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Hazardous Waste Storage Explosion Threat Assessment

by James K. Ingram
Structures Laboratory

Prepared for Headquarters, U.S. Army Corps of Engineers
and Martin Marietta Energy Systems

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U.S. Army Corps of Engineers
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3909 Halls Ferry Road
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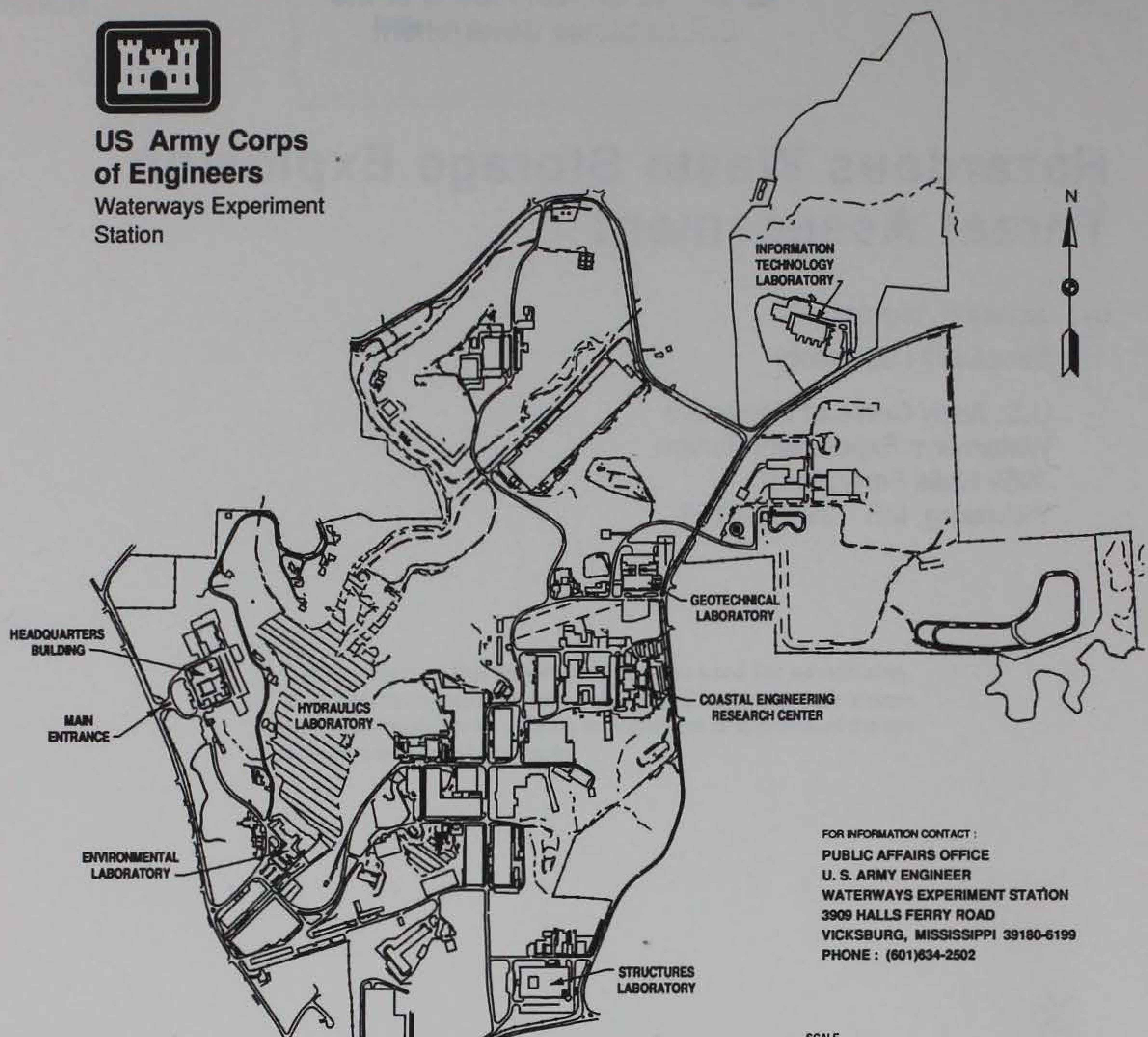

