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COST ESTIMATE OF GROUTING THE PROPOSED TEST PITS AT IDAHO NATIONAL ENGINEERING LABORATORY USING THE ORNL-RECOMMENDED GROUTS

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ABSTRACT

EG&G Idaho plans to construct three experimental pits to simulate the TRU waste trenches at Idaho National Engineering Laboratory (INEL). Two of these pits will be grouted and then one will be destructively examined as soon as the grout cures and the other will be monitored for 10 years. Oak Ridge National Laboratory (ORNL) is evaluating grouts and will recommend a grout to EG&G Idaho to reduce the permeability of the pit, fill the large voids, and encapsulate the waste. A previous ORNL report (ORNL/TM-9881) discusses the grouts evaluated and the grout recommended based on those evaluations. This report evaluates the economics of grouting the experimental pits.

The cost of double grouting two of the EG&G Idaho design pits at the Idaho National Engineering Laboratory using lance injection was estimated to be $100,000. Jet grouting the same two pits was estimated to cost $85,000. Both techniques have advantages, and it is suggested that both be tried as part of the test EG&G Idaho is conducting.

1. INTRODUCTION

Approximately 2.2 x 10^6 ft^3 of transuranic (TRU) waste is buried in shallow land burial at the Idaho National Engineering Laboratory (INEL). EG&G Idaho, Inc., prime operating contractor at the INEL, has developed a long-term management plan for INEL Buried TRU Waste. During FY-1985 and FY-1986, the improved-confinement technology in-situ grouting will be investigated by the EG&G Idaho Waste Technology Programs Branch. Oak Ridge National Laboratory (ORNL) is providing technical support and consultation services to EG&G Idaho in the area of grout selection. ORNL will provide (1) the rationale, (2) laboratory comparative results of different grout formulations and grout chemicals with Idaho soils, (3) cost comparisons, and (4) the final selection of the recommended grout formulations for the INEL in-situ grouting test. A previous ORNL report dealt specifically with grout formulation and selection[1], but this report deals specifically with cost comparisons and grout placement.

Laboratory studies of (1) coarse particulate grouts, (2) soil grouts, and (3) fine particulate grouts were reported previously.[1] Also, solution grouts were discussed as an alternative to the fine particulate grouts. Since that study had a limited scope, solution grouts were never studied in the laboratory; but they were kept as an alternative in case the microfine particulate grout was considered unsatisfactory. Acceptable grouts were ones that met the following performance criteria:

● 7 d drainable water	0 vol %
● 28 d compressive strength	≥ 50 psi, expected 200-800 psi
● Compressive strength after freeze/thaw	>200 psi
● Hydraulic conductivity	$\leq 1 \times 10^{-7}$ cm/s
● 10 min gel strength	≤ 100 $lb_f/100$ ft^2
● Shrinkage during curing	<1 vol %

Acceptable grouts were determined for all three particulate grouts, but the soil grouts studied were not considered fluid enough to use in grouting the test pits. A range of grout compositions satisfy the above criteria, but the following two compositions were recommended as being the most economical of those that produced satisfactory test results.[2]

Coarse grout	Wt %	Fine grout	
● Water and fluidizer	35	● Finely ground cement	8 lb/gal
● Type I,II Portland cement	35	● CFR-1 sugar	0.02 wt %
● Class C fly ash	25		
● Bentonite	5		
● Fluidizer	0.5		

These two grouts were used as the basis for the cost analysis of grouting the design pits. The following two emplacement techniques were evaluated: (1) lance injection grouting with a coarse grout followed by lance injection grouting with a fine grout, and (2) jet grouting with a coarse grout. The cost analysis and evaluation of those two techniques are the subjects of the rest of this report.

2. PIT DESIGN

The pit design used as a basis for this cost estimate was taken from an EG&G Idaho document. Three identical test pits will be constructed for this in-situ grouting experiment with one serving as a control and the other two will be grouted. The pits will be ~6 ft wide, 18 ft long, and excavated to the basalt underlying the entire area. The basalt will be covered with the excavated soil to a depth of approximately 3 ft, i.e., the underburden. The next 10 ft will be the waste zone, followed by 3 ft of overburden. One wall of the pit will have a 45° slope, unlike the actual waste pits. This slope was required for safety reasons during container emplacement and will be backfilled.

One end of the waste zone will contain stacked boxes with horizontal dimensions of 4 ft wide and 8 ft long. The pit will be widened to 8 ft for this section to accommodate the long dimensions of the boxes. Three boxes will be stacked to make up the 10 ft waste zone: two 4 ft high with one 2 ft high on top. Adjacent to the stacked boxes will be stacked drums followed by dumped drums. The volumes associated with one of these pits is given in Table 1.

Table 1. Volumes of parts of one EG&G Idaho design pit

Description	Volume (ft^3)
Waste zone	
Box section	320
Drum section	840
Subtotal	1160
Underburden	324
Overburden	348
Total for test pit	1832
45° Slope (excavated)	1521

3. ESTIMATION OF VOIDS

The following assumptions[2] were used to estimate the void volume in the design pit.

1. Disturbed soil bulk density is 85% of undisturbed soil bulk density, i.e., 85% compaction factor.
2. Volume of waste and backfill soil is 30% less than the volume excavated in the waste zone.
3. The bulk density of the as-received Idaho soil tested by ORNL is the disturbed soil bulk density.
4. The moisture content of the as-received Idaho soil is typical.
5. The boxes contain 80% voids.
6. The drums containing scrap metal, combustibles, concrete/asphalt, and filters are 80% voids.
7. The drums containing sludge are 20% voids.
8. No backfill soil in the box section of the waste zone.
9. The volume of one drum is 7.4 ft^3.

