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Metals that Drive Health-Based Remedial Decisions for Soils at U.S. Department of Defense Sites

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ABSTRACT

This study was undertaken to establish which metals are most likely to drive the risk-based remedial decision-making process at those U.S. Department of Defense (DoD) sites that are affected by metals in site soils. Our approach combined queries of various databases, interviews with U.S. Environmental Protection Agency (USEPA) experts in each Region, and communication with database administrators and DoD personnel. The databases that were used were comprehensive for DoD sites, yet sometimes contained inaccuracies. Metal concentration data for various DoD facilities were screened against established regulatory criteria for both human health and ecological endpoints. Results from this analysis were compared against the information gleaned from the interviews. This preliminary analysis indicates that the five metals that most frequently exceeded risk-based screening criteria for potential human health concerns at DoD sites, in descending order of frequency, are lead, arsenic, cadmium, chromium, and antimony. The metals that most frequently exceeded ecological screening criteria, in order, are lead, cadmium, mercury, zinc, arsenic, chromium, and selenium. Although the majority of USEPA personnel interviewed indicated that human health risk, rather than ecological endpoints, generally drives remedial decision-making, the data indicated that ecological screening thresholds were exceeded more often than human health standards.

Key Words: metals in soil, Department of Defense, human health risk, ecological risk, remedial decision-making.

INTRODUCTION

The U.S. Department of Defense (DoD) has undertaken the task of cleaning up wastes that have resulted from industrial, commercial, training, and weapons testing activities, as well as cleaning up and closing military bases so that properties can be transferred to local communities for economic revitalization (USEPA 1997a). It is estimated that DoD is responsible for remediation of approximately 8000 sites in

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the United States, a majority of which (67%) contain metal contamination in soils (USEPA 1997a). Among the challenges in this effort is the process of prioritizing sites for clean up, and determining what needs to be cleaned up and to what extent.

For properties on which soils are contaminated with metals, the amount of the metal in soil that could actually be absorbed by human or ecological receptors (*i.e.*, the bioavailability of the metal) can be an important factor in determining the degree to which the contaminated soils need to be remediated. This occurs because the bioavailability of metals from soil is generally less than that assumed by the default values used in human health and ecological risk assessment.

Frequently, the factors that determine bioavailability are highly site specific. Thus, to guide research on bioavailability of metals from soil, the research reported herein was undertaken to determine which metals potentially drive risk-based remedial decisions for soils at DoD sites. The research was structured to answer the following three questions:

1. What metals potentially drive risk-based remedial decisions at DoD facilities?
2. For facilities where more than one metal exceeds risk-based screening criteria, what are the metals of concern, and how do they compare in perceived importance?
3. For the metals that most often exceed the screening criteria, what is the receptor of greatest concern (human or ecological)?

To accomplish this, information was solicited from:

- Various branches of the military (Army, Navy, Air Force)
- U.S. Environmental Protection Agency (USEPA) regional toxicologists
- Coordinators within the Federal Facilities Restoration and Reuse Office (FFRRO)
- Comprehensive Environmental Response, Compensation and Liability Information System (CERCLIS)
- USEPA Records of Decision (RODs)
- DoD Environmental Cleanup Office.

This article describes the avenues that were pursued to locate useful information, presents the data obtained, describes the manner in which these data were assessed, and discusses the conclusions that can be drawn regarding the metals and exposure pathways that are important determinants for remediation of metals in soils at DoD facilities.

METHODS

Various individuals within the DoD and USEPA were contacted to identify sources of information on metal concentrations at DoD sites, their potential for health effects on human and ecological receptors, and their influence on remedial decisions for soil. Our goal in contacting these individuals was to identify and gain access to databases that would provide answers to the three questions posed in the Introduction. Overall, we found that no single database exists that contains the entirety of the information we sought. Therefore, we extracted information from several sources, and augmented the data with subjective opinions of professionals involved in the assessment and remediation of federal facilities. Selection of individuals who provided opinions and information is described in the section titled "USEPA Interviews."

Databases

Ultimately, we identified five databases that could be queried to provide information relevant to our task. Three were military databases: the Environmental Restoration Program Information Management System (ERPIMS) database from the Air Force, an unnamed database containing metals data from Army sites, and the Normalization of Environmental Data System (NORM) database from the Navy. We also analyzed the data contained in the Restoration Management Information System (RMIS) maintained by the Environmental Cleanup Office of the DoD, and the CERCLIS database maintained by the USEPA. In addition, the Superfund Hazardous Waste Site website (available at http://www.epa.gov/superfund/) includes a Resource Center in which databases can be searched by the general public. Using the advanced query option, we extracted information pertaining to Site Names, CERCLIS ID, Site ID, City, Metal Contaminants of Concern, and Contaminated Media (we selected soil); however, no concentration data were available on this website.

