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ABSTRACT

Many options are available today for the immobilization and disposal of wastes that contain environmentally harmful materials. The option chosen depends upon the type of waste, regulatory requirements, and economics of process. Some options are specific to a given waste type; others are more versatile.

This presentation will discuss a very versatile option for waste immobilization/disposal — grouting. Many types of grout are available, such as chemical, clays or other particulates, fly ash, cements, or a combination of these. Within the limited allowable time, this presentation will discuss the application of a variety of cement-based grouting techniques available for disposal of environmentally harmful materials.

Areas discussed are in situ grouting of pits, ponds and lagoons, grouting as remedial action, and fixation for disposal in burial trenches or vaults.

INTRODUCTION

This paper briefly reviews four cement-based waste-form development programs at three U.S. Department of Energy (DOE) sites. The successful applications of cement-based waste forms to many radioactive waste streams from nuclear facilities demonstrates the flexibility and reliability of this class of immobilization materials.¹

The U.S. DOE sites and their programs are:

1. Oak Ridge National Laboratory;
 - (a) hydrofracture grouting,
 - (b) in situ trench grouting,
2. Hanford Transportable Grout Facility;
3. Idaho National Engineering Laboratory - in situ grouting.

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Even though this paper gives only a brief process description, it must be remembered that any waste form must meet certain minimum regulatory requirements which are beyond the scope of this presentation; but, in general, all waste forms resulting from the described processes meet or exceed local, state, and federal regulations.

DESCRIPTION OF HYDROFRACTURE PROCESS

Hydrofracture is essentially a large-scale batch process.² Each injection is, however, a semicontinuous operation designed to dispose of an accumulation of about 600,000 to 800,000 L (150,000 to 200,000 gal) of waste solution or slurry. A flow diagram of the process is shown in Fig. 1.

Prior to the injection, the waste solution or slurry is accumulated in waste storage tanks at the injection site. Also prior to the injection, the dry solids are blended and stored in bins at the injection facility. During the injection, the waste solution is pumped to the mixer, continuously mixed with the preblended solids, and then the mixture is discharged into the mixing tub. The mixing tub is sized to provide a holdup of about 2 min - sufficient time to allow the grout to deaerate. From the mixing tub, the grout is picked up by the injection pump and pumped down the injection well, out a slot cut in the bottom of the injection well, and into the shale formation. The injection pressure is about 20 MPa (3000 psi), and the normal grout injection rate is about 1000 L/min (250 gal/min). The resulting grout sheet is approximately 1 cm (0.5 in.) thick and up to 300 m (1000 ft) wide. The orientation of the fracture generally follows the bedding planes in the shale, which are inclined about 10 to 15° to the horizontal.

An injection may be halted by malfunction or failure of any of several instruments or pieces of equipment. It is stopped, in any event, after about 10 h of operation in order to minimize operator fatigue. For either circumstance, the well is flushed with about 4000 L (1000 gal) of water so that the slot at the bottom of the well will be free of grout and can be reused for the continuation of the injection. After repairs have been made, or the following morning (if the shutdown was a scheduled one), the