Measurement results on the Idaho soil received by ORNL include a true density (dry and voidless) of 2.75 g/cm^3, an as-received bulk density (still moist) of 1.17 g/cm^3, and an as-received moisture content of 13.0 wt %. Applying these results for the soil samples and the assumptions listed above to the design pit resulted in the void volumes given in Table 2.

From Tables 1 and 2, 671 ft^3 of large voids reside within the 1160 ft^3 of the waste zone, or 57.8%. The backfill soil is estimated to contain 143 ft^3, or 12.3%, of tight air voids. Together these voids account for 70.1% of the waste zone. The disturbed soil areas are estimated to contain 47.8% air voids and the undisturbed soil 38.4% air voids.

The effective grain diameter of the Idaho soil is 0.03 mm (see Appendix A) which implies a hydraulic conductivity of about 10^{-4} cm/s.[3] The large voids are estimated to increase the ungrouted pit hydraulic conductivity to 4×10^{-4} cm/s (see Appendix A). Filling the large voids with coarse grout decreases the hydraulic conductivity to about 2.4×10^{-5} cm/s and grouting further with a fine grout will reduce the hydraulic conductivity to about 10^{-6} cm/s, estimated using a simple model and measured grout hydraulic conductivities (see Appendix A). Jet grouting is assumed to give a solid block having the hydraulic conductivity of soil grout or coarse grout (~10^{-9} cm/s).

Table 2. Estimated void volumes contained in and around one EG&G Idaho design pit

Description	Void volume (ft^3)
1. Waste zone	
Large voids	
Drum section	
Backfill soil	207
Sludge drums (13)	19
Other drums (32)	189
Boxes	256
Subtotal	671
Packed soil voids	
Air	143
H_2O	46
Subtotal	189
2. Underburden	
Air	155
H_2O	49
Subtotal	204
3. Overburden	
Air	166
H_2O	53
Subtotal	219
4. 45° Slope sidewall	
Air per ft^3 of sidewall	0.478
H_2O per ft^3 of sidewall	0.152
Subtotal per ft^3 of sidewall	0.630
5. Undisturbed sidewalls	
Air per ft^3 of sidewall	0.384
H_2O per ft^3 of sidewall	0.179
Subtotal per ft^3 of sidewall	0.563

4. GROUT EMPLACEMENT

The grouting of the pits can be done in essentially three, or perhaps more, ways. The three that were considered for this report were (1) injection wells, (2) injection lances, and (3) jet grouting. The flexibility and mobility of the latter two techniques were considered desirable enough to reject the first technique for the purposes of this analysis. This does not imply that that technique would not work and should be rejected for all such applications. But, for the limited scope of this project, some selections had to be made a priori, based only on readily available information and subjective judgment. Both of the other techniques warrant consideration for this experiment and are discussed separately below.

4.1 LANCE INJECTION

The lance technique basically involves forcing a hollow lance into the soil or matrix to the desired depth and pressure injecting the grout from that point and up as the lance is withdrawn (or the process can be reversed and grout injected as the lance is forced down). A double injection has been suggested to accomplish EG&G Idaho's goals.[1] The first injection would be with a coarse particulate grout to fill the large voids expected inside and around the waste containers. This injection would be followed by a second injection with a penetrating grout to fill the small voids, incorporate as much of the backfill soil as possible in the grout structure, and to penetrate the sidewalls to form a grout curtain.

4.1.1 Coarse Grout Quantity

To estimate the amount of coarse grout needed, assume that all of the large voids are accessible and that the coarse grout will not penetrate any packed soils (backfill, overburden, underburden, or sidewalls). From Table 2, 671 ft^3 or about 5020 gal of grout will be required to fill the large voids in one experimental pit. The grout formula recommended to EG&G Idaho consists of 35 wt % type I,II Portland cement, 25 wt % class C fly ash, 5 wt % bentonite, and 35 wt % water and fluidizer (fluidizer makes up 0.5 wt % overall).[2] This grout has a density of 14.5 lb/gal[1], meaning about 73,000 lb of coarse grout will be required for one pit, or a total of 146,000 lb Table 3 gives the quantity required of each component to make up 146,000 lb of this coarse grout.

Tallent et al.[2] found in simple laboratory tests that this coarse grout would fill 37% of the voids in disturbed Idaho soil. We shall assume this would be indicative of penetration into the backfill soil for the actual grout emplacement (i.e., no penetration of coarse grout into overburden, underburden, or sidewalls). From Table 2, 189 ft^3 of voids per pit are available in the packed soil voids; and then using Tallent's void basis (i.e., including water voids) about 70 ft^3 per pit represents 37% of this void volume, an increase of about 10% in the amount of grout needed.

Thus, increasing the quantities in Table 3 by 10% or more will ensure enough coarse grout to fill the large voids inside the containers and outside the containers plus filling 37% of the small voids in the backfill soil.

4.1.2 Fine Grout Quantity

From the first set of assumptions in Sect. 4.1.1, all of the voids inside the containers and the large voids in the backfill around the containers will be filled with coarse grout. This assumption is too optimistic for the real case, though we hope to approach it; but is reasonable for estimating how much coarse grout will be needed. For these assumptions, the small voids in the underburden, overburden, sidewalls, and backfill will still need to be filled by the fine grout. Also, assume that the water present in the soil cannot be forced out by the grout. With these assumptions and using Table 2, 464 ft^3 of voids are present in the underburden, the overburden, and the backfill. In addition, the basalt will take up some grout in existing "fissures." Assuming the pits are located over "tight" basalt (i.e., no lava tubes, etc.), we further assume that the basalt will take 10% of what the underburden takes[4] which adds about another 16 ft^3 of voids.

