DETERMINING THE "R" IN ALARA: A PARAMETRIC STUDY TO ESTABLISH CLEANUP CRITERIA

R. Bonilla, R. T. Johnson, and N. Ramachandran
Bechtel National, Inc.
Oak Ridge, TN

ABSTRACT

This paper describes the use of a tool for establishing criteria for cleanup of low-level radioactive contamination that will result in cost-effective remedial action. Central to this tool is the application of the principles of ALARA (as low as reasonably achievable). ALARA goals are driven by a desire to remediate a site to meet the strictest criteria practicable; to meet economic requirements, waste volumes must be minimized. The result of using this tool is the development of a remedial action program that satisfies ALARA requirements while limiting health and environmental risks to acceptable levels.

Topics discussed in depth include the ALARA process, its principles, and its application to remedial action programs. The paper concludes with a case study in which the tool is applied to establishing cleanup criteria for the Department of Energy's Formerly Utilized Sites Remedial Action Program (FUSRAP).

INTRODUCTION

The Department of Energy (DOE) has adopted ALARA (as low as reasonably achievable) principles for use in the Formerly Utilized Sites Remedial Action Program (FUSRAP). FUSRAP was initiated in 1974 to identify, cleanup, or otherwise control sites where radioactive contamination remains from the early years of the nation's atomic energy program or from commercial operations causing conditions that Congress authorized DOE to remedy. As project management contractor for FUSRAP, Bechtel National, Inc. (BNI) has taken an integral role in the development of standard procedures for planning and performing remedial action. The objective of these guidelines is to limit potential health risks from exposure to contaminated materials while remaining within practical economic and operational limits. To evaluate the guidelines according to ALARA principles, a parametric analysis is recommended.

DOE has established radiological protection guidelines for cleanup of residual radioactive material at FUSRAP sites. The guidelines for radioactivity levels and radionuclide concentrations are applicable to sites to be released for public or private use without radiological restrictions. The guidelines are classified as either: (1) generic, such as existing radiation standards, or (2) site-specific, derived from site-specific exposure models and data. Levels for radium-226, radium-228, thorium-230, and thorium-232 (four of the most prevalent isotopes found in FUSRAP investigations) are stated in the generic guidelines (1). Consideration of the other prevalent radionuclides, specifically isotopes of uranium, fall in the second category. DOE currently uses the RESRAD computer model to develop total uranium cleanup criteria based on a maximum allowable nonoccupational exposure limit of 100 mrem/yr above background. Other regulatory agencies often disagree with these criteria in favor of lower values. Thus, determination of a cleanup level that is acceptable to those agencies and meets the goals of ALARA is necessary.

THE ALARA PHILOSOPHY

Application of ALARA principles is required in DOE Orders on environmental protection and safety and health and in DOE guidelines for residual radioactive material. Requirements for limiting radiation exposures to as-low-as-practicable levels were introduced in the Energy Research and Development Administration Manual, Chapter 0524, in 1975. These requirements formalized the position practiced within DOE and by its contractors and did not represent a new commitment. Applying ALARA principles is a process with basically one objective: to attain dose levels that are as far below applicable limits as is practicable and reasonably achievable, taking into account technical, economic, safety, and social factors. No single set of specific and detailed criteria exists as a prescription for achieving the ALARA objective. Instead, general guidance, in the form of broad principles, has been established to acquaint management with ALARA concepts.

Therefore, no defined set of dose levels exists for determining when ALARA objectives are achieved. For example, when an area cannot be decontaminated to the derived concentration guideline, a decision must be made as to whether the area can be used without radiological restrictions or whether controls will be required (2, 3, 4, 5).

Applying ALARA principles during remedial action is in many cases more complex than applying it during operating situations. Factors that must be identified and considered when selecting remedial action alternatives include characteristics of the waste stream, pathways of contaminant migration, individual exposure to contaminants, and cost of remedial action over time. Two approaches are used for determining ALARA objectives: (1) qualitative, or judgmental, procedures, or (2) quantitative, or optimization, procedures.

The first, more traditional method for determining ALARA requirements consists of a decision-maker judging each situation based on an understanding relevant economic, social, and technical factors. The most important economic factor is the cost of performing remedial action, including costs for planning, operation, labor, materials, equipment, energy, and services over the period of remediation and any subsequent maintenance and monitoring activities. Implementing either a remedial action or a no-action alternative may have positive or negative effects on everyday operations at a site and/or the environment.