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Contents

Preface

Capping of old hazardous waste disposal sites at the Oak Ridge, TN, nuclear production facility with soil required that there be an assessment of explosion hazards and a reduction of surface ground-shock potential to acceptable levels. Funding for this assessment effort was provided to the U.S. Army Corps of Engineers by Martin Marietta Energy Systems, through the Geotechnical Laboratory (GL), to the Structures Laboratory (SL), U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

The study was conducted by Mr. James K. Ingram, Explosion Effects Division (EED), SL, WES, during November 1989 through January 1990, in coordination with Mr. Gene P. Hale, Chief, Soils Research Center (GE-S), GL. During this investigation, Mr. L. K. Davis was Chief, EED, and Mr. Bryant Mather was Director, SL.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
inches	25.40	millimetres
feet	0.3048	metres
feet per second	0.3048	metres per second
pounds (mass)	0.4536	kilograms
pounds (force) per square inch (psi)	0.006894757	megapascals

Summary

A desk study was undertaken to assess the minimum soil cover depth required to safely contain possible hydrogen gas detonations which could occur in old nuclear/chemical hazardous waste storage sites located at Oak Ridge, TN. The potential explosive source is primarily from chemical reaction between the stored materials and moisture within the soil cover, the naturally occurring by-product of which is hydrogen gas. Condensation, percolation, leaching, or direct inflow of ground water are the potential moisture sources.

This study investigated TNT equivalent detonations ranging from 2 lb to 50 lb. The estimated probable TNT charge equivalent was approximately 5 lb (or 10-lb equivalent black powder).

Soil cover thickness requirements were determined which would prevent explosion products and gases from venting through the surface, and ensure that ground-shock levels were limited to no more than 3 g's acceleration, 4 in./sec velocity, and 0.06 in. displacement.

1 Introduction

Background

Martin Marietta Energy Systems is managing the capping of old mixed nuclear and chemical waste storage sites at the Oak Ridge, TN, site with adequate earth material cover to prevent hazard to humans who might intrude into the area and walk on top of the burial mounds. An equally important consideration is the safety of equipment operators during the actual placement of the backfill cover material. Most of the disposal sites in question are on the crests of natural soil mounds and in shallow erosion trenches in these mounds. The protective soil cover to be added would, in effect, be a berm. Cost considerations include the type of soil and depth of backfill required. Native, scavenged soil is desired; it is typically a clayey-to-silty loam. If sand is required, it would have to be fabricated from crushed local limestone; an expensive operation, and would require more material than native soil because of the slope stability angle required. Figure 1 is an idealized schematic of the hazardous material storage profile and proposed soil backfill cap.

A contractor study suggested that the only probable source for an explosion event is in hydrogen gas that is released by reaction of the stored materials with available moisture. Quantities of the shock-sensitive materials contained

