method employed for quantification of possible effects will be that of comparing single effect and exposure values. This method is also known as the quotient method or hazard quotient (HQ) index.

The HQ is a tool primarily useful in Tier 1 and some Tier 2 levels of investigation. Simple hazard quotients are point estimates relating presumed or measured point concentrations to known or extrapolated levels of effect of a given toxicant. Conceptually, the hazard quotient is represented as:

$$HQ = EEC/TEC$$

Where EEC is the expected exposure point concentration and TEC is the appropriate toxicological endpoint concentration. As a basis for risk assessment, a separate HQ is calculated for each contaminant/receptor pair¹⁵.

The measured deposition values from Bowers et al.¹¹ (Table 3) will be used for calculating EEC and HQ values for this ERA. The TEC values employed will be those identified in Section 5.1.1.2 from available laboratory toxicological data for earthworms and plants. The TEC is limited to assessment endpoints where a measurable response of LOEL has been effectively established. In the event that contradicting information has been obtained, the use of the information is left to the judgement of the risk assessor. The risk assessor may also use professional judgement to eliminate nonrepresentable measurement endpoints from the assessment process. This may occur when an established LOEL would produce an HQ orders of magnitude lower than what may be possibly experienced in the field. From the conceptual model, it was speculated that brass material may impact the environment through two scenarios that follow

- from direct deposition to plant foliar surfaces and the soil

- through incorporation into the soil through penetration or mixing.

From the data presented in the Ecological Effects and Risk Characterization section, it was concluded that

- there is NOEL for direct brass deposition to plants⁹
- there is NOEL to earthworms from brass material deposited to the soil surface.

Therefore, these two routes of brass exposure may not directly cause any measurable adverse environmental impact, but do have a threshold below which there is no observable environmental impact.

The data that have been presented that does imply possible adverse environmental impact include effects on plants, soil invertebrates, and soil microbes through soil amendment.

Data have been presented that document movement of brass material 5.0 cm deep into the soil¹³. Brass soil concentrations have been calculated based on this 5.0 cm depth and used brass surface deposition rates measured by Bowers et al.¹¹. The calculated brass soil concentration levels and calculated HQ levels for possible effect of brass on the soil microbial activity, earthworm avoidance, seed germination and seedling growth are listed in Table 9.

Table 9. Predicted Hazard Quotients Calculated for Soil Microbial Dehydrogenase and Phosphatase Activity, Plant Seedling Germination and Growth, and Earthworm Avoidance at Specific Distances Downwind from the Detonation Point of a Salvo of M76 Grenades.

Distance	Brass Soil	Soil Microbial	Soil Microbial	Seedling	Earthworm
Downwind	Concentration	Dehydrogenase	Phosphatase	Germination &	Avoidance
Meters (M)	ug/g	Activity, HC	Activity, HC	Growth, HC	HC
40	2.76E+01	1.104	1.104	0.552	0.46
65	1.86E+00	0.0745	0.0745	0.0372	0.031
115	7.40E-01	0.0296	0.0296	0.0148	0.0123
115	7.70E-01	0.0308	0.0308	0.0154	0.0128
255	1.50E-01	0.006	0.006	0.003	0.0025
315	5.50E-02	0.0022	0.0022	0.0011	0.0083
315	1.38E-02	0.00055	0.00055	0.00027	0.00023
615	1.38E-02	0.00055	0.00055	0.00027	0.00023

The HQ values presented in Table 9 are indications that the associated stress response will be observed under the prescribed exposure scenario. Once again, the dissemination scenario for this ERA is detonation of a single M76 grenade salvo under relatively gentle wind and atmospheric mixing conditions. The chance of observing the stress response are more likely as the HQ values approach 1. The higher the value is above 1, the more likely the chance that the stress response will occur.

Table 10 documents the environmental assessment endpoint, the measured assessment endpoint stress response, and the environmental measurement endpoint used in a HQ index determination. The most sensitive indicator of environmental stress for this assessment has been shown to be the effect on the soil microbial community. For factors including soil dehydrogenase and phosphatase activity, total microbial biomass production, microbial diversity, and total nitrogen-fixing bacteria, only the soil total dehydrogenase and phosphatase activity have HQ values near 1, and those occur only at the highest expected brass soil concentration. Soil microbial biomass production, diversity, and total nitrogen fixing bacteria have LOEL and HQ values low enough to eliminate those particular stress responses from consideration. Therefore, the stressor response indicators that remain and show potential negative impact are soil microbial dehydrogenase and phosphatase activity, earthworm avoidance, and seedling germination and growth.

