Unexploded Ordnance

A Critical Review of Risk Assessment Methods

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SUMMARY

Unexploded ordnance (UXO) and munitions constituents[1] on former military bases in the United States are causing increasing concern. While civilian fatalities from UXO explosions on U.S. soil have been rare, the risk of such accidents could increase substantially as more closed bases are transferred from military to civilian control. Since the end of the Cold War, approximately 20 percent of major domestic military bases and many smaller ones have been closed and designated for eventual transfer to civilian ownership. Reflecting the growing concern about domestic UXO sites, the National Defense Authorization Act of 2002 directs the Department of Defense to inventory UXO sites, establish a new program element for UXO remediation, and assess progress to date on cleaning up UXO.

This report addresses one part of the process of cleaning up UXO and munitions constituents at domestic military installations: the assessment of risks associated with these contaminants. Risk assessment helps define the technical dimension of UXO problems. It provides a technical basis for setting priorities among sites and choosing among alternative cleanup strategies.

It is important to keep in mind that even the best-designed set of risk assessment methods will not resolve all the controversies that arise at UXO sites. Risk assessment can help to educate the participants in the decision process about the nature and magnitude of risk in-

[1]The term "munitions constituents" refers to any materials originating from UXO or other munitions, including the chemical contaminants that result from their breakdown.

volved. However, the ultimate decision about how to respond to UXO must account for many other factors—including ethical concerns, socioeconomic issues, and costs—in addition to risk. The risk assessor's job is not to decide what risk is acceptable; it is to do the best possible job calculating the risk. Risk assessment can illuminate the nature of risks at UXO sites, but it cannot make people agree on what amount of risk is acceptable. Nonetheless, we believe that pursuing the recommendations below will lead to better-informed decisions about how to manage UXO sites.

In this report, we evaluate the adequacy of methods developed for UXO risk assessment, review the risk assessment methodologies of other federal agencies for possible application to UXO, and propose strategies for improving risk assessment methods for UXO sites.

MULTIPLE RISK ASSESSMENT METHODS ARE NEEDED

A single method for assessing risks at UXO sites will not suffice. Rather, the Army needs to develop different methods for different steps in the UXO risk assessment process and for different elements of UXO risk.

One set of risk assessment methods would establish priorities in the UXO response program. We call this type of method *programmatic prioritization risk assessment*. Such methods could inform decisionmakers about which installations and sites within installations pose the greatest risk and thus merit the most immediate attention. This type of information is useful for allocating financial and other resources, such as equipment and personnel.

The second set of risk assessment methods would provide detailed analyses of specific UXO-contaminated areas within installations. We call this type of method *site-specific risk assessment*. Site-specific risk assessment methods could provide quantitative information about the potential for harm to people living near UXO sites and to local ecosystems. They could also estimate the effectiveness of alternative UXO response options in reducing those risks.

Programmatic prioritization methods and site-specific methods would require different designs. Programmatic prioritization methods would serve as a coarse screen for large groups of sites; their

purpose would be to establish relative risk levels among sites. At the stage when prioritization is usually carried out, site data are often limited. In contrast, site-specific methods would serve as tools for understanding the details about how people and ecosystems might become exposed to UXO and the probable consequences of such exposures using information specific to the sites. Detailed data collection would be necessary for a comprehensive understanding of the risks. As a result of these differences, two risk assessment approaches are needed for UXO sites: one for programmatic prioritization and another for site-specific assessment.

Two sources of risk at UXO sites also must be considered: (1) risks from UXO explosions and (2) risks from munitions constituents that have leached into soil and water. These two hazards differ substantially in the nature of the threats they pose and in the reaction of stakeholders to them. For example, the consequence of a human accidentally detonating UXO is immediate and typically results in serious injury or death. In contrast, the consequence of a human exposure to munitions constituents is most likely chronic and increases the risk of illness only after prolonged exposure. As a result, the methods used to assess explosion risks—whether for establishing priorities or conducting detailed site investigations—will necessarily differ substantially from those used to assess munitions constituents risks.

Thus, one risk assessment method cannot meet all the Army's needs for UXO sites. Different methods are needed for site prioritization and for site-specific assessment. Within each of these methods, different approaches are required to evaluate munitions constituents and explosion risks. Table S.1 summarizes the needs for UXO risk assessment. The last column of the table identifies existing risk assessment methods that could be used or could serve as a model for developing a new method; the basis for this column is discussed below.