Social factors include risks to the people exposed to contamination and perceptions about exposure risks. To meet ALARA objectives, reductions in risks before and after remedial action should be compared to the incremental risk during the remedial action. Risk studies should identify potential users and individuals in the area near the remedial action site following completion of the remedial action. In addition, risk studies should consider incremental risk from exposure to contaminants to individuals in the same area and to workers during remedial action activities.

Technical factors are primarily related to the techniques used to determine the extent of contamination and the remedial action alternatives (3).

The International Commission on Radiological Protection recommended the use of cost-benefit analysis as a method for balancing cost against benefit to achieve the objectives of ALARA. Cost-benefit analysis is a quantitative technique that compares risk (and therefore costs of health factors related to radiation) with the cost of reducing levels of radiation. This relationship can be expressed as a simple mathematical expression:

Benefit $\geq$ Cost + Risk

This expression is idealized and many unknowns and subjective factors complicate its use. Cost-benefit analysis is a procedure for quantitatively determining some of the input to a specific decision concerning radiological protection. In applying this to an ALARA program, the difficulty of determining how to measure costs and benefits becomes obvious. Some investigators have attempted to assign monetary value to the effects of exposure to radiation. The cost/risk ratio for deriving ALARA guidelines is assumed to be $1,000 per person-rem. It is usually assumed that a linear extrapolation of risks versus dosage holds at all levels down to zero (2, 3, 5). Unlike risk cost, which is defined by a linear relationship, dose reduction cost follows a hyperbolic trend. Larger doses are reduced at low relative costs. As doses become smaller, each additional increment of dose reduction becomes more costly. If both curves (cost of dose reduction and cost of risk) are plotted and summed, a minimum is obtained. The minimum represents the theoretical optimum situation whereby an incremental increase in the cost of protection is exactly balanced by a corresponding incremental decrease in the cost of detriment.

THE TOOL

The tool is an X-Y graph showing the relationship between volume of soil to be remediated and cleanup criteria (Fig. 1). The graph represents a hyperbolic function of the two variables. The y-axis represents the volume of soil to be remediated (but may be modified to represent cost). Cost is all inclusive of labor, equipment, material, personnel protective equipment, and other related items. The x-axis represents cleanup criteria. Therefore, for *varying cleanup* criteria, the volume to be remediated and the accompanying costs are determined and plotted.

Managers can use this tool to decide whether to perform cleanup based on the funds available, realizing that cleanup would not meet required criteria, or to make budgetary plans, based on the graph, to remediate to the criteria. The optimum point for achieving remedial action objectives while meeting ALARA goals based only on cost and cleanup criteria is determined by extending tangents from the two asymptotic regions of the curve to the point of intersection and bisecting the angle thus formed (Fig. 1). Determining volume for varying cleanup criteria will be discussed later. However, controls for health and environmental risks will always be maintained, as the safety of personnel performing the cleanup or those who reside near the remedial action site is not negotiable.

As shown in the graph, the volume of soil to be removed drops at a high rate as cleanup criteria are relaxed. The drop in volume is abrupt at the lower end of the criteria, meaning that a slight relaxation could bring about great cost savings, unlike the upper end where the curve is smoother and great savings cannot be achieved without sacrificing ALARA goals and possibly health and environmental safety. Therefore, care should be taken in generating data for the graph and un using the graph for decision making.

If available, risk that correlates to the criteria for which volumes were determined may be shown on the right side y-axis (Fig. 1). This can be done by extending a vertical line from the criteria on the x-axis to the risk-versus-criteria curve, and projecting a horizontal line from that intersection to a point on the newly created y-axis and denoting the calculated risk value. The newly created axis reflects risk increasing with relaxation in criteria or decrease in volume. Risk tends to drop with stringent criteria or increase in volume. Determining risk is a complex task in itself and is beyond the scope of this paper. Managers could use this graph to determine not only volumes of soil to be remediated for a particular criteria, but also the related risk that may be incurred in doing so.