Table 3. Component quantities for coarse grout to fill all the large voids in two EG&G Idaho pits

		Quantity required	
Component	Wt %	(lb)	(ton)
Type I,II Portland cement	35	51,000	25.6
Class C fly ash	25	36,500	18.3
Bentonite	5	7,300	3.7
Fluidizer	0.5	730	0.4

The amount required for the sidewalls requires an estimate of how far the grout will penetrate the sidewall. No one can say definitely how and where a grout will penetrate into a given soil matrix. The grout will follow the path of least resistance, whether it is a solution grout or a particulate grout. Thus, it could end up as a stringer many feet from where one wants it rather than as a uniform "curtain" or front. Nevertheless, we shall assume a uniform penetration of 6 in. for the undisturbed sidewalls and 7 in. for the disturbed sidewall.[5] This assumption gives about 280 ft^3 of undisturbed soil and 177 ft^3 of disturbed soil (45° slope) penetrated by grout. On this basis and using Table 2, 192 ft^3 of voids are present in the sidewalls to be filled. Altogether, about 672 ft^3 of voids are present in the groutable region of one pit.

What fraction of this volume will actually be filled with grout can only be guessed at at this time. Tallent et al. assumed that a fine cement grout would be used for this second grouting.[2] The possibility of syneresis led to the rejection of solution grouts in favor of penetrating cement grouts. This conclusion was a reasonable assumption for the limited scope of this study, and it does not imply that solution grouts would definitely not work for this or any other application. The fine grout tested by Tallent et al. filled about 52% of the air and water voids or about 69% of the air voids (i.e., the voids used as a basis for this section).[2] The implication is that about 464 ft^3 of Tallent's fine grout would be required for one experimental pit. Of course, additional voids may be available in the containers that the coarse grout failed to penetrate. On the other hand, how well can a secondary grouting be done? Will the lances be able to penetrate the first grout after initial set? Are set retarders required?

The excess fine grout quantity used as a basis for this report was based on the lack of quick availability of the finely ground cements. Both types of cement considered for this report come from Japan with a delivery time of three weeks or more compared to the 24-h delivery time for the Portland cement used in the coarse grout. Although the fine cements are much more expensive than the Portland cement, severe economic penalties result from underordering since the grouting contractor must be paid while waiting for delivery. The only alternative in such a case is to not grout completely with the fine grout which is not technically acceptable. For this reason, the void volume estimated, 672 ft^3 or 5027 gal per pit, was used as the quantity of fine grout required. Thus, 10,054 gal of fine grout will be required.

The fine grout tested by Tallent et al. was a water-cement mixture of 8 to 10 lb cement/gal water containing 0.02 wt % CFR-1 sugar. Using a mix ratio of 8 lb/gal, the density of the grout is 12.5 lb/gal.[2] Therefore, approximately 125,000 lb of grout are needed containing 61,190 lb (30.6 ton) of cement and 25 lb of CFR-1.

4.1.3 Cost of Lance Injection

The costs of grouting the two experimental trenches include: (1) material, (2) shipping, (3) contractor's mobilization, and (4) the contractor's emplacement costs. Grout materials may be bought and supplied by EG&G Idaho or the contractor may be responsible for his own supplies. In the latter case, an additional handling fee may be added by the contractor. In the former case, logistics and timing (i.e., the materials must be there when the contractor needs them) must be handled by EG&G Idaho. The same suppliers used by ORNL for the materials in their lab tests is recommended for the actual grouting since any substitution can change grout properties. Also, EG&G Idaho may wish to have QA/QC procedures that require them to purchase the materials. Therefore, it was assumed that EG&G Idaho would purchase the materials and have them available for the contractor. Table 4 gives the suppliers, prices, and freight costs for the grout materials.

Sack costs rather than bulk costs are used in the calculations in this report. Sacks will increase the labor for grouting, but they will eliminate the need for bulk storage and handling on-site. The bulk costs do give an idea of the cost savings for scaling up to the TRU trenches. Of course, actual TRU trenches will add operational costs not considered for the experimental pits, just from the fact that TRU waste is involved.

The mobilization cost will be $5000 to $10,000 depending on the contractor and his location. This cost can be considered a fixed cost, but it would likely increase if actual TRU trenches were involved. The cost for emplacing the grout in the pits ranges from $2000 to $3000 per day with time estimates ranging from 10 to 25 d (2 to 5 work weeks). The grouting contractors contacted for these costs are listed in the Appendix. This list is by no means a complete list of the grouting contractors in the country and does not imply bidding should be limited to these few. The contacts were limited to a few well-established names in the field just for general cost information. A mobilization cost of $10,000, a daily charge of $2500, and 20 d to complete the grouting of two EG&G Idaho pits were