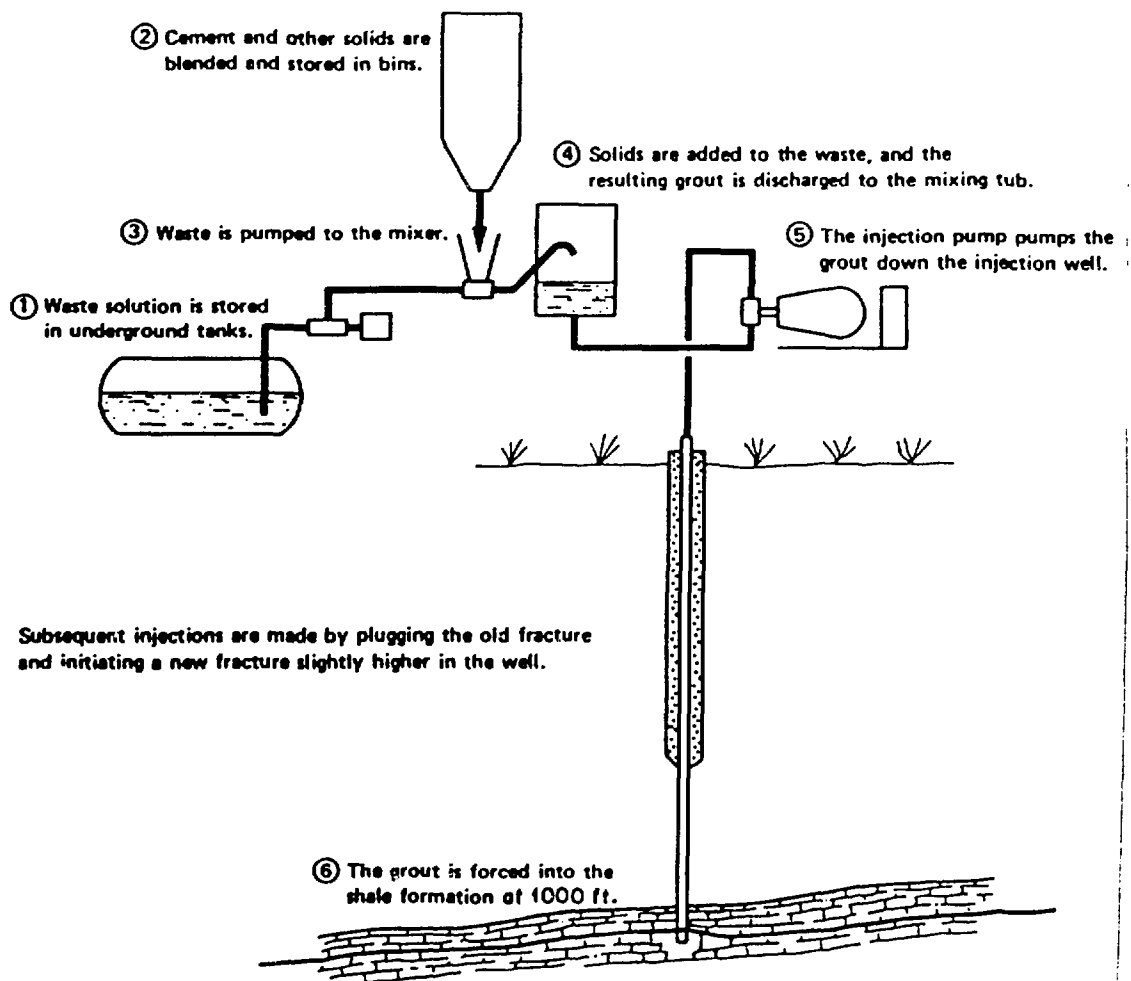


Fig. 1. Flow diagram of hydrofracture process.

well is pressurized to verify that the slot is still open; if so, the injection is then resumed. The operation is continued in this fashion until the supply of dry solids has been consumed. The well and slot are then flushed a final time, the wellhead valve is closed, and the injected grout is allowed to set.

The next injections in the series can be made through the same slot in the well; the grout sheets that are formed by this next injection are generally parallel to the grout sheets of the preceding injection but may be displaced up or down a few feet. Following a series of several injections, the slot in the bottom of the well is plugged with a small volume of grout and a fresh slot is cut in the casing of the well about 3 m (10 ft) above the old one. Another series of injections is then made through this new slot.

A few days after each injection, the approximate orientation of the grout sheet is determined by logging the network of observation wells that surrounds the facility (these are cased wells that extend to the bottom of the disposal formation). A gamma-sensitive probe lowered into these wells detects the presence of the grout sheet and establishes the depth of the grout sheet at that point. A network of six to eight observation wells is needed to verify the horizontal orientation of the grout sheet. The type of response from a series of logs made in one observation well is shown in Fig. 2.

The log for May 25, 1965, shows the response to the grout sheet that intercepted this well at an elevation 12 m (40 ft) above the point of injection. The log for October 26, 1966, shows the response to the grout sheet of the next injection - a response that indicates the presence of several grout sheets at an elevation of from 3 to 6 m (10 to 20 ft) above the point of injection. The third log indicates that the grout sheet from the next injection was slightly above the grout sheet from the preceding injection and about 4.5 m (15 ft) above the point of injection.