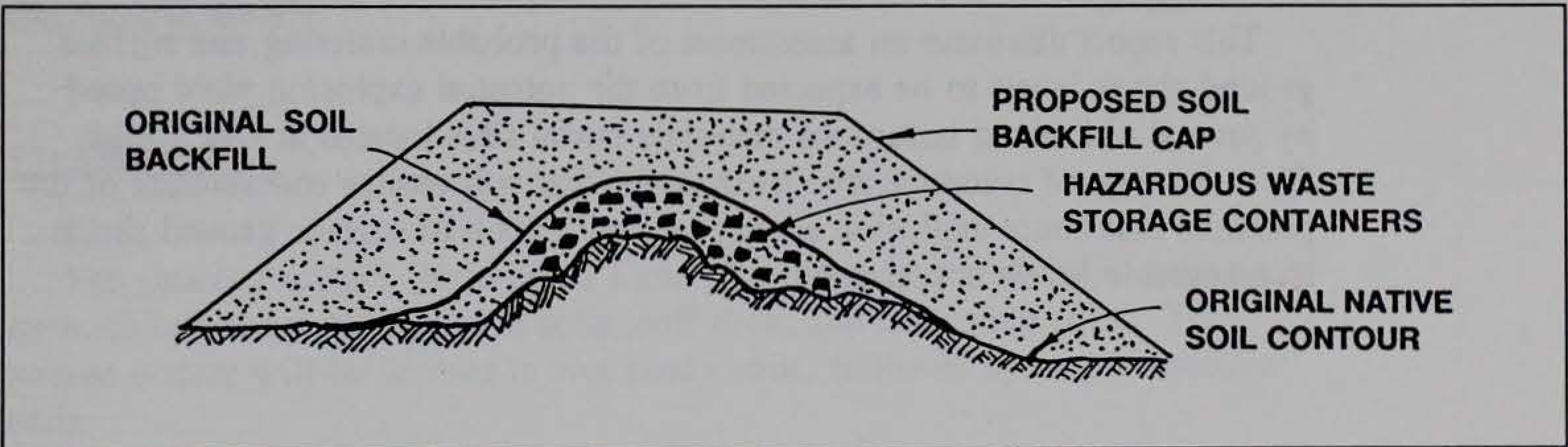

Figure 1. Idealized cross-section of proposed protective soil cover for hazardous waste storage, Oak Ridge, Tennessee

in the storage areas are in small concentrations that are well dispersed within the existing soil cover. Analyses indicated that the probable maximum explosive equivalence approximates a 10-lb black powder charge.

The stated human tolerance shock criteria at the ground surface are listed in Table 1.

Table 1
Human Tolerance Shock Criteria

Parameter	Provided Criteria Maximum Value	Accepted Criteria Maximum Value Vertical Motion
Displacement	0.02 to 0.06 in.	---
Velocity	2 to 4 in./sec	120 in./sec
Acceleration	3 g's	20 g's

[1] Values provided in References 1 an 2.
[2] Normally accepted values, References 3 and 4.

Objectives

The concern of this study was to determine the depth and type of soil cover required from human safety from explosive energy release for observed, occasional, spontaneous detonations in some of the older storage sites.

Scope

This report discusses an assessment of the probable cratering and surface ground-shock levels to be expected from the potential explosion yield posed by several old mixed hazardous materials burial sites located at Oak Ridge, TN. A range of recommended earth cover that will ensure containment of the potential maximum explosion energy and mitigation of surface ground shock to acceptable levels is presented.

2 Assessment

Environment

The assumed lumped charge equivalent of the detonable products (primarily hydrogen gas) was given as representing a 10-lb black powder charge. The normal standard explosive reference for blast effects is TNT. Black powder has a blast efficiency of 0.46 that of TNT. Therefore, the equivalent TNT charge would be (0.46 x 10 lb) equal 4.6 lb of TNT. Because of uncertainties in the actual explosive yield, TNT equivalent charges of 2, 5, 10, and 50-lb were investigated.

Considerable information is available for crater formation from buried charges in a wide variety of soil types. A review of pertinent numerical code calculations and empirical motion data for various earth materials yielded little information for the soil surface directly above a buried detonation except for a few materials.

Since scavengeable native soil available in the immediate vicinity of the waste storage area is a moist clayey loam (approximately 35 percent water content), this type of material was primarily investigated. Both ground-shock transmission and cratering are relatively constant for a relatively wide variation of moist (unsaturated) alluvial soils, and a modest data base exists for these materials.

Cratering

The smallest craters (References 1 and 2) will be formed in hard competent rock, followed by dry cohesive soils, soft rock, and dry sandy soils. The largest craters will be formed in wet sandy soils, followed by moist cohesive soils.

A sufficiently thick soil cover must be placed over the hazardous waste site to ensure that the potential explosion yield is fully contained, i.e., all of the explosive energy is coupled into the ground with no venting into the atmosphere. References 3-7 provide guidance for the depth of containment required. The minimum depth is $> 3.5\ W^{1/3}$, where W is the TNT equivalent charge weight in pounds. At burial depths greater than 3.5 $W^{1/3}$, a camoflet, or closed cavity, is formed by the explosion, and essentially all of the explosion by-products are contained.

The minimum soil cover requirement was determined for explosive weights ranging from 2 to 50-lb (Figure 2), using the ground-shock criteria from References 1 and 2. Soil cover requirements were first based on the minimum cover depth for full containment as listed in Table 2.

Ground Shock

Ground-shock parameters attenuate exponentially with increasing distance through earth materials. Expected surface velocities and displacements as functions of explosive charge weight were derived from empirical data and are plotted in Figure 3.