At the outset of our effort to collect data, we also attempted to obtain information from the database on Records of Decision (RODs INFO) maintained by the USEPA. The RODs INFO database provides a compilation of the information that is part of Records of Decision for sites that have been addressed under the Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA, generally referred to as "Superfund"). While this information may have proved quite useful, extracting appropriate data from this database was extremely cumbersome. In addition, the database includes information only for sites where RODs have been issued, thus excluding sites where data exist but a remedial approach has not been selected, and a ROD has therefore not been issued. Because of these obstacles, the RODs INFO search was aborted, and subsequent efforts focused on the other available databases.

Ultimately, we received from each of the databases a download of information, hereafter referred to as "data sets," regarding the soil concentration data for sites that are known to have metals in soil. These concentration data were then compared to a consistent set of risk-based screening criteria (described later) to determine which metals most frequently exceeded these criteria.

It is important to note that we generally relied on the information in the data sets as supplied by the various sources. Aside from very minor modifications required to streamline the screening (*e.g.*, standardization of units and spelling of metal names), few changes were made to the data sets, and the integrity of each data set was not compromised. It was assumed that the information provided in the data sets was technically accurate, and no outside verification of the data was performed. However, we did identify what appeared to be errors within several of the databases. It was beyond the scope of this evaluation to verify and/or correct the data included in the various databases; however, specifics regarding the flaws identified in the databases, and their implications, are discussed further in the Conclusions.

USEPA Interviews

In addition to the objective information provided by the data sets, we queried individuals who are involved with the risk assessment of federal facilities regarding their opinions on the questions posed in the Introduction. Specifically, within each of the 10 USEPA regions, we attempted to contact a Regional Toxicologist and the Regional Contact in the FFRRO. We were not able to interview both of these persons in every region, but we persisted until we had made contact with at least one individual in each region. These individuals were asked the questions listed in the Introduction, and their responses are discussed later.

Screening Criteria

As described earlier, the Army, NORM, ERPIMS, RMIS, and CERCLIS databases were queried by their database managers, and query results from each database were provided to the authors. The data sets included soil metal concentrations for sites where metals had been detected. The concentrations in each data set were then compared to health-based screening criteria to determine which sites contained metals in soil at concentrations that exceed screening criteria and might, therefore, suggest a further need for investigative consideration in health risk assessments.

Screening criteria are used during Step 2 of the Superfund Ecological Risk Assessment process, the screening-level risk calculation (USEPA 1997b, 1998, 1999). These criteria are intentionally conservative and are tools used to facilitate prompt identification of contaminants and exposure areas of concern during both remedial actions and some removal actions under CERCLA (USEPA 1996). The screening values are risk-based (*i.e.*, derived from toxicity information and assumptions regarding potential exposure levels) and are used to determine whether additional study is warranted, but do not necessarily eliminate the need to conduct site-specific risk assessments. If environmental concentrations of chemicals are below the screening criteria, then it is reasonable to assume that the chemicals present no significant potential for adverse health effects. Exceeding the screening levels suggests the potential need for further evaluation. Additionally, these levels can be used as Preliminary Remediation Goals (PRGs), provided appropriate conditions are met (USEPA 1999). Therefore, given the importance of health-based screening levels in the decision-making process, these criteria were compared to the soil concentrations provided in the data sets to draw preliminary conclusions regarding which metals may warrant additional study and potential remediation at DoD sites.

To conduct this screening, we compiled health-based screening concentrations for several endpoints. Because we were interested in determining what metals require further risk investigation for both human and wildlife receptors, we screened the site concentration data against criteria based on human health (for both industrial and residential exposure scenarios) and ecological receptors (mammalian and avian receptors).

Human Health Criteria

Human health criteria were obtained from USEPA's Soil Screening Guidance (USEPA 2001), which is a tool developed by USEPA to help standardize and accelerate the evaluation and cleanup of contaminated soils at sites on the National Priorities List (NPL) for which future land use may be residential. Criteria adopted from the generic Soil Screening Levels (SSLs) that were developed for combined ingestion and dermal exposure in a residential scenario were used to assess human receptors in a residential setting (USEPA 2001). Screening criteria that would be protective under industrial land use were selected from the generic SSLs for an outdoor worker scenario (USEPA 2001).

All values were used as reported by USEPA, with the exception of arsenic. For arsenic, the health-based screening criteria reported by USEPA are 0.4 mg/kg and 2 mg/kg for the residential and industrial land use scenario, respectively. Although these values are consistent with the specified method for setting screening levels equal to a cancer risk of one in a million, these specific values fall below background concentrations for arsenic in soil throughout much of the United States (Dragun and Chiasson 1991). Regulatory agencies have acknowledged this complicating issue with the standard screening values for arsenic, and they recommend use of alternative risk-based screening values for arsenic that fall within USEPA's "acceptable cancer risk range of 10E-6 to 10E-4" (USEPA 2000a; Washington State Dept. of Ecology 2001). Therefore, both the residential and industrial criteria for arsenic listed by USEPA were multiplied by a factor of 10, effectively raising the target cancer risk associated with each to one in one hundred thousand, the middle of the acceptable risk range specified by USEPA. This was done to ensure that the importance of arsenic in risk-based decisions was not artificially elevated due to the natural background concentrations for this metal.