Table 4. Grout material suppliers and costs

Material	Supplier	Prices		Freight Costs
		Coarse Grout		
Type I,II Portland cement	Ash Grove Cement Co. Pocatello, Idaho Bill Mahorney Boise, Idaho (208) 344-8468 ≤24 h notification	$4.40/94 lb sack $73/ton bulk		$0.32/94 lb sack (min. 50,000 lb) $7.80/ton bulk (min. chg. 50,000 lb)
Class C fly ash	Pozzalanic Northwest, Inc., Mercer Island, Washington Tom Fox (800) 426-5171 24 h notification	$47.80/ton bulk		--
(Laramie River fly ash)	Ross Island Dry Mix Portland, Oregon Ken Gunther (503) 228-2299 within week	$2.85/80 lb sack		<$500/truckload (min. chg. 50,000 lb)
MC103 Bentonite	Black Hills Bentonite Mills, Wyoming Duran Grenir 1 day	$41/ton (50 lb sacks) $38/ton (100 lb sacks) $32/ton bulk		$180/ton, <2.5 tons $142.43/ton 2.5-5 ton Truckload (23-24 ton) $35.40/ton bulk $21.20/ton sacks
Dowell D-65 Fluidizer	Dowell, Inc. Denver, Colorado Ron Root (303) 773-8800	$4.15/lb (50 lb sacks)		$0.15/lb (min. chg.?)
		Fine Grout		
Colloidal Cement	Avanti International Co., Webster, Texas Mike Jaques (713) 554-7541 3 weeks	$0.36/lb (88 lb sacks) 38,000 lb/containers $0.33/lb for 5 containers		$5.10/100 lb from Portland $5.38/100 lb from Seattle (min chg. 40,000 lb)
		per MT[a]	Pallets[b] (1 MT/ Pallet)	
Microfine Cement and NS-200 dispersant (add ~1% to the listed cost for the dispersant)	Geochemical Corp. Ridgewood, New Jersey Bill Clark (201) 447-5525 5 weeks	$1300 $1200 $1100 $1000 $900 50 sacks (20 kg) per pallet	1-5 6-12 12-19 10-60 >60	$50/pallet

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[a] MT = Metric ton = 1000 kg.

[b] i.e. The price is discounted as larger quantities are ordered.

assumed. Table 5 summarizes the costs for a double grouting of two EG&G Idaho experimental pits using lance injection.

Table 5. Cost estimate for lance injection grouting at two EG&G Idaho design pits

Description	Cost ($)
Material costs:	
Coarse grout	
Portland cement; 1 truckload; 532 sacks	2,511
Fly ash; partial truckload; 500 sacks	1,700
Bentonite; partial truckload; 80 sacks	3,610
Fluidizer; partial truckload; 16 sacks	300
Subtotal	8,121
Fine grout:	
Colloidal cement; 2 containers; 76,000 lb	31,440
Sugar; 25 lb	--
Emplacement costs:	
Fixed (mobilization)	10,000
Coarse grout; 3 d/pit @ $2500/d	15,000
Fine grout; 7 d/pit @ $2500/d	35,000
Subtotal	60,000
Total	99,561 ~100,000

The quantity of Portland cement in Table 5 is less than that listed in Table 3 because of the awkwardness of the size of a truckload and the quantity estimated to be required. It was assumed that one truckload would be used and that the supplier would quickly respond if more was needed. Considering the cheapness of the coarse grout, EG&G Idaho may opt to purchase two truckloads (or an additional partial truckload). The other components of the coarse grout are listed in greater amounts in Table 5 than in Table 3.

The two seatrain containers used in Table 5 gives significantly more fine cement than is estimated to be required to fill all of the voids reachable during fine grouting. In addition, there is some doubt that a secondary injection will work that well. In other words, the initial set of the coarse grout may prevent the lances from penetrating in some areas that require fine grout. Thus, the amount of fine grout may be grossly overestimated. Of course, the lances may be designed to penetrate, fracture if necessary, the hardening coarse grout. That would create voids that the fine grout should then fill. Such special lances may require development and will increase the contractors costs. In our opinion, the request for bids should specify that such penetration into the coarse grout will be expected for a double lance injection.

From Table 5, the cost of the grouts is about $40,000 with more than 75% being the fine grout. If the supposedly more penetrating "microfine" cement sold by Geochemical Corp. is used, then 57 pallets (57 metric tons) would be required along with its dispersant at a cost of $57,570. Thus, total cost for coarse and fine grout would increase to about $66,000. Since Tallent's report[2] is based on Avanti's "colloidal" cement, this cost analysis is based on that cement. Substitution would require testing of the new cement in the same manner as the one in Tallent's report.[2]

In conclusion, a double lance injection grouting of two of the EG&G Idaho design pits is estimated to cost about $100,000.

4.2 JET GROUTING

Jet grouting was developed to cement grout fine sands or silts, i.e., soils that could not normally be penetrated by a cement grout. Usually, the jet is mounted on a drill rig just above the drill bit. This drill bit bores a hole slightly bigger than the jet to the appropriate depth. Next, the grout (usually a water-cement mixture) is forced at very high pressure through the jet as the jet is rotated in the hole and slowly withdrawn from the hole. The jet converts the potential energy of the high pressure into kinetic energy that churns the surrounding soil and forms a well-defined column of "soil-crete," similar to the soil grouts tested by Tallent et al.[1] According to one contractor, this technique will form columns 3 ft in diameter composed of 20 % wt cement.

The question is whether this technique will work on a waste trench filled with large voids, scrap metal, metal drums, and a potpourri of other items. Will metal "shadow" voids and/or soil? One contractor estimated the cost of making one EG&G Idaho pit into a solid block using jet grouting at $30,000 to $33,000 (including the cost of cement). Table 6 contains the breakdown of this cost estimate.

The following options were considered in this study:

1. Jet grout the entire pit as a soil grout,
2. Jet grout the curtain as a soil grout and the remainder of the pit with the coarse grout. A variation of this option is to use the soil grout as the basis for the overburden and underburden as well,

Table 6. Cost estimate of jet grouting two EG&G Idaho design pits using a cement-water grout

	Cost ($)
Mobilization, 1400 miles	6,900
Personnel	12,650
Mixing and pumping equipment	37,950
Portland cement, 2200 ft^3	7,590
Total	65,090
Estimated time - 11 d	

3. Jet grout the entire pit with the coarse grout,
4. Lance double grout the waste zone and jet grout the rest of the pit (including the perimeter),
5. Lance inject grout with the coarse grout first in the waste zone to fill the large voids followed by jet grouting of the entire pit.