Surface ground-shock levels were derived from various empirical data bases (References 3-5). Most of the available data were from large-yield nuclear detonations and required extreme scaling down to the very small chemical charges we are dealing with. The most consistent data set at charge yields reasonably close to our target charges were obtained on the CENSE-2 test series (Reference 8) and were used as the primary base for this assessment. Acceleration, velocity, and displacement values were fixed at the suggested safety levels of 3 g, 4 in./sec, and 0.06 in., respectively. The soil cover depths associated with these levels and charge weight are listed in Tables 3, 4, and 5 and are felt to be somewhat conservative, since much of the data were from beneath or radially out from the charges and will be higher because of the significantly increased confinement. Ground shock along the upward vector directly over the buried charge would tend to be lower due to the lower confinement (the soil is not confined at the soil-air interface). Ground shock beneath or horizontally out from the buried charge would increase in confinement due to the stress applied by the detonation pressure. This would, in effect, stiffen the soil along these vectors and would significantly increase the energy coupling, hence, the ground-shock levels.

A composite plot of Tables 2-5 is shown in Figure 3, which is a parametric plot of surface acceleration, velocity, and displacement and full charge containment as functions of charge weight and soil cover depth.

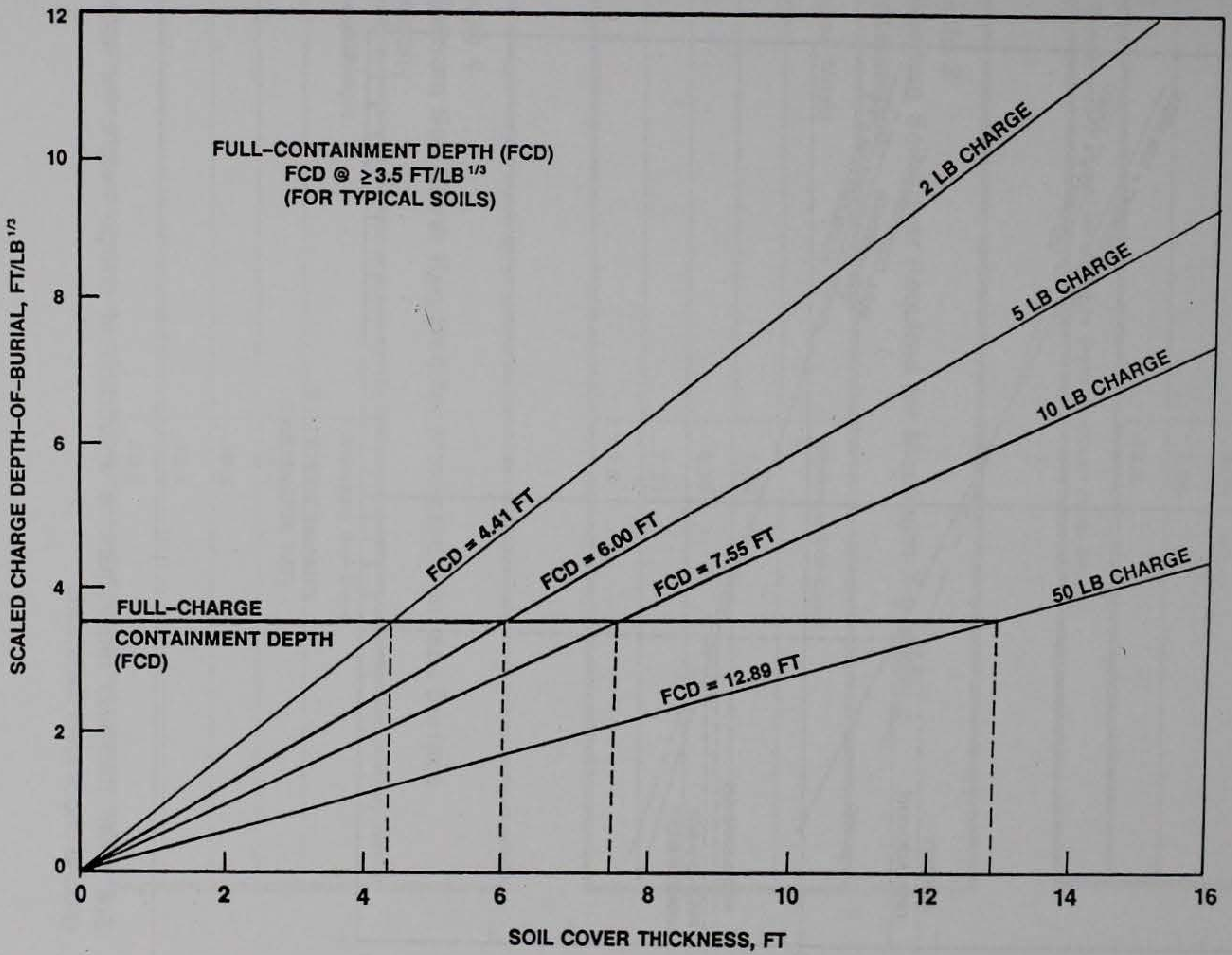

Figure 2. Soil cover thickness requirement for full-containment (no venting) as a function of charge weight (TNT equivalent)