If the USEPA guidance did not contain values for the metals that were measured at DoD sites, health-based screening values from USEPA Region IX Preliminary Remediation Goals (PRGs) were incorporated as surrogates (USEPA 2000a). These values were selected as surrogates because of their common use by regulatory agencies outside of Region IX, and because their derivation is similar to the SSLs and incorporates several routes of potential exposure, thereby resulting in more health-protective screening values. Table 1 lists the human health-based screening criteria, and denotes whether the values were selected from the list of SSLs (USEPA 2001) or PRGs (USEPA 2000a).

Ecological Criteria

Specific screening values for avian and mammalian receptors were selected for each metal. Ecological Soil Screening Levels (EcoSSLs; USEPA 2000b) were used, if they were available. If EcoSSLs for avian and mammalian receptors were not available for a particular metal, we used the Preliminary Remediation Goals for Ecological Endpoints (Efroymson *et al.* 1997)—specifically, American woodcock goals—as a surrogate for avian screening values, and short-tail shrew goals as a surrogate for mammalian screening values. Table 1 lists the specific values and the source for each of the ecological screening criteria that were used in this evaluation.

Although it is beyond the scope of this report to review the technical basis and merits of the screening value for each metal, it is important to mention that the screening concentration for mercury is highly conservative for use in most contexts. This is because the current screening value (from Efroymson *et al.* 1997) is based on

Table 1. Human health and ecological screening criteria.

	Human health criteria		Ecological receptor criteria	
Metal	Residential	Industrial	Mammalian	Avian
Arsenic	4[a,b]	20[a,b]	9.9[c]	102[c]
Lead	400[b]	750[b]	740[c]	40.5[c]
Cadmium	70[b]	900[b]	6[c]	4.2[c]
Copper	2900[d]	76000[d]	370[c]	515[c]
Chromium	230[b]	3,400[b]	360[e]	21[e]
Nickel	1,600[b]	23,000[b]	246[c]	121[c]
Zinc	23,000[b]	340,000[b]	1,600[c]	8.5[c]
Mercury	23[b]	340[b]	0.146[c]	0.00051[c]
Aluminum	76,000[d]	100,000[d]	—	—
Antimony	31[b]	450[b]	21[e]	—
Barium	5,500[b]	79,000[b]	329[c]	283[c]
Beryllium	160[b]	2,300[b]	—	—
Boron	5,500[d]	79,000[d]	—	—
Cobalt	4,700[d]	100,000[d]	340[e]	32[e]
Iron	23,000[d]	100,000[d]	—	—
Lithium	1,600[d]	41,000[d]	390[c]	—
Manganese	1,800[d]	32,000[d]	—	—
Molybdenum	390[d]	10,000[d]	4.75[c]	44[c]
Selenium	390[b]	5,700[b]	—	0.000001[c]
Silver	390[b]	5,700[b]	—	—
Strontium	47,000[d]	100,000[d]	—	—
Thallium	6[b]	91[b]	2.1[c]	—
Tin	47,000[d]	100,000[d]	—	—
Vanadium	550[b]	7,900[b]	55[c]	—
Zinc phosphide	23[d]	610[d]	—	—

Chromium(VI) values were used to screen chromium. However, because Cr(VI) criterion was not available for avian receptors, we used Cr(III) criterion instead.
—, data not available.
[a]Increased original value by one order of magnitude; [b]USEPA (2001); [c]Efroymson *et al.* (1997); [d]Region IX PRG (USEPA 2000a); [e]U.S. EPA (2000b).

the assumption that 100% of the mercury present in soils exists as methyl mercury. In aerobic soil environments, which are the soils of interest for evaluating ingestion by wildlife, mercury exists almost entirely in the inorganic form, which is substantially less toxic than the organic form. Therefore, the SSL based on organic mercury is highly conservative for most sites.

DATA ANALYSIS AND RESULTS

Each specific concentration within each of the five data sets was compared to human and ecological screening criteria, and the ratios of the concentrations to the criteria were calculated. If the calculated ratio was less than or equal to unity (*i.e.*, ≤ 1), then it was assumed that the concentration did not present a potential human or ecological health hazard. If the ratio of a concentration to the screening criterion did exceed unity (*i.e.*, value >1), then this was assumed to indicate the potential for affecting risk-based remedial decisions at the site. Fully characterizing the potential risk of adverse effects would require further evaluation on a site-specific basis, but this was beyond the scope of the present project. Therefore, this screening-level approach served as the backbone of the data-set queries that we conducted.

The first set of analyses was aimed at determining, for all data sets combined, which metals most frequently exceeded the health-based screening criteria. For human health screening, the metal concentrations were compared to residential and industrial criteria (Table 1), and for the ecological screening, the metal concentrations were compared to mammalian and avian criteria (Table 1). If data exceeded criteria more than once for a particular site, the site was counted only once. The results denoting the percentage of sites that exceeded human health criteria for each metal are presented in Figure 1, and those that exceeded ecological criteria are displayed in Figure 2.