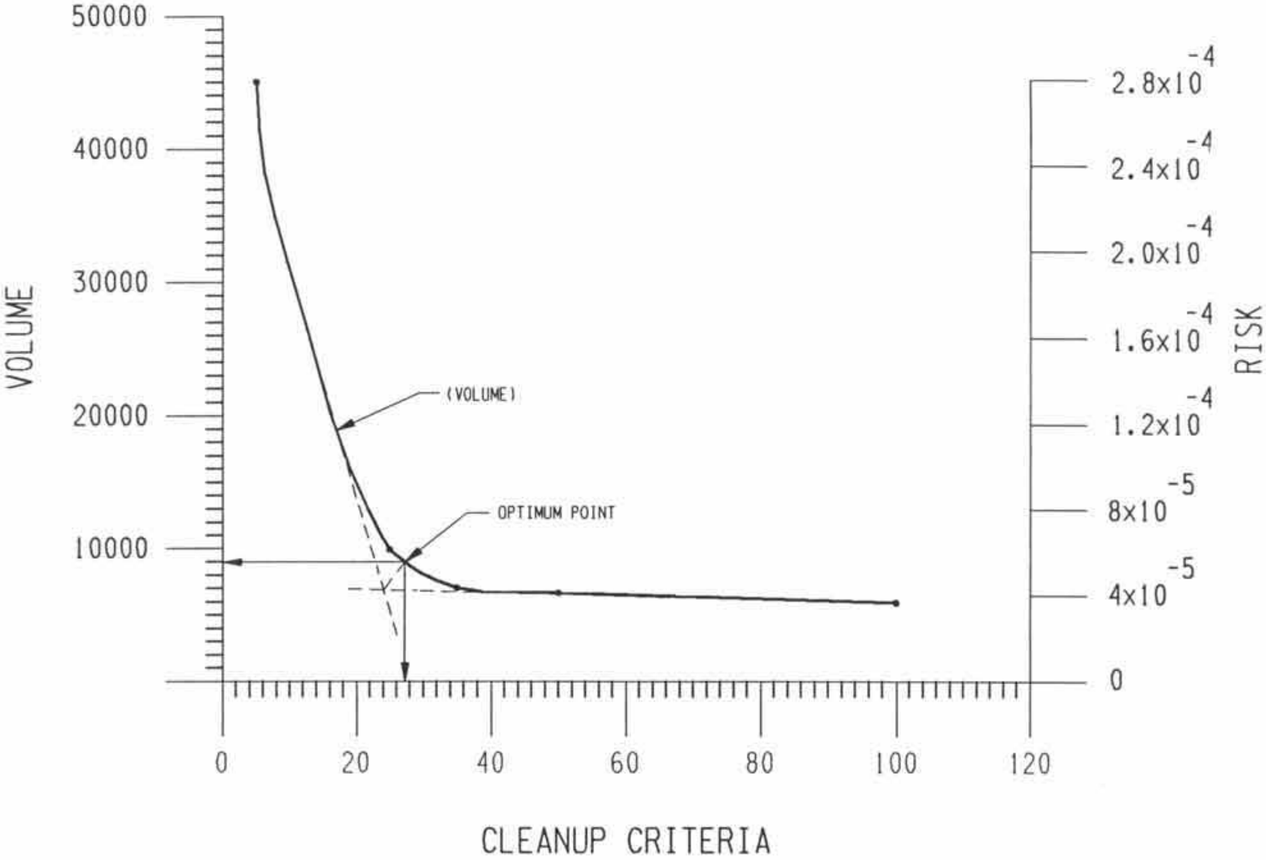

Fig. 1. Volume of contaminated soil vs. cleanup criteria.

GENERATION OF THE TOOL

Generating volume data for varying cleanup criteria is painstaking and time-consuming. It includes the following.

CHARACTERIZATION

Work begins with field sampling, logging of field data, and proper packaging and delivery of samples to the analytical laboratory. Locating sampling points systematically to determine the horizontal extent of contamination and to determine sampling depths are critical tasks.

Analysis and reporting of data are performed in the laboratory and involve analysis of the matrix for the contaminants of concern and reporting of the data to interested parties. All quality assurance/quality control requirements will be met during this activity. Laboratory data is checked against field information for correctness and possible reporting errors. The data is analyzed to determine depths of contamination at each sampling location, which is then correlated with varying cleanup criteria.