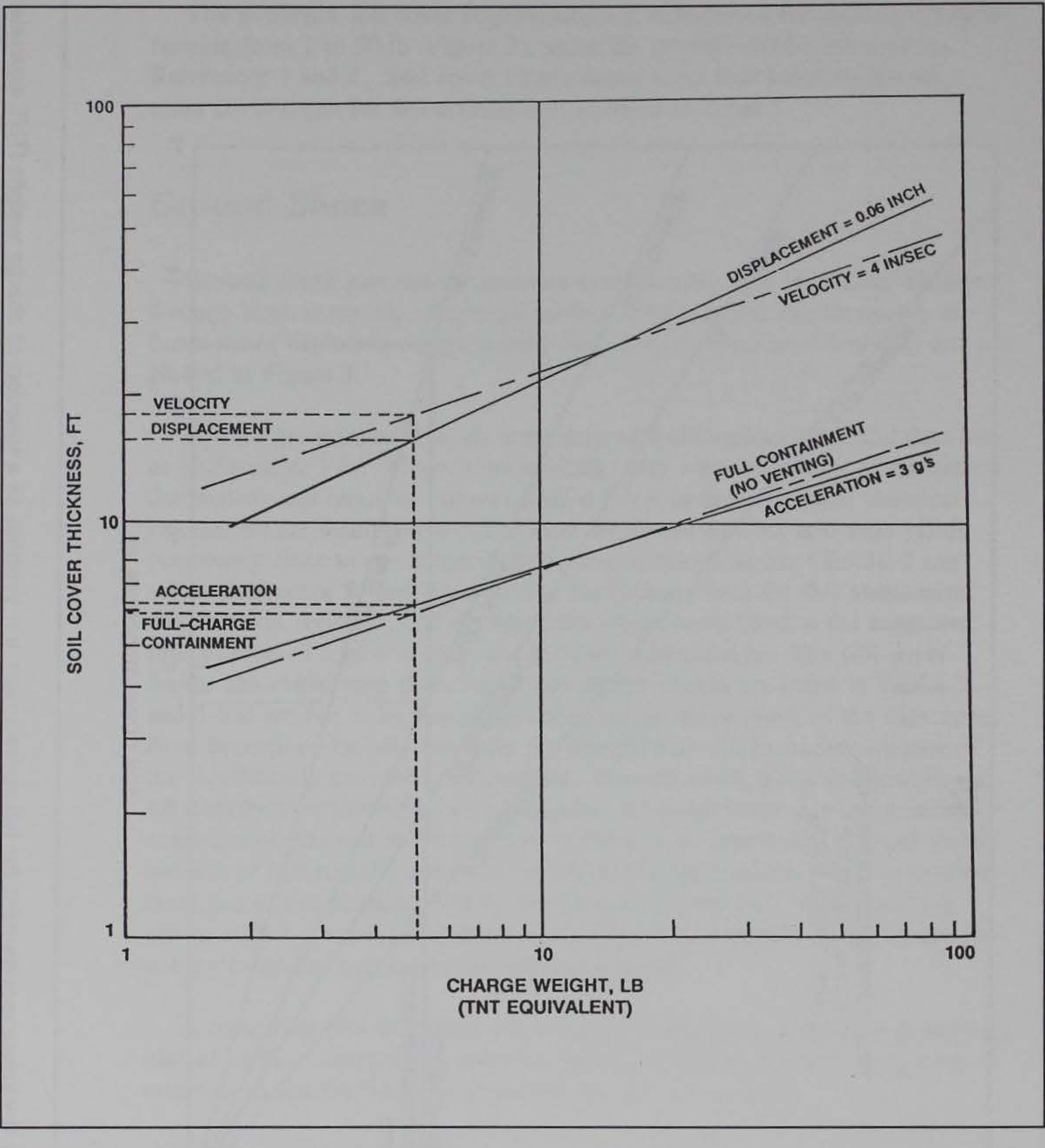

Figure 3. Soil cover thickness requirement as a function of charge weight, for specified ground shock level thresholds

Table 2
Minimum Soil Cover Required for Full (Non-Venting) Soil Containment

Charge Weight lb	Minimum Soil Cover[1] ft
2	4.39
5	6.00
10	7.66
50	12.9

[1] Conservatism should be added to these minimum cover depths.