In the second set of analyses, the five sites presenting the highest potential concern (*i.e.*, the highest ratio of site average metal concentrations to screening criteria when averaged across all metals for each site) were selected from all data sets combined. For those five sites with the highest overall ratio of screening level to site soil concentrations, we determined what metals were present at concentrations above screening values. The goal of this effort was to determine the relative contribution from metals in soil at facilities where more than one metal exceeds screening criteria. This analysis was conducted separately for each potential receptor (human—residential [Figure 3], human—industrial [Figure 4], mammalian [Figure 5], and avian [Figure 6]).

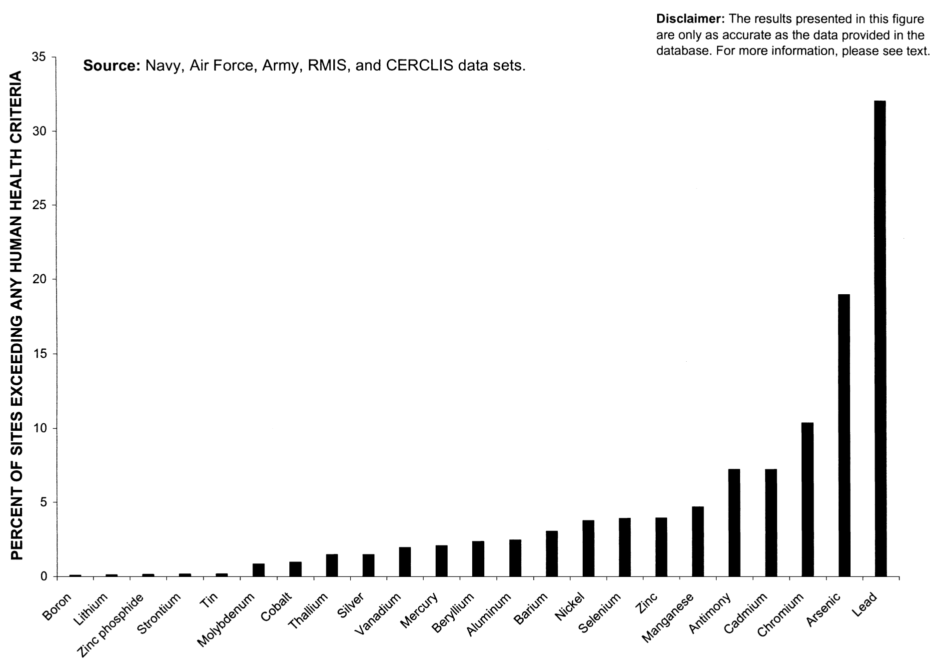

Figure 1. Percent of metal-contaminated sites that exceed any human health criteria (industrial or residential) at least once for all data sets combined.

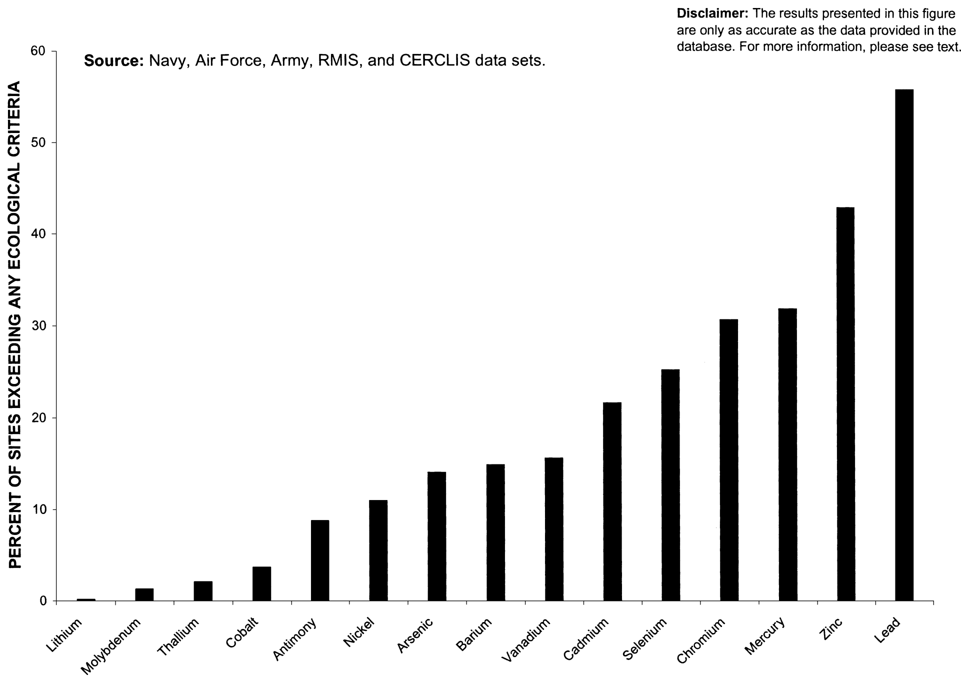

Figure 2. Percent of metal-contaminated sites that exceed any ecological criteria (avian or mammalian) at least once for all data sets combined.