ADEQUACY OF AVAILABLE UXO RISK ASSESSMENT METHODS

The Army asked us to review five existing risk assessment methods that were designed specifically for UXO. We compared the attributes

Table S.1

Summary of Needs for UXO Risk Assessment

Use of Risk Assessment	Methods Required to Support Use	Example Questions Answered by Method	Applicable Existing Methods
Programmatic prioritization	Munitions constituents prioritization method	At which sites do munitions chemicals that have leached into soil and water pose the highest risks to public health? At which sites do munitions chemicals in soil and water pose the highest risks to the environment?	EPA Hazard Ranking System Defense Environmental Restoration Program Relative Risk Site Evaluation Primer
	UXO explosion prioritization method	At which sites does the potential for accidental UXO detonation pose the highest risks to the public? At which sites does the potential for accidental UXO detonation pose the highest risks to workers?	Risk Assessment Code (modified with stakeholder input)
Site-specific assessment	Munitions constituents site-specific assessment method	What is the probability that those living near a specific UXO site will experience health problems (e.g., cancer, lead poisoning) due to exposure to munitions chemicals in local soil and water?	EPA Risk Assessment Guidance for Superfund EPA Ecological Risk Assessment Guidance for Superfund

Table S.1—continued

Use of Risk Assessment	Methods Required to Support Use	Example Questions Answered by Method	Applicable Existing Methods
		How and to what extent might munitions chemicals in soil and water damage the local ecosystem? How will the probability of adverse health consequences change due to specific remediation methods at sites?	
	UXO explosion site-specific assessment method	What is the probability that a person living near a given UXO site will be harmed by accidental UXO detonation? If all UXO items on the surface are cleared, what is the probability of a person being harmed by remaining, buried UXO? If detection devices are used to identify and clear UXO to a given depth, what is the probability of a person being harmed by any remaining UXO? If future land-use scenarios are changed, how will the probability of a person being injured by UXO change?	Probabilistic risk assessment (used by the Nuclear Regulatory Commission, National Aeronautics and Space Administration, Army Chemical Stockpile Program, and others; details for UXO application would need to be developed)

of these methods to criteria necessary for a technically sound risk assessment. We developed these criteria based on a survey of risk assessment literature and consultations with leading national experts in risk assessment. We conclude that none of the five risk assessment methods fully answers the Army's needs, either for programmatic prioritization or for site-specific assessment. Table S.2 summarizes the results of our evaluation and the basis for this conclusion.

APPLICABLE CONCEPTS FROM RISK ASSESSMENT METHODS OF OTHER FEDERAL PROGRAMS

Our review of risk assessment approaches available from other federal programs indicates that some of them apply directly to assessing some (but not all) of the risks associated with UXO sites, as Table S.1 indicates. Many others are not directly applicable to UXO risk assessment, but they provide examples of approaches for addressing problems in risk assessment that the Army has encountered at UXO sites. Chapter Four describes a range of federal methods for analyzing uncertainty, involving stakeholders and gaining their trust, standardizing the risk analysis process, and considering multiple end points in risk assessment. We do not repeat the details here.

As Table S.1 shows, *existing methods from other programs can be applied directly to assessing the risks of munitions constituents in soil and water*. No new methods need to be developed for this purpose. The Defense Environmental Restoration Program Relative Risk Site Evaluation Primer and the Environmental Protection Agency's Hazard Ranking System, Risk Assessment Guidance for Superfund, and Ecological Risk Assessment Guidance for Superfund all meet needs for assessing risks from munitions constituents. The former two methods are well established for prioritizing sites according to risks posed by chemical contaminants that have dissolved in water, absorbed to soil, or dissolved in the air in spaces between soil grains. The latter two methods are well established for site-specific assessment of risks from contaminants in water or present in soil. Munitions constituents, when present in relatively dilute concentrations in soil and water, can be treated just as any other type of chemical contaminant in soil and water; they pose no unique risks, compared to other types of contaminants found at hazardous waste sites.

Table S.2

Overview of UXO Risk Assessment Methods

Method	Purpose	Pros	Cons	Summary Evaluation
Interim Range Rule Risk Methodology (IR3M)	Assess	Simple output	Output does not always correlate to risk Output can mask important risk information Decision rules not technically justified Basis for input values not justified Not always reproducible Does not address uncertainty Data requirements insufficient to reflect problem complexity Instructions unclear	Significant limitations; should not be developed further
Ordnance and Explosives Cost Effectiveness Risk Tool (OECert)	Developed to prioritize, but in practice used to assess	Comprehensive modeling of exposure process Analytical process used to determine explosion potential of different munitions Adaptable	Does not address munitions constituents risk Exposure models not validated Many exposure assumptions not justified Uncertainties not addressed Calculations not presented clearly Not easily communicated to stakeholders Lack of stakeholder involvement in developing exposure assumptions	Elements of the method (exposure models, UXO categorization method) might form part of future risk assessment method but would need much refinement

Table S.2—continued

Method	Purpose	Pros	Cons	Summary Evaluation
Risk Assessment Code (RAC)	Prioritize	Appears logically sound Assumptions clearly explained Reproducible Practical (data requirements suitable for purpose) Adaptable	Does not consider munitions constituents Does not address uncertainty Basis for some assumptions not provided	Well suited for purpose, but only addresses explosion risk; assumptions may need to be modified with stakeholder input
Ordnance and Explosives Risk Impact Analysis (OERIA)	Assess	Easy to use Adaptable	Does not address munitions constituents risk Risk model relation to actual magnitude of site risk unknown Assumptions not explained Uncertainty not addressed Not reproducible Data requirements too minimal for use Results easily manipulated	Has many limitations and should be discontinued
Natural and Cultural Resources Bank (NCRB)	Prioritize	Appears to be reproducible Adaptable	Focused exclusively on ecological risks Does not consider munitions constituents Assumptions not justified Uncertainties not addressed Instructions somewhat unclear	Meets need to identify UXO sites with regulatory requirements related to natural or cultural resources, but needs substantial further development and validation