VOLUME CALCULATIONS

Volume calculations are performed using the software package SURFER (by Golden Software). However, if the input data is not complex, the volume may be calculated without the use of proprietary software. The software program creates a surface that represents the bottom of contamination for the area. The volume can then be calculated using the elevation "0" for ground level and the SURFER-generated surface. The volume of soil to be removed is generated for each set of cleanup criteria.

APPLICATION OF THE TOOL

When performing remedial action, limiting factors, such as availability of storage space, achievability of ALARA goals, minimum cleanup criteria set by governing agencies, acceptable limits of risk for health and environmental factors, cost, and budget, must be weighed carefully. The range of acceptability for each factor is determined to effectively evaluate the options for performing remedial action. For example, if storage space is the limiting factor, the manager determines the corresponding cleanup criteria, risk, and cost. If these three factors fall within the acceptable range, then the storage space is sufficient. If not, the manager can implement the ALARA concept by accepting a higher risk for a lower cost. In selecting the more stringent criteria, the manager accepts a higher cost (within the allowable budget) and, subsequently, a lower risk. Generally, the increase in cost will be minimal to certain criteria; costs will increase sharply as the criteria become stricter.

Therefore, it is essential to determine an optimum point within this range of minimal cost increase.

CASE STUDY

The 8.1-ha (20-acre) Elza Gate site is located in the eastern portion of the city of Oak Ridge, Tennessee, in what is now known as Melton Lake Industrial Park. In the early 1940s, the site was developed by the Manhattan Engineer District as a storage area for pitchblende (a high-grade uranium ore from Africa) and ore processing residues. In 1946, ownership of the site was transferred to the Atomic Energy Commission (AEC). AEC used the site until the early 1970s, at which time it was vacated. After a radiological survey and appropriate decontamination activities were conducted in 1972, the site was deemed acceptable for use with no radiological restrictions under existing criteria. At that time, the property was transferred to the General Services Administration and then to the city of Oak Ridge. The property was subsequently sold to Jet Air, Inc., and used for the operation of a fabrication and metal plating facility. In 1987, at the request of the Tennessee Department of Health and Environment, Oak Ridge Associated Universities conducted a survey at the site because of the possibility of contamination from the metal plating facility. This survey confirmed the presence of heavy metals and polychlorinated biphenyls. In October 1988, a preliminary radiological survey of the site was conducted by Oak Ridge National Laboratory for DOE; the survey indicated contamination exceeding current guidelines for declaring a site eligible for remediation under FUSRAP. As a result, on November 30, 1988, the entire Melton Lake Industrial Park was designated a FUSRAP site. In 1988, ownership of the site was transferred to MECO, a development company. The site is presently under further development for use as an industrial park (6).

On FUSRAP, cleanup criteria for radium-226, thorium-230, and thorium-232 radionuclides are 5 pCi/g above background concentration for the first 6 in. of soil and 15 pCi/g above background concentration for soil deeper than 6 in. No DOE cleanup criteria have been established for uranium-238, the other radionuclide of concern; a value of 60 pCi/g was derived using the RESRAD computer model and is based on several site-specific parameters (7). Justifiable deviation from this guideline, within reasonable limits of risk and cost savings, is an option, and variation from it with the intent to meet project goals is acceptable.

Volume calculations were performed for the following uranium criteria: 5, 25, 35, 50, and 100 pCi/g. These volume values were plotted on a graph (Fig. 2). Table I shows the calculated values. Relative cost is not shown. The mortality risk has been calculated for 70 pCi/g to be 4×10^{-5} and is shown on the right side y-axis. Values above the 4×10^{-5} mark were greater and therefore unacceptable according to Environmental Protection Agency and DOE guidelines.

The optimum cleanup criteria was determined by extending the tangents to the asymptotic regions of the curve to the point of intersection and bisecting the formed angle. In this case, the optimum criteria is 27 pCi/g, requiring that 9,000 yd^3 of soil be removed. The risk is slightly decreased.

CONCLUSIONS

Certain radionuclides, such as uranium at FUSRAP sites, are not addressed in radiological protection guidelines for cleanup of residual radioactive contamination; thus, the options are open to investigation. DOE currently uses the RESRAD computer model to establish a uranium cleanup criteria based on an allowable nonoccupational exposure limit of 100 mrem/yr.