The final analysis was designed to determine what receptor (human—residential, human—industrial, ecological—mammalian, or ecological—avian) is of primary importance for the metals associated with the highest exceedance of screening criteria, across all DoD sites evaluated. To accomplish this, we constructed a table (Table 2) of the metals that exceeded criteria in all data sets combined and indicated the percentage of sites at which specific criteria were exceeded. For each metal, boldface values show the specific receptor for which the highest percentage of sites exceeded the screening criterion.

Interviews With USEPA Staff

Professional staff within each USEPA region were queried regarding their knowledge or impressions of which metals are driving risk-based remedial decisions at DoD sites. The individuals contacted were either regional toxicologists or the Regional Contact for the FFRRO. One individual with the California EPA was also included in the interviews. Five specific questions were posed to each contact:

- Which DoD facilities present risks from potential exposures to metals in soils?
- Which specific metals are of concern?
- Which receptors (human or ecological) are of concern for metals in soils?
- Which human and ecological exposure pathways are potentially of concern for metals in soils?

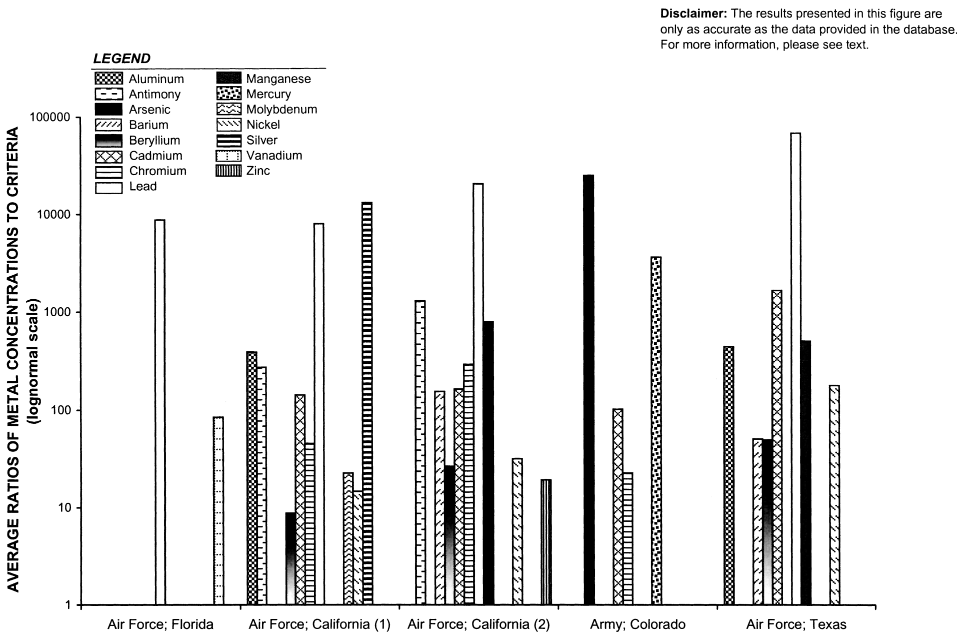

Figure 3. Average ratios of metal concentrations to residential screening criteria for the five sites with the highest screening criteria exceedances across all metals.

- Which human exposure scenarios (*e.g.*, workers, residents, trespassers) are potentially of concern for exposure to metals in soils?

The information provided by these individuals was generally anecdotal. None of the USEPA personnel indicated that they had compiled information from the DoD sites within the region. For some regions (*e.g.*, Region VIII), it appears that metals are not driving risks at the DoD facilities, but rather, organic compounds are the primary concern. In nearly all instances, the interviewees indicated that human receptors were driving remedial decisions, and that ingestion of soils was the exposure pathway of concern. Only occasionally were ecological receptors or other exposure pathways mentioned.

Because of the requirement to evaluate human exposures under the scenario of potential future residential development, residential receptors were the primary receptors of concern, but interviewees indicated that worker, trespasser, and recreational exposure scenarios could also be risk drivers. In general, the metals of concern coincide with the historical land use of the site. For example, lead is of concern for former firing ranges, arsenic appears to be a problem from historical use of pesticides, and chromium occurs near former plating shops. Several individuals suggested that frequent concern about chromium may be an artifact of the screening process, which incorporates the assumption that all chromium occurs in the more toxic hexavalent form, rather than the comparatively benign, but much more environmentally common, trivalent form.