Option 2 is favored if both lance injection and jet grouting will be tried in separate pits and Option 5 if only the original three pit design will be tried. Option 5 reduces some of the uncertainty in using jet grouting in waste trenches by filling the large voids with coarse grout prior to jet grouting. Presumably the emplaced coarse grout will be cut up and blended in with the fresh grout used in the jet grouting. The disadvantage of this option is that one contractor may not be able to do both, which could significantly increase the cost. Since this section addresses jet grouting separately from lance injection, only Option 2 is analyzed for its costs in the remainder of this section.

The grout curtain for this technique is assumed to be a soil-crete extension 3 ft beyond the nominal pit dimensions of 18 x 6 ft. The contractor usually uses a cement-water mixture, but he believes the jet can handle fly ash in the grout and bentonite too if properly homogenized (meaning extra equipment may be required). Also, the contractor believes the jet can be hydraulically inserted down to the basalt layer for this application. Thus, no cuttings from the pit will be brought to the surface. To calculate the quantity of grout required, any soil in the grouted region is assumed 20 % vol grout and the large voids are assumed 100% grout. From Table 7, 1427 ft^3 of grout per pit, or 2874 ft^3 total, will be required for jet grouting, compared to the 2200 ft^3 total used in Table 6. The personnel cost, equipment cost, and time estimate from Table 6 will be increased by the ratio of these two total quantities to estimate the costs based on the above assumptions for jet grouting the EG&G Idaho pits.

Table 7. Estimation of grout quantity required for one EG&G Idaho design pit for jet grouting

Description	Volume (ft^3)	Grout volume (ft^3)
Soil		
Grout curtain	2880	576
Underburden	324	65
Overburden	324	65
Backfill	300	60
Large voids	671	671
Total		1437

The cost basis will be for the grouts studied by Tallent et al. or the closest approximation. For the soil grouts, the mixtures used by Tallent et al. will not be duplicated with this in situ mixing technique. Instead, a grout made from a mixture of Portland cement and fly ash (the ratio of these two component quantities based on Tallent et al.'s soil grout) was assumed for the grout curtain. Tallent et al.'s particulate grout was assumed for the pit proper. (The contractor may be able to use the "soil grout" for the overburden and underburden as in Option 2, but such was not assumed here.) The grouts suggested by Tallent et al. meet certain specifications that a substituted grout may not, e.g., the bentonite will be important in order to have no bleed water for the grout in the large voids. Any substitution requires the same testing Tallent et al. performed on his recommended grouts. (This means that the grout assumed for the grout curtain needs to be tested.) Table 8 contains the estimate of component quantities for jet grouting to form a 3 ft "soil grout" curtain and a block of particulate grout encapsulating the waste inside this curtain. Combining the quantities estimated in Table 8 with the cost information in Tables 4 and 6 led to the cost estimate summarized in Table 9 for jet grouting two of the EG&G Idaho design pits. From Table 9, the grout costs less than $10,000, the emplacement costs more than $75,000, and the total costs for jet grouting is about $85,000.

Table 8. Component quantities for jet grouting two EG&G Idaho design pits

Component	Wt %	Quantity required (lb)	Quantity required (ton)
Curtain grout[a] (assume 14.5 lb/gal, 125,814 lb grout):			
Type I,II Portland cement	42	52,842	26.4
Class C fly ash	16	20,130	10.1
Pit grout[b] (14.5 lb/gal, 186,511 lb grout):			
Type I,II Portland cement	35	65,293	32.7
Class C fly ash	25	46,638	23.3
Bentonite	5	9,328	4.7
Fluidizer	0.5	933	0.5

Basis: 1160 ft^3 of curtain grout and 1720 ft^3 of pit grout.

[a] An untested grout mix, but based on Tallent et al.'s soil grout mix No. 1.

[b] Based on Tallent et al.'s series II particulate grout mix No. 1, same as the coarse grout for Sect. 4.1 in Table 3.

Table 9. Cost estimate for jet grouting two EG&G Idaho design pits

Description	Cost ($)
Material costs:	
Portland cement; 2 truckloads; 1064 sacks	5,022
Fly ash; 1.34 truckloads; 835 sacks	2,650
Bentonite; partial truckload; 94 sacks	848
Fluidizer; partial truckload; 19 sacks	300
Subtotal	8,820
Emplacement costs:	
Fixed (mobilization)	6,900
Personnel for 15 d	17,250
Equipment for 15 d	51,750
Subtotal	75,900
TOTAL	84,720

4.3 OTHER COSTS

The other costs, mainly involved in this experiment, are the QA/QC costs and experimental monitoring and analysis costs. EG&G Idaho will develop their own programs for these aspects of the experiment and no attempt was made to assess the costs involved. Nevertheless, the following two items were considered: (1) acceptability of the materials purchased and (2) hydraulic conductivity of the pits.

Since EG&G Idaho may not have the laboratory capability to test the purchased grout materials, ORNL may be asked to perform this service for EG&G Idaho. Since a quick answer may be necessary, samples may have to be hand delivered to ORNL and then a technician used to perform the 24-h tests. Although this may suffice for the quick answer, EG&G Idaho may want the complete set of tests for the purchased material (including the 28-d cure time and long term freeze-thaw tests). Negotiations between ORNL and EG&G Idaho will settle what is necessary and the cost.

To help ascertain the effectiveness of grouting the pits, the hydraulic conductivity of the pits can be measured before and after grouting. One way to do this would use the apparatus actually used in the grouting.