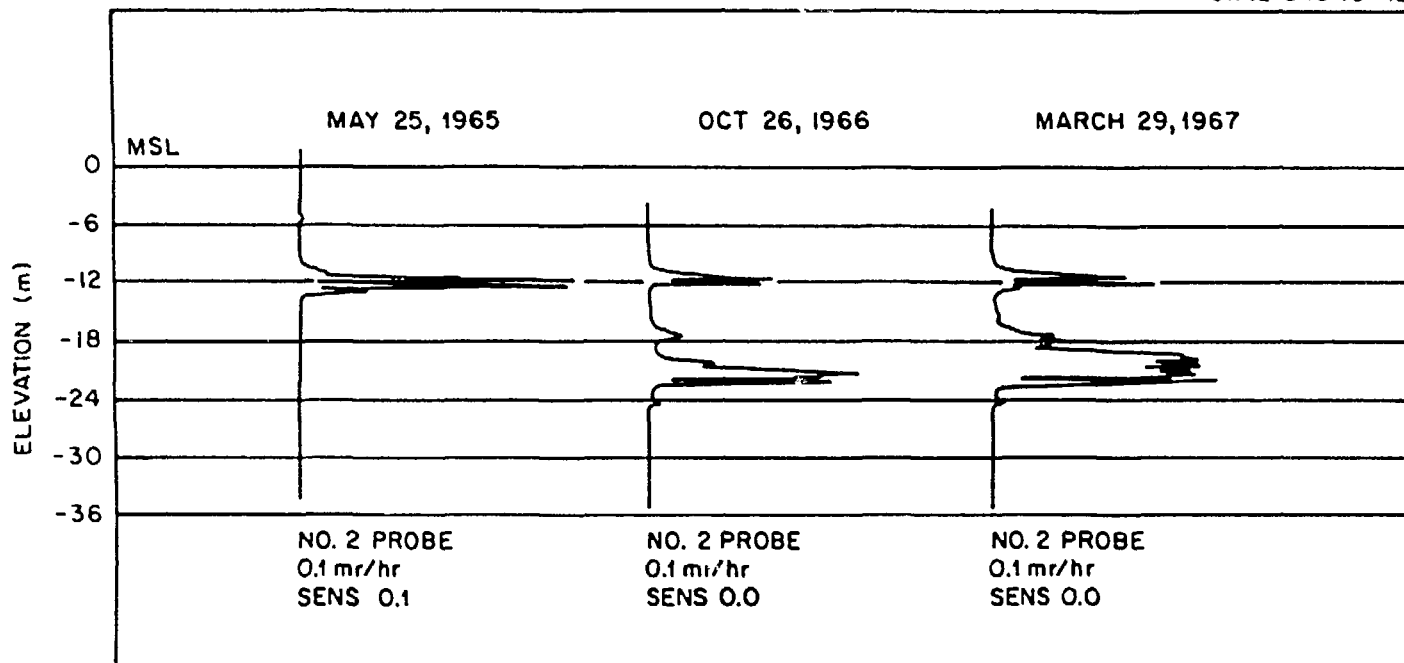


Fig. 2. Gamma ray logs of observation well following three injections.

Some process water is always injected with the grout. In addition, small volumes of free water can be formed in the disposal zone by phase separation from the grout. This excess water is recovered from the formation by a bleedback procedure. After the injected grout has set, the wellhead shutoff valve is opened and as much recoverable free water as may exist is bled back through the injection well and collected. The volume of this bleedback water does not exceed 10% of the injected waste volume and is usually much less.

Following some of the early injections, cores of the grout sheets were obtained. Fig. 3 shows one of these grout sheets embedded in the shale matrix.