Table 3
Minimum Soil Cover Required for Maximum 3-g Surface Acceleration

Charge Weight lb	Minimum Soil Cover ft
2	4.72
5	5.98
10	7.31
50	12.3

Table 4
Minimum Soil Cover Required for Maximum 4-in. sec Surface Velocity

Charge Weight lb	Minimum Soil Cover ft
2	13.2
5	18.0
10	22.6
50	38.6

Table 5
Minimum Soil Cover Required for Maximum 0.06-in. Surface Displacement

Charge Weight lb	Minimum Soil Cover ft
2	13.2
5	18.0
10	22.6
50	38.6

3 Conclusions and Recommendations

Conclusions

Assuming a 5-lb TNT explosive charge equivalence, the minimum native soil cover depth recommended is 18 ft.

Recommendations

The most economical fill material to use in the containment cover is scavenged native soil, a moist clayey loam. Although use of a dry coarse sand would allow a shallower cover depth, the material would be significantly more costly to obtain and transport to the site. A significant additional amount of sand would also be required to provide the proper angle for long-term slope stability.

References

1. Martin Marietta Energy Systems, Inc. (1989). "Technical Memorandum on Bear Creek Burial Ground, Areas B, C, and D, Plant Y-l2 Feasibility Study, Oak Ridge, TN," CH2M Hill Report, prepared under Task Authorization No. K-01, General Order No. 13B-97385C.

2. ________. (1989). "Alternate Closure Strategies Assessment for Bear Creek Burial Ground Plant Y-12, Oak Ridge, TN," CH2M Hill Report, prepared under Task Authorization No. Y-05, General Order No. 18B-9777C.

3. White, C. S., Bowen, I. G., and Richmond, D. R. (1965). "Biological Tolerance to Air Blast and Related Biomedical Criteria," AEC Report CEX-65.4, October 1965, U.S. Atomic Energy Commission, Washington, DC.

4. Odello, Robert J. (1976). "Ground Shock Effects from Accidental Explosions," Technical Memorandum Report TM M-51-75-22, Civil Engineering Laboratory, Naval Construction Battalion Center, Port Hueneme, CA.

5. U.S. Army Engineer Waterways Experiment Station. (1961). "Cratering from High Explosive Charges, Analysis of Crater Data, Report 2," WES Technical Report No. 2-547, Vicksburg, MS.

6. Rooke, A. D., Jr., Carnes, B. L., and Davis, L. K. (1974). "Cratering by Explosions: A Compendium and an Analysis," WES Technical Report No. N-74-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

7. Rocco, J. R., et al. (1986). "A Comparison in 1-D of Fully Contained and Surface Burst Estimates from Five Generic Materials," DNA-TR-86-406, Defense Nuclear Agency, Washington, DC, Contract report by California Research and Technology, Inc., Albuquerque, NM.

8. Ingram, James K. (1977). "CENSE Explosion Test Program, Report 2, CENSE 2, Explosions, in Soil," WES Technical Report N-77-6, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

9. Sauer, F. M., Clark, G. B., and Anderson, D. C. (1964). "Nuclear Geoplosics, A Sourcebook of Underground Phenomena and Effects of Nuclear Explosions, Part Four Empirical Analysis of Ground Motion and Cratering Data," DASA-1285 (IV), Defense Atomic Support Agency, Washington, DC, Contract Report prepared by Stanford Research Institute.

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13. ABSTRACT *(Maximum 200 words)*

A desk study was undertaken to assess the minimum soil cover depth requirement to safely contain possible hydrogen gas detonations which could occur in old nuclear/chemical hazardous waste storage sites located at Oak Ridge, TN. The potential explosive source is primarily from chemical reaction between the stored materials and moisture within the soil cover, the naturally occurring byproduct of which is hydrogen gas. Condensation, percolation, leaching, or direct inflow of groundwater are the potential moisture sources.

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Displacement	Soil cover	

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