Conceptually, several probes would be forced into the pit and uncoupled from the hydraulic and pumping equipment. Then, the hydraulic conductivity would be measured using the probes stuck into the pit. If a probe cannot be inserted after grouting, then that would be considered a successfully grouted area and relatively impermeable. However, this approach requires two additional trips by the contractor with the attendant mobilization costs and at least one day's operating costs (i.e., about $25,000 for both hydraulic conductivity tests). A geotechnical firm specializing in such tests appears more attractive and may only cost a tenth as much. This destructive examination test should be conducted only on the short-term grouted trench. The second hydraulic conductivity test could be done shortly before the destructive examination of this pit.

Another method that could be used is sonic evaluation of the pit. With the designed and documented pits proposed, sonic evaluation of one pit before grouting will help evaluate the technique and after grouting will help establish the success of grouting.

Other miscellaneous costs include the cost and availability of water. Not being familiar with the site, it was unknown whether an adequate supply was available at the test site.

Additional costs that need to be considered for actual TRU wastes include health physics personnel, containment structures, and personnel protection. In addition, both emplacement techniques will result in fluids and/or grout coming to the surface (around the probes, if nowhere else). EG&G Idaho should be prepared for this and have the contractor capture this material and recycle it into the pit or dispose of it in some acceptable manner. In addition, one way of increasing the success of the lance injection is to add to the overburden so higher pressures can be used. This cost was not evaluated, though it would likely be minor, unless this extra overburden needs to be removed (which could be costly in the case of TRU waste trenches, but not in the case of the experimental pits).

5. CONCLUSIONS AND RECOMMENDATIONS

Based on the given assumptions and the grouts that have been tested thus far, lance injection grouting of two of the EG&G Idaho design pits will cost about $100,000 and jet grouting of the same pits will cost about $85,000. The advantages of the lance technique are:

1. It is developed for pressure injection into loose and voidy soils;
2. developed for shallow grouting, though lances are available 40 ft long;
3. has been used for grouting waste trenches;
4. machines are available that handle multiple lances; and
5. lances are mobile, allowing an operator to thoroughly cover an area as needed.

The advantages of the jet grouting technique are:

1. The placement of the grout is potentially well-defined;
2. no penetrating grout is required;
3. waste, soil, and grout will potentially be one solid matrix; and
4. the placement probe is mobile.

The disadvantages of the lance technique are:

1. The placement of the grout is uncertain since the grout follows the path of least resistance. Large voids usually fill first;
2. an expensive penetrating grout is needed to grout the soil matrix (underburden, overburden, backfill, and curtain);
3. oozing of grout to the surface around the lances; and
4. the possibility that the first grouting with the coarse grout will interfere with the second grouting with the fine grout.

The disadvantages of the jet grouting technique are:

1. It is developed for use in tight soils but not with large voids;
2. flow around large objects such as drums is uncertain;
3. waste will be well-mixed with grout (which may be an advantage or disadvantage); and
4. flow of grout to the surface around the probe.

From these advantages and disadvantages, the lance technique seems to have an edge in grouting large voids, but the jet technique seems to be better for grouting tightly packed soils or matrices. Selection depends on one's objectives as well as the particular application. The outcome of neither technique is certain, a priori, and both should be tested before rejection of grouting as a solution for stabilizing the INEL TRU trenches.

Both techniques can be expected to have grout (carrying some waste) push to the surface around the probe penetration. This material should be captured and disposed of properly. It is suggested that such material be recycled back into the pit. One method to help control such emissions (and increase the pressure for lance injection) would be to increase the overburden layer for the grouting operation (building a soil cap around the jet grout probe may reduce the flow from the oversized probe hole). Some emissions should still be planned for and trapped. Details such as this should be included in the request for bids, and the grouting contractors should propose a solution and give costs.

The disadvantage of mixing waste with the grout, mentioned for jet grouting, concerns compatibility of the waste with the grout. Both techniques are faced with a problem at the grout-waste interface, but jet grouting increases this interface by essentially making the waste part of the grout (locally). This aspect of the grout to be selected has not been addressed, as yet; but it must be before a final grout formula can be selected, regardless of which technique is chosen. Cement grouts usually require additives for use with acids, bases, or organics. No interaction problem is anticipated for the metal, wood, combustibles, concrete, or filters. However, sludge will be the main problem and asphalt could also be a problem in jet grouting. The experimental pits will contain a simulated sludge (with a composition given in the pit design) which should be tested for compatibility with the grout.

Based on the available information, the following suggestions are recommended:

1. The number of test pits to be grouted should be doubled so that both lance injection and jet grouting can be tried and compared. Although the feasibility of this suggestion is uncertain (site availability, etc.) it can be stated that it would be desirable.
2. Of the above recommendation is rejected, consider ways of evaluating both techniques (such as grout part one way and part the other).
3. Selection of only one technique depends on EG&G Idaho's objectives.
4. The compatibility of the waste and grout needs to be evaluated.

5. The ability of the grouting contractors to handle emissions to the surface and to propose ideas for better penetration (reverse grouting, extra overburden, etc.) should be planned for, and evaluated in, the test.
6. Evaluate (as best as possible) the effectiveness of accomplishing EG&G Idaho's goals by studying the pits with available nondestructive experimental techniques. (EG&G Idaho is working hard to do this, but a unique opportunity exists to evaluate nondestructive tests on a predesigned pit that will be destuctively evaluated shortly after grouting.)