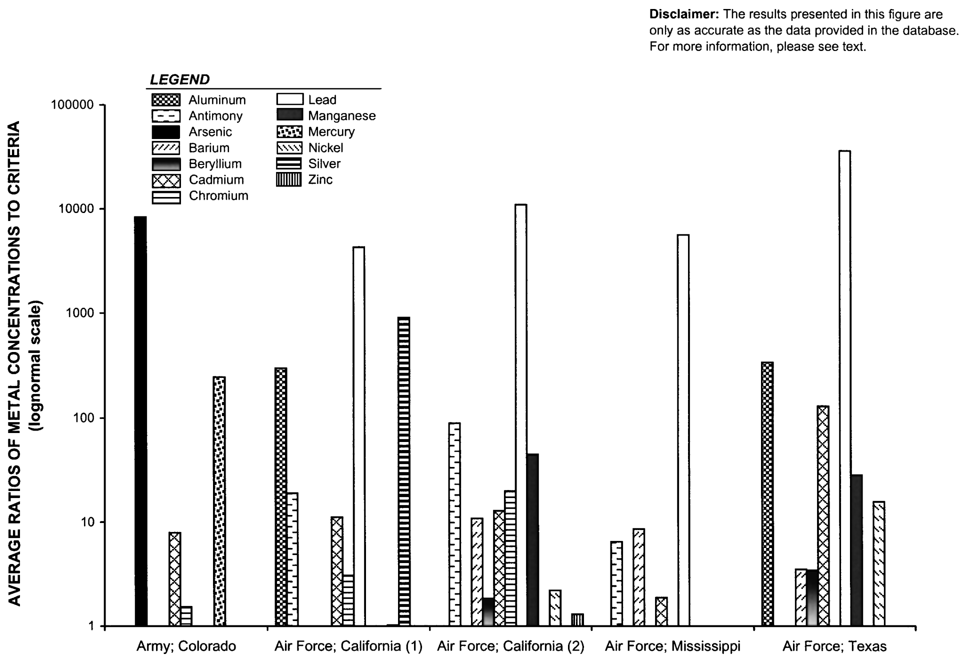

Figure 4. Average ratios of metal concentrations to industrial screening criteria for the five sites with the highest screening criteria exceedances across all metals.

Compilation of the interview results indicates that, overall, lead and arsenic are the metals that most frequently present health threats at DoD facilities. Cadmium and chromium follow next, and then beryllium. No other metals were mentioned consistently during the interviews.

DISCUSSION

What Metals Potentially Drive Risk-Based Remedial Cleanup Decisions at DoD Facilities?

Results presented in Figure 1 suggest that, for human receptors, lead, arsenic, chromium, cadmium, and antimony most commonly exceed residential and industrial human health screening criteria. Figure 2 results suggest that lead, zinc, mercury, chromium, selenium, and cadmium most commonly exceed avian and mammalian ecological screening criteria.

For DoD Facilities Where More Than One Metal Exceeds Screening Criteria, What are the Metals of Concern and How Do They Compare in Perceived Importance?

The answer to this question is depicted for five DoD sites that consistently exceed screening criteria in Figures 3 through 6. These graphs indicate that at the five sites with the highest overall screening criteria exceedances, none of the metals

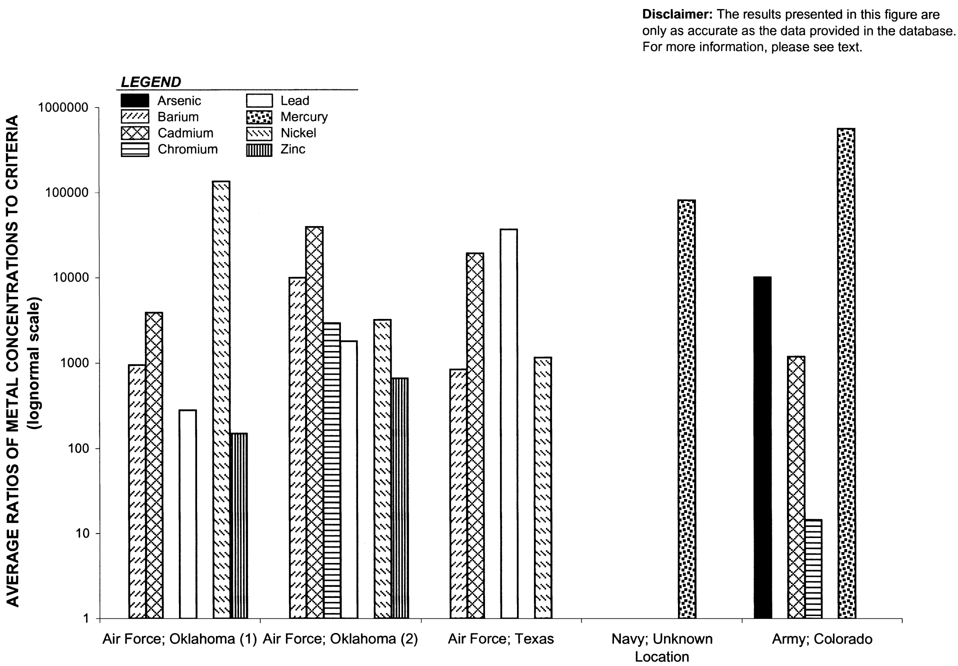

Figure 5. Average ratios of metal concentrations to mammalian screening criteria for the five sites with the highest screening criteria exceedances across all metals.

consistently show an ordered pattern in terms of driving exceedances, with the exception of lead. Lead consistently appears as a metal that exceeds screening criteria in both residential and industrial human receptors (Figures 3 and 4).