Table 10. Environmental Endpoints, Measured Stress Response and Measurements Endpoints Used in HQ Index Calculations

Assessment Endpoint	Stressor Response	Measurement Endpoint
Soil Microbial Activity	soil dehydrogenase & phosphatase activity	LOEL, 25.0 ug/g
Soil Invertebrates Loss of Habitat	earthworm avoidance	LOEL, 60.0 ug/g
Plants, Primary Production	plant seed germination seedling growth	LOEL, 50.0 ug/g

The proposed dissemination scenario for this assessment is the activation of a ROS mounted on a tracked or wheeled tactical vehicle with the detonation of a complete salvo of M76 grenades. The meteorological conditions would include low wind conditions and low atmospheric turbulence. These conditions would cause the least amount of cloud dispersal and maximum amount of deposition in the area near the detonation point. These conditions are near those observed by Bowers et al.¹¹ during collection of deposited brass material from a M76 grenade salvo. The brass deposition data collected¹¹ closely agree with data developed using the Volume Surface Diffusion Model¹². Using deposition numbers generated by Bowers et al.,¹¹ and

brass fate in soil data from Wentsel and Guelta⁸ brass soil concentration data have been calculated for points downwind from the detonation point (Table 9). The integration of effects data from laboratory studies, using indicator species tested in a sandy loam soil, has allowed expression of possible exposure-responses in the form of a hazard quotient. For this given scenario, some effect on soil microbes in the area of grenade detonation to a point perhaps 40 M downwind could be expected. This prediction is based on the HQ calculated to be near or above "1" in Table 9. The effect to plants and earthworms would be expected to be negligible if any effect was present at all. However, dissemination of additional grenades at the same site would be expected to have an additive effect.

5.1.2 Uncertainty.

The uncertainty analysis identifies and, to the extent possible, quantifies the uncertainty in the problem formulation, analysis, and risk characterization phases. The uncertainties from each of these phases of the process are carried through as part of the total uncertainty in the risk assessment. The output from the uncertainty analysis is an evaluation of the impact of the uncertainties on the overall assessment and, when feasible, a description of the ways in which uncertainty could be reduced².

Outcome uncertainty infers a degree of risk uncertainty. The degree of uncertainty around the estimate is related to the precision of the stressor-response used and the degree to which any indicator species employed represent the response of site-specific populations. The more conservative response variables are more likely to err on the side of safety. Within each tier, there will be assumptions and uncertainties involved in characterizing the ecological risk. By the nature of the lower effort and cost at the lower tiers, risk characterization will have larger uncertainties. The benefit of more focused effort in the higher tiers becomes primarily one of incorporating more site-specific information, thus reducing the need for simplifying assumptions, and therefore reducing the level of associated uncertainty⁷.

Specific uncertainties of this predictive assessment lie first in the use of a generic environment under consideration. While the description of a terrestrial field environment is reasonably appropriate for a smoke training site, the site-specific soil type and use of native flora and fauna species for determining stress-response profiles would eliminate much of the uncertainty. The use of site-specific meteorological conditions, including a matrix of possible test condition scenarios would improve assessment accuracy. In the event of need for an ERA to support testing at a specific site, the risk manager would be advised to conduct a site-specific Tier 1 or Tier 2 assessment when possible.

The use of generic environmental descriptions and indicator-species for this predictive risk assessment is appropriate for the level of investigation. There are presently some data gaps that could be filled if a more specific assessment was required. Effects of brass on other terrestrial producers (insects), movement of material up the food chain, and direct effects

on wildlife exposed to brass material smoke plumes are areas presently open for further investigation. The predictive effect of a smoke exercise on more sensitive local aquatic environments, although outside the application of this assessment, is also open for investigation.

5.2 **Risk Description.**

Risk description has two primary elements. The first is the ecological risk summary, which summarizes the results of the risk estimation and uncertainty analysis and assesses confidence in the risk estimates through a discussion of the weight of evidence. The second element is the interpretation of ecological significance, which describes the magnitude of the identified risks to the assessment endpoint.

5.2.1 **Ecological Risk Summary.**

The ecological risk summary summarizes the results of the risk estimation and discusses the uncertainties associated with the problem formulation, analysis, and risk characterization phases. Next, the confidence in the risk estimates is expressed through a weight-of-evidence discussion. The ecological risk summary may conclude with identification of additional analyses required or data that might reduce the uncertainty in the risk estimates².

Section 5.1 of this ERA presented the stressor-response profiles associated with the dissemination, deposition, and environmental impact of brass smoke material. The degree of toxicity has been related to the types of environmental components that the brass material contacts. The risk associated with direct deposition to plant and soil surfaces pose virtually no direct risk to plants or organisms living below the soil surface. However, if brass becomes incorporated into the soil chemistry or nutrient cycle, there is a direct dose-response relationship with plants, soil invertebrates, and soil microbiota. As discussed earlier, such incorporation into the soil may occur when tracked vehicles pass over soils with brass deposition. Although this assessment did not discuss site-specific data, it often alluded to variations in toxic levels that are associated with different soil types. The most distinguishing factor is the buffering capacity of the soil and its corresponding capacity to reduce ecotoxic effects due to the presence of brass by binding with brass into chemical forms that are less bioavailable. Every soil type will tend to have a different buffering capacity based on its CEC, pH, and OM content. Generally, nutrient-rich, fertile soils have a larger buffering capacity than nutrient-poor sandy soil. The discussions of soil type versus toxic effects are best reserved for a more site-specific assessment. It was never the intention of this assessment to cover all possible scenarios. For the most part, the assumptions made and scenarios employed are perhaps more conservative than would be seen at the average field site. However, there may be sites and scenarios where the dissemination assumptions and soil types employed may be very near those represented here.