In this paper, a new tool for use in the decision-making process is discussed. A parametric study was performed to establish cleanup criteria for low-level radioactive contamination. A key parameter in the analysis is the volume of material to be removed. The volume becomes a function of the cleanup criteria in that the more stringent the criteria, the deeper the required excavation. The depth of contamination to be removed varies over the range of criterion, thereby producing a corresponding range of volumes. The speed of computer-aided volume computation methods make this calculation feasible and reproducible.

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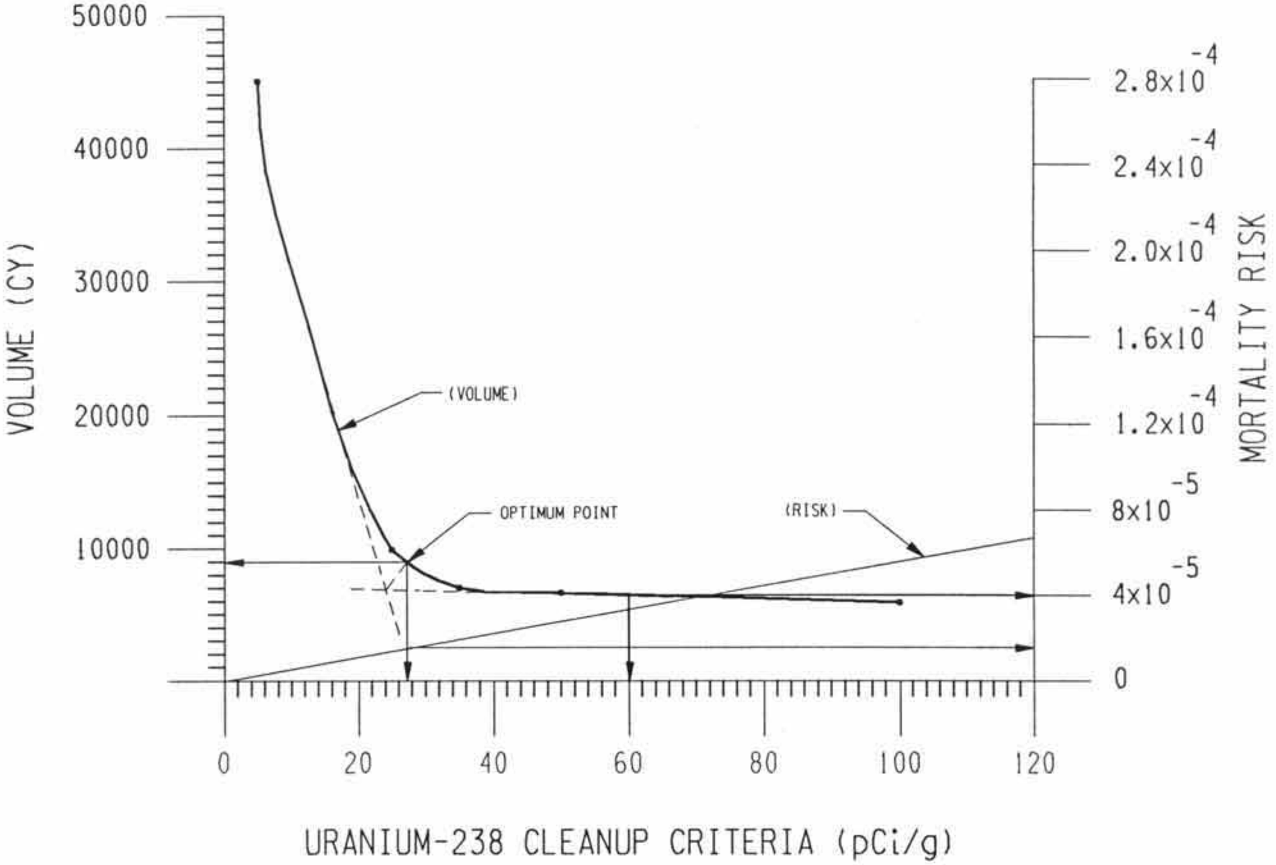

Fig. 2. Volume of contaminated soil vs. uranium cleanup criteria for the Elza Gate Site.

TABLE I

Volumes of Soil to be Remediated at the Elza Gate Site Under Various Uranium-238 Cleanup Criteria

Criteria (pCi/g)	Calculated Volumes of Soil(yd^3)
5	45,000
25	9,900
35	7,000
50	6,600
100	5,900

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