Table S.1 also indicates that existing methods from other programs could serve as models for developing new site-specific explosion risk assessment methods. The probabilistic risk assessment (PRA) approaches used by the Army Chemical Stockpile Disposal Program, the Federal Aviation Administration, the National Aeronautics and Space Administration, and the Nuclear Regulatory Commission provide representative examples. In particular, the fault tree and event tree analysis tools used in PRA seem most relevant. These tools are used for systematic mapping of the steps necessary to trigger acute events. The approaches are widely used not only in the federal government but also in industry for determining the probability of system failures and identifying the most important contributors to the risks of those failures. These tools could meet the need for a new method to assess site-specific UXO explosion risk.

No existing method is adequate for considering both explosion risk and munitions constituents risk when prioritizing sites. A new process will need to be developed for this purpose. Nonetheless, as Table S.1 shows, the Risk Assessment Code could be modified and combined with the Relative Risk Site Evaluation Primer or the Hazard Ranking System for the purpose of prioritization.

RECOMMENDATIONS

In summary, two separate processes are needed for UXO risk assessment. The first would apply to prioritizing UXO sites across the nation to determine which sites pose the greatest risks. The second process would be used for detailed evaluations of appropriate responses to UXO at specific sites. Within each process, separate methods are needed for assessing explosion risks and for assessing other constituent risks. None of the existing methods developed for UXO risk assessment that we reviewed is suitable for any of these applications, although elements of some of the methods could serve as input to new methods.

We recommend the following steps toward improving risk-based prioritization of UXO sites:

- **Develop a new UXO prioritization process that (1) sorts sites into bins by explosion risk and (2) within these bins, sorts sites by munitions constituents risks.** The suggested prioritization

process would preserve the information about the two separate risk types: although sites would be grouped first according to explosion risk, within these groups the sites would be ordered by munitions constituents risk. Policymakers could then decide how to distribute limited resources among sites with different combinations of explosion and constituent risk.

- **Develop a new process for sorting sites by explosion risk (stage one of the prioritization process).** The existing Risk Assessment Code could provide elements for the new process, but stakeholder concerns would need to be addressed.
- **Use the EPA Hazard Ranking System or Defense Environmental Restoration Program Relative Risk Site Evaluation Primer for sorting sites by munitions constituents risks (stage two of the prioritization process).** These methods are well established and well accepted. There is no need for a new approach for munitions constituents risk ranking, since the behavior of these contaminants and the risks they pose are analogous to those of chemical contaminants found at non-UXO hazardous waste sites.
- **Produce two UXO site priority lists: one for sites with known and documented future land use and another for sites with uncertain future land use.** Having two lists would prevent manipulation of the process by choosing the least restrictive land uses. Also, it would allow policymakers to decide how to trade off current and future risks when allocating funds. The lists could be updated periodically (e.g., annually) or as often as new information became available.
- **Appoint an independent technical review board and an advisory committee of stakeholders to oversee development of the prioritization process.** The technical board would consist of independent experts in risk assessment and explosive ordnance disposal. The advisory committee would include representatives of the different groups of stakeholders (state regulators, federal regulators, Native Americans, members of the public, military personnel) involved at UXO sites.

We recommend the following steps for improving risk-based selection of remedies at UXO sites:

- **Use available processes (RAGS and ERAGS) for site-specific assessment of munitions constituents risks.** RAGS and ERAGS are well established for assessing risks of chemicals in water and soil, and there is no need for the Army to develop a new method.
- **Develop a new, probabilistic approach using fault and event trees or similar methods for site-specific assessment of explosion risks.** None of the available UXO explosion risk assessment methods by itself satisfies technical criteria for an effective risk assessment method, so a new approach is needed. Many other agencies use probabilistic risk assessment tools to assess risks of acute events analogous to UXO explosion.
- **Create a set of fault and/or event trees at the national level that could serve as templates for local assessments and guidelines for use of those trees in computing probabilistic risk estimates.** One advantage of tree-based approaches is that they are easily adapted to local conditions, but having national models in place would allow for efficient development of trees at the local level. With significant modification and stakeholder input, some of the exposure scenarios developed for the Ordnance and Explosives Cost-Effectiveness Risk Tool might provide elements of UXO probabilistic risk assessments.
- **Involve an independent technical review board and an advisory committee of stakeholders from the beginning of development of the probabilistic site-specific risk assessment process.** Seeking input from independent reviewers as the risk assessment process is conceived will ensure that it is technically sound and that it meets the needs of stakeholders.