For mammalian receptors, none of the metals display an ordered pattern of importance when compared to mammalian screening criteria (Figure 5). However, selenium consistently appeared as the metal that exceeded screening criteria when avian receptors are the focus of screening assessments (Figure 6).

For the Metals with the Highest Exceedance of Screening Criteria, What is the Receptor of Greatest Concern (Human or Ecological)?

Based on the information provided in Table 2, it is evident that screening criteria for ecological receptors (mammalian and avian) were exceeded at more sites than those for human receptors (residential and industrial). This can be seen by scanning the rows for boldface numbers in Table 2, which indicate the receptor that exceeded criteria for the greatest percentage of sites.

These results could be interpreted to indicate that ecological receptors are at greater risk from metals present in soil at DoD sites than are humans, but these results more likely reflect the conservative nature and uncertainty associated with the ecological screening criteria. For example, screening levels for wildlife are typically developed for relatively small species with higher metabolic rates, smaller home ranges, and a clear direct or indirect exposure pathway link to soil. Therefore,

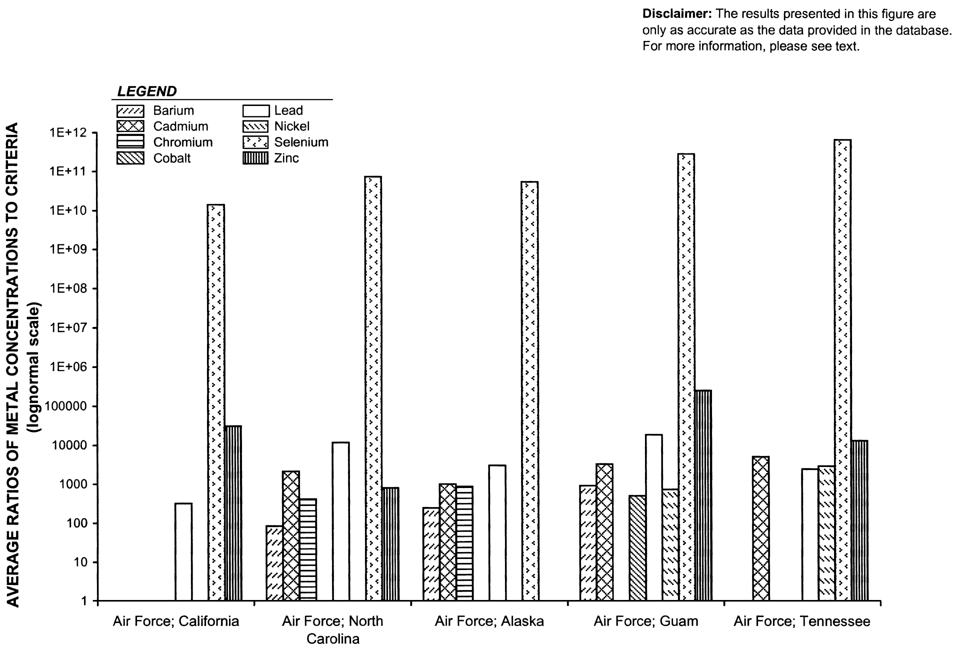

Figure 6. Average ratios of metal concentrations to avian screening criteria for the five sites with the highest screening criteria exceedances across all metals.

exposure could be assumed to be high, providing conservative screening values for various trophic groups (USEPA 2000b). Additionally, soil-screening levels are developed to be protective of rare, endangered, and threatened species that may not be present in the vicinity of a particular site. Also, uncertainty plays a significant role in setting the screening criteria. For ecological receptors, the available database for many metals regarding the toxicity or exposure levels is quite limited. In the face of such uncertainty, conservative (*i.e.*, health-protective) assumptions are incorporated into the calculations, thereby forcing the screening values lower.

Uncertainties Associated with the Data Sets

As discussed earlier, the screening conducted under this effort relied on data supplied by various sources. Global verification of the values reported in each data set was beyond the scope of the study. However, during the screening of the various data sets, we concluded that the databases that were queried to provide us with the relevant information, although comprehensive for DoD sites, are not completely accurate.