The scenario proposed in the Problem Formulation portion of this ERA is appropriate and sound for the level of sophistication intended. Most frequently, an ERA is intended for a specific site where a stressor or even multiple stressors have already been released. In that instance, fewer assumptions would be made, an actual site-specific environment-of-concern would be properly identified and site-specific plant and animal species would be evaluated for stressor-response profiles.

The data presented in the Characterization of Exposure phase of this ERA was also appropriate for this predictive, Tier 1 assessment. The modeling of smoke plumes over complex terrain is still in its infancy. The models employed by Bowers et al.,¹² and Cataldo et al.,⁹, are appropriate for a predictive generic assessment such as this. In the presence of site-specific data on terrain and meteorological conditions, perhaps more precise modeling would be possible. Testing by Bowers'et al.,¹¹ adequately validated the information gained through the Volume Surface Depletion Model. Other than possible further validation of brass deposition testing and model validation, including additional deposition data points directly in the vicinity of dissemination, the deposition data were adequate.

The Characterization of Ecological Effects section presented sufficient data for the intended complexity of this ERA. The data presented from Wentsel et al.^{14,15}, and Wentsel and Guelta⁸ and Cataldo et al.⁹ mutually corroborate the importance of differences in bioavailability of brass material in different soil types and the effects on a variety of plant species when exposed to brass amended soil. The characterization of ecological effects would benefit by determinations of both effects to wildlife and effects on the food chain, such as biomagnification information which is presently unavailable. In the event that such site-specific assessment was to be performed, the ecological effects section should include site-specific plant and animal species as well as soil types for stressor-response characterization.

5.2.2 Interpretation of Ecological Significance.

The interpretation of ecological significance places risk estimates in the context of the types and extent of anticipated effects. It provides a critical link between estimation of risks and the communication of assessment results. The interpretation step relies on professional judgement and may emphasize different aspects depending on the assessment. Several aspects of ecological significance that may be considered include the nature and magnitude of the effects, the spatial and temporal patterns of the effects, and the potential for recovery².

The predictive nature of this assessment limits the degree to which specification of ecological significance can be made. Repetitive use of brass smoke material is certain to accumulate in the soils at training or testing sites, as well as areas downwind. The level of effects is difficult to predict without direct application to a specific site due to the differences in

soil type, buffering capacity, and incorporation of brass, as well as decreases in brass toxicity with aging in the field. The data presented in this ERA indicated the possibility of adverse effects to soil microbial activity only in the immediate area of dissemination (within 40 M of the detonation area). In the event that the environment of concern consisted of a soil more fertile than those used in the assessment examples, the effect from a single grenade salvo may produce little or no permanent effect. However, testing or training sites are rarely established with the intent of conducting only one test. The sites, once established, would be used many times and there would be certain accumulation of materials in the soils. Still, the level of effect would be determined by the buffering capacity and pH of the soil. Another consideration would be the types of plant and invertebrates species present. In a dry area, wild plant species could have root zones much deeper than anticipated brass penetration. In this area, surface concentrations of brass could become elevated without impacting established vegetation. In the event that soil brass levels were accumulating in the top few centimeters, there may be potential negative impact on the establishment of new plants from seedlings or root elongation. Brass accumulation could have a significant effect on establishment of new vegetation when roots are near the surface in shallow zones of contamination. If vegetation were, stripped or killed, re-establishing a young vegetative crop could be difficult.

The effect on soil invertebrates could be negligible in a nutrient rich soil with a high buffering capacity. In poor soils, the additive effect of continued testing could cause earthworms to avoid the area where brass levels are above their tolerance levels. Insect larvae living near the soil surface could also be affected.

Soil microbial populations seem to be the most sensitive of the terrestrial community inhabitants. Whereas most of the richer soils tested had good buffering capacities, heavy use of a specific site could cause brass concentrations to reach toxic levels.

In studies done by Cataldo et al.,⁹ it was determined that all soils tested had the capacity to recover at all levels tested, even those at high concentration levels representing multiple releases such as happens at training sites. Wentzel and Guelta⁸ established that soils contaminated months before testing were much less toxic than recently amended soils. As the brass material in soil weathers, it tends to have reduced toxicity as it ages in and reacts with the soil. Treatment of soils with the addition of pH buffers and organic matter has also been shown to reduce toxic effects of brass.

Training site environmental coordinators, risk managers and troop training activity officers need to understand the potential negative impact proposed training exercises may have on a particular sites environment. Training sites that are located in an area with sandy soils(which have low in OM, soil nutrients, and CEC), will have a low buffering capacity against the toxic effects of brass. Training sites with soils that have higher clay content and are more fertile, with higher OM and correspondingly high CEC, will have a greater buffering capacity. These are good generalizations; however, the effect levels associated with brass smoke dissemination must be evaluated on a more site-specific basis. The use of brass smoke and other

materials should be monitored at any test site. Site remediation is possible when necessary, but accumulation of brass contamination to toxic levels should be avoided through risk management and development and use of more environmentally-safe smokes for training purposes.

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