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APPENDIXES

APPENDIX A: ESTIMATION OF PIT HYDRAULIC CONDUCTIVITY

The particle size distribution of the Idaho soil sample received by ORNL is given in Fig. 1. From this figure, the effective grain diameter, d_{10} (i.e., 10 % by wt of the soil particles are smaller than this diameter), is about 0.03 mm. Herndon et al.[3] give a hydraulic conductivity of about 10^{-4} cm/s in their Fig. 34 for this d_{10}. Disturbing this soil will increase its hydraulic conductivity some, but the hydraulic conductivity will decrease over time as the soil resettles and recompacts. The presence of the large voids will have a much greater effect that is not easy to evaluate. Some of the large voids will not be immediately, if ever, available. Water will permeate through the path of least resistance and thus tend to follow the large voids. The large voids will offer little resistance to permeation, so the hydraulic conductivity will be dictated by the overburden, backfill, underburden, and sidewalls. Assume that the overburden is in series with the large voids and that the backfill is in parallel with large voids. For resistances in series, the resistances (inverse hydraulic conductivity for the present case) are additive. For parallel resistances, the inverse of the resistances (the hydraulic conductivities) are additive. Conceptually for this model, this means water flow through the waste zone is via the large voids and the flow rate is dictated by the surrounding matrices (overburden, underburden, and sidewalls).

Consider the case of permeation through the overburden and waste zone and ignore the pathways out of the waste zone (i.e., the water will permeate into the bottom of sidewalls or collect at the bottom). Permeation will only effectively occur in the area represented by large voids and the permeation will be dictated by the overburden in that area.

$$\text{Permeation rate} \ \alpha \ \frac{PA}{L} \qquad (1)$$

where P = hydraulic conductivity,
A = area of permeation, and
L = length of permeation.

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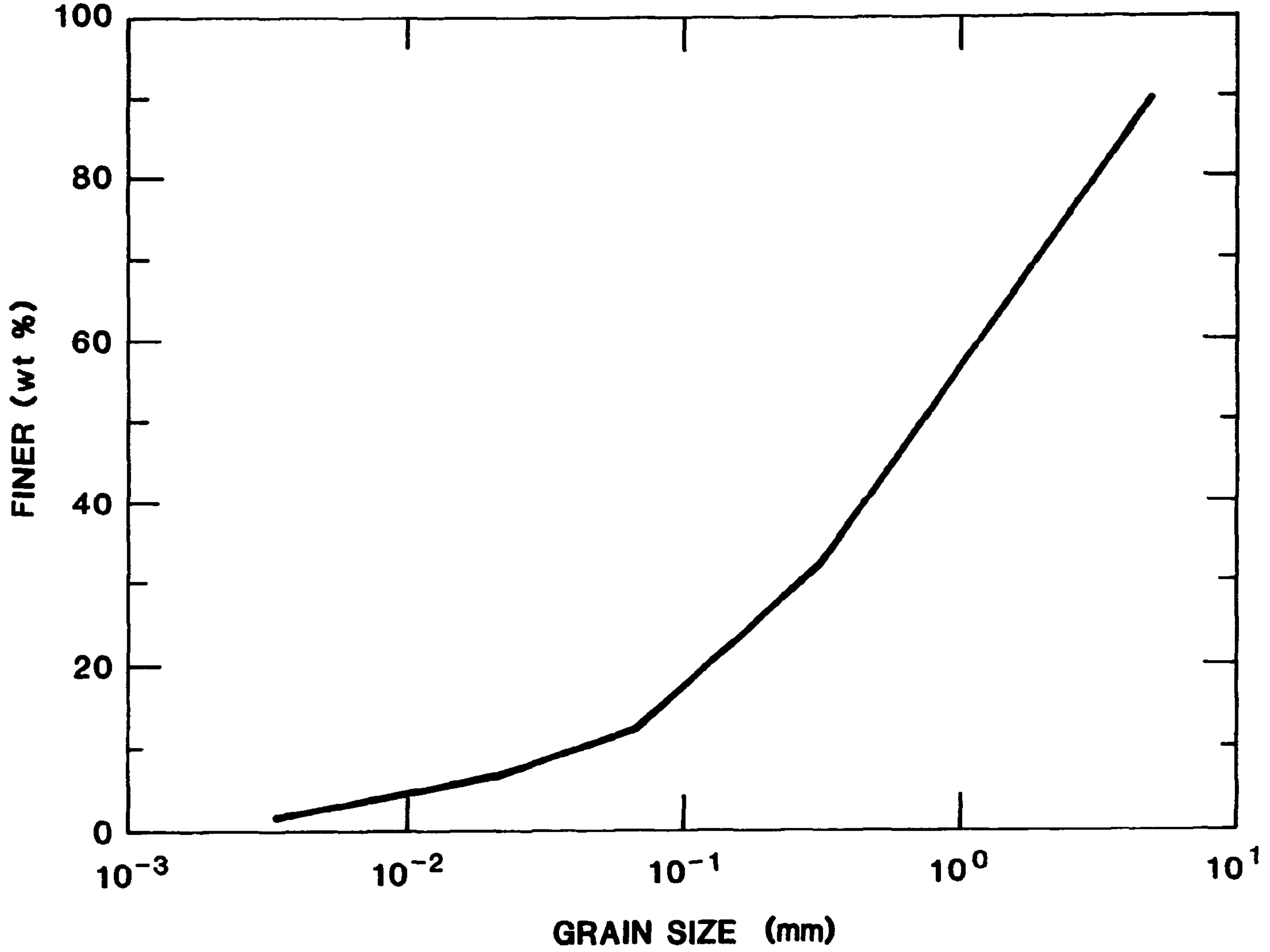

Fig. 1. Particle-Size Distribution of Idaho Soil Sample Received by ORNL.