The hydrofracture facility was designed to dispose of two different radioactive waste streams:

1. A locally generated evaporator concentrate solution. This solution is alkaline, about 1 to 2 M in NaNO_3 , and has a radionuclide content (predominately ^{137}Cs) of up to about 0.3 Ci/L (1 Ci/gal). About 380,000 L (100,000 gal) of this waste is generated annually.
2. Resuspended sludge that was generated by clean-out operations at old waste storage tanks. The sludge particles were 100 μm or smaller in diameter, and their concentration was up to about 20 wt % in a 2.5% bentonite suspension. The predominate radionuclide was ^{90}Sr and there was nearly 8 million L (2 million gal) of this sludge.

Different dry solids mixes, as required for these two waste streams, are listed in Table 1. They differ only in the deletion of the drilling clay from the mix for the sludge injection since the bentonite that is already in the sludge waste stream serves a similar function.

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Fig. 3. Core of grout sheet.

Table 1. Composition of Dry Solids Mixes for Hydrofracture

Ingredient	Waste solution mix (wt %)	Resuspended sludge mix (wt %)
Cement (type 1)	38.5	46.0
Fly ash	38.5	46.0
Drilling clay	15.4	
Pottery clay	7.7	8.0

The uplift of the ground surface was measured by surveying a network of benchmarks before and after the last five injections. These data indicate an uplift pattern similar to that obtained at the Old Hydrofracture Facility with a maximum surface uplift centered on the injection well of about 0.7 cm per million L (1 in. per million gal) injected. The data also indicate that some subsidence occurs between injections.

The cost of the injection series averaged about 25 cents per L (90 cents per gal) of waste injected. This cost includes dry solids, Halliburton's fee for injection assistance, and various maintenance and service charges. It does not include capital costs, the one-time cost of the well recovery operation, or special monitoring charges.

DESCRIPTION OF THE HANFORD TRANSPORTABLE GROUT FACILITY PROCESS

The grout production and disposal system³ consists of four major components: (1) a 1-million gallon (3.8×10^6 L) feed tank, (2) a Dry Materials Receiving and Handling Facility (DMRHF), (3) the Transportable Grout Equipment (TGE), and (4) a near-surface disposal site. The DMRHF and TGE are collectively called the Transportable Grout Facility (TGF) and comprise the "heart" of the grout disposal system.

Low-level liquid radioactive waste will be staged in 1-million gallon (3.8×10^6 L) batches in a double-shell tank which is currently under construction as part of another project. The waste will then be pumped to the TGE where it is mixed with the blended dry solids (prepared at the DMRHF) and pumped to the near-surface disposal site. After the grout

monolith has cured to the desired state of hardness, it will be covered with a thick layer of backfill. The disposal concept is described in more detail in the succeeding paragraphs, and a diagram depicting the entire disposal process is provided in Fig. 4.

The DMRHF will consist primarily of railcar and truck unloading hoppers, four dry materials storage bins, a dry materials blender, and a blended materials storage bin. These bins have been sized to support a continuous, seven days per week, 24 h per day grouting operation. The DMRHF will be capable of producing between 15,000 and 30,000 lb/h (6,820 and 13,640 kg/h) of dry blended solids.

The dry materials will be delivered to the Hanford Site in covered hopper railcars and in bulk material transport trucks. Capabilities will be provided at the DMRHF for gravity flow unloading of the delivery vehicle and pneumatically transferring the bulk dry solids to the storage bins. Unloading is to be accomplished at a rate of no less than 5,000 lb/min (2,270 kg/min) for railcars and 2,000 lb/min (910 kg/min) for trucks.

The dry solids will be pneumatically conveyed to a ribbon blender which will be designed and operated to produce a homogeneous blend. Each constituent in any one pound (0.45 kg) sample of the homogenized dry material will be within $\pm 5\%$ of its specified weight. The blended dry solids will be discharged from the blender to the blended materials storage bin by gravity flow.

The dry blended materials storage bin will be designed to assure that the material does not segregate beyond the desired ± 5 wt% accuracy. Materials from this bin will be gravimetrically fed to 27-ton (24.5 Mg) bulk material transport trucks for delivery to the TGE site, about one mile (1.61 km) away.

Performance Assessment and Verification

The performance of grout in immobilizing radioactivity for extended periods of time is being assessed using the allowable residual contamination level (ARCL) method and Hanford specific exposure scenarios, pathway-to-man models, and dosimetry models. Data gathered from lysimeter and