For example, the RMIS and Navy data sets occasionally reported impossible metal concentrations in soil media. This took the form of reporting concentrations greater than one million parts per million. After examining the entire RMIS data set that was provided to us, we found that approximately 2% of all the data entries exceed one million parts per million, and that this error occurs for 14 separate metals. These errors may be due to incorrect data entry or incorrect reporting of units. In

Table 2. Percentage of sites exceeding specific criteria.[a]

	Residential	Industrial	Mammalian	Avian
Lead	32.0	25.9	25.9	**55.6**
Zinc	3.8	1.0	10.4	**42.8**
Mercury	1.9	0.27	22.1	**30.4**
Chromium	10.3	3.3	7.9	**30.5**
Cadmium	7.2	3.1	19.1	**21.5**
Arsenic	**14.1**	8.9	10.4	2.2
Copper	7.4	1.3	**13.6**	12.3
Barium	2.9	1.4	12.8	**14.2**
Nickel	3.6	1.4	7.6	**10.9**
Vanadium	1.8	1.3	**14.9**	—
Iron	**14.5**	2.8	—	—
Antimony	6.9	2.1	**8.3**	—
Selenium	1.0	0.44	—	**7.2**
Manganese	**4.4**	1.5	—	—
Aluminum	**2.3**	1.8	—	—
Thallium	1.4	0.20	**1.9**	—
Beryllium	**2.1**	0.55	—	—
Molybdenum	0.20	0.068	**1.2**	0.41
Silver	**1.3**	0.48	—	—
Cobalt	0.24	0	0.38	**1.0**
Lithium	0.068	0	**0.10**	—
Zinc Phosphide	**0.068**	0.034	—	—
Strontium	0.034	0.034	—	—
Tin	0.034	0.034	—	—
Boron	0.034	0	—	—

Source: All data sets. *Note:* — no criteria.
[a]For example, lead concentrations exceeded residential screening crtierion at 32% of the sites. For each metal, the receptor with the greatest percentage of sites exceeding criteria is bolded.

evaluating this data set, caution was used to ensure that these incorrect data did not unduly influence the study results.

CONCLUSIONS

According to USEPA's analysis of the RMIS database (USEPA 1997a), lead was the most frequent soil contaminant associated with DoD sites that exceeded screening criteria. Following lead were nickel, zinc, barium, cadmium, copper, and beryllium. In our analysis of the various databases, the metals that most frequently were associated with exceeding human health screening criteria or remedial action criteria at DoD facilities were lead, arsenic, chromium, cadmium, and antimony (Figure 1). Similar results were obtained from the USEPA staff interviews, which indicated an order of lead, arsenic, chromium, cadmium, and beryllium for the top five metals of concern for human health. The metals at DoD facilities that most frequently exceeded ecologically based screening criteria were lead, zinc, mercury, chromium, and selenium for birds, and arsenic for mammals (Figure 2).

In evaluating these results, it is important to keep in mind that our analysis relied on data only from sites with metals detected in soils. We did not assess the percentage of sites where other compounds are considered potential contaminants of concern. Several of those contacted mentioned that volatile or semi-volatile organic compounds (VOCs or SVOCs) or radioactive components are more important at DoD sites than are metals in soils. However, USEPA indicated that for DoD sites that need cleanup, and that have identified soil contamination, the majority (>70%) are contaminated with metals (USEPA 1997a).

As would be expected, different metals are associated with different site operations. For example, as stated earlier, lead contamination occurs at former firing ranges, arsenic in areas of historical pesticide use, and chromium at locations of former or current plating shops. This association results in significant heterogeneity regarding what metals are of concern, and suggests that contamination by some metals may be relatively localized (*e.g.*, chromium), whereas others may be dispersed (*e.g.*, arsenic). These interviews also indicated that human health considerations usually drive remedial actions for metals in soils, and that ecological receptors typically become an issue only if wetlands and sediments are part of the assessment. This information provided to us from interviews contrasted with our screening of data against different criteria, which indicated that exceedances of screening criteria for ecological receptors occur more frequently than exceedances of human health criteria. Similarly, at sites where more complete risk assessments have been conducted, ecological receptors (*e.g.*, American robin or burrowing animals) can drive risk for metals in soils. The focus on human health considerations may simply reflect the interest or technical background of the individuals interviewed (*e.g.*, more interviewees were human health toxicologists, as opposed to ecologists or ecotoxicologists), or the prioritization of human over ecological health as a general societal trend.

According to USEPA staff interviews, ingestion exposures typically are of greatest concern, whereas dermal exposure is the second most important pathway, followed by inhalation. Dermal absorption was considered an issue only for arsenic and cadmium in soils. However, USEPA staff did report that dermal exposures would be more important if point-of-contact symptoms (*e.g.*, rashes) were "taken more seriously" in the risk assessment process.

The primary goals of this research were to identify and prioritize metals for bioavailability research, and to identify which metals were most relevant to human and ecological receptors. Combined evaluation of the results from the data set screening and the USEPA interviews indicated that bioavailability studies for human receptors should be focused on lead, arsenic, cadmium, chromium, and antimony. A similar evaluation for ecological receptors indicated that bioavailability research should focus on lead, cadmium, mercury, zinc, chromium, arsenic (for mammals), and selenium (for birds).

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