Series

$$\frac{L}{AP_A} = \frac{L_o}{AP_o} + \frac{L_w}{AP_w} \qquad (2)$$

Parallel

$$\frac{AP_w}{L_w} = \frac{A_L P_L}{L_w} + \frac{A_R P_R}{L_w} \qquad (3)$$

where

P_A = average hydraulic conductivity for trench,
P_o = overburden hydraulic conductivity,
P_w = waste zone hydraulic conductivity,
P_L = large void hydraulic conductivity,
P_R = remainder of waste zone hydraulic conductivity,
A = area of pit,
A_L = area of large voids,
A_R = area of remainder,
L = height of pit above underburden,
L_o = height of overburden, and
L_w = height of waste zone.

Since $P_L >> P_R$, we can neglect the second term of Eq. 3 and derive,

$$P_w = \frac{A_L}{A} P_L \qquad (4)$$

Substituting in Eq. 2, we obtain

$$\frac{1}{P_A} = \frac{L_o}{L} \frac{1}{P_o} + \frac{L_w}{L} \frac{A}{A_L} \frac{1}{P_L} \qquad (5)$$

Since $P_L >> P_o$, the second term of Eq. 5 may be neglected, and

$$P_A = \frac{L \, P_o}{L_o} \; . \qquad (6)$$

As expected, the hydraulic conductivity is increased by the large voids reducing the distance of permeation and bypassing the backfill (assuming large voids are interconnected as in this simple model). With an overburden hydraulic conductivity of 10^{-4} cm/s, a total height of 13 ft and an overburden height of 3 ft, the effective hydraulic conductivity is estimated to be 4×10^{-4} cm/s.

Applying this same model to a pit with the large voids filled by coarse grout, i.e, $P_L \sim 10^{-9}$ cm/s,[1] results in $P_R >> P_L$, $P_o >> P_L$ (the reverse of the previous assumptions), and

$$P_w = \frac{A_R}{A} P_R \quad , \text{ and} \tag{7}$$

$$\frac{1}{P_A} = \frac{L_o}{L} \frac{1}{P_o} + \frac{L_w}{L} \frac{A}{A_R} \frac{1}{P_R} \quad . \tag{8}$$

Assume $P_o \sim P_R \sim 10^{-4}$ cm/s, $L_o = 3$ ft, $L = 13$ ft, $L_w = 10$ ft, $A = 116$ ft^2, and $A_R = 23$ ft^2 (area for backfill soil only). Thus, $P_A = 2.4 \times 10^{-5}$ cm/s.

Furthermore, if 52% of the soil's water and air voids are assumed filled with fine grout[1], i.e., the area available for permeation reduces by 69% in the overburden and backfill, then substituting in Eqs. 7 and 8

$$P_w = \frac{0.31 A_R}{A} P_R \quad , \text{ and} \tag{9}$$

$$\frac{1}{P_A} = \frac{L_o}{L} \frac{A}{0.31 A_R} \frac{1}{P_o} + \frac{L_w}{L} \frac{A}{0.31 A_R} \frac{1}{P_R} \quad , \text{ and} \tag{10}$$

$$P_A = 0.31(2.4 \times 10^{-5} \text{ cm/s}) = 7.4 \times 10^{-6} \text{ cm/s} \quad . \tag{11}$$

The reduction in area proportionally reduces the hydraulic conductivity without taking credit for a lower soil hydraulic conductivity by virtue of filling the bigger soil voids leaving a soil matrix with a reduced effective grain diameter. Assume that 69% (dry wt) of the larger sizes illustrated in Fig. 1 is grouted leaving 31% of the finer material as the loose soil matrix to determine the approximate hydraulic conductivity. Thus, the

$D_{3.1}$ of 0.006 mm from Fig. 1 represents the new D_{10} giving a new hydraulic conductivity of about 5 x 10^{-6} cm/s for the remaining ungrouted soil compared to about 10^{-9} cm/s for the coarse grout and about 10^{-8} cm/s, for the fine grout. Thus keeping the same assumptions (including the hydraulic conductivity of soil being much greater than either grout) and substituting the new hydraulic conductivity for soils into Eq. 10 gives a hydraulic conductivity of 4 x 10^{-7} cm/s for the pit grouted first by coarse grout than by fine grout.

For jet grouting, assume a solid block of soil grout or coarse grout, giving a hydraulic conductivity of about 10^{-9} cm/s.

APPENDIX B: LIST OF GROUTING CONTRACTORS CONTACTED

Gelco Grouting Service
Salem, Oregon
Steve Waring
Kent, Washington
(206) 872-2550

Halliburton
Ernie Carter
Duncan, Oklahoma
(405) 251-2095
Dr. Paul Pettit
Gaithersburg, Maryland
(301) 258-6045

W. G. Jaques Co.
Steven Jaques
Des Moines, Iowa
(515) 276-5464

Woodbine, Inc.
Art Pengelly
Fort Worth, Texas
(817) 625-4242

APPENDIX C: EXTRAPOLATING THE COSTS FOR GROUTING THE TEST PITS INTO COSTS FOR GROUTING THE TRU WASTE TRENCHES AT INEL

The volume scale up factor going from the two experimental pits to the actual TRU trenches is 1000. Thus, the simplest extrapolation gives \$85,000,000 to \$100,000,000 to grout the TRU trenches. This simple approach ignores several differences including (1) the fact that TRU waste is now involved which will increase costs, (2) a time span of several years is involved, (3) economies of scale will apply, and (4) some of the costs are fixed and do not scale up proportional to the job size. Taking into account the fixed costs in Tables 5 and 9 will decrease the simple extrapolation above \$7,000,000 to \$10,000,000 to make the extrapolated estimate \$80,000,000 to \$90,000,000. Any such estimate using the costs in this report will be much more inaccurate than analyzing the actual costs in grouting the design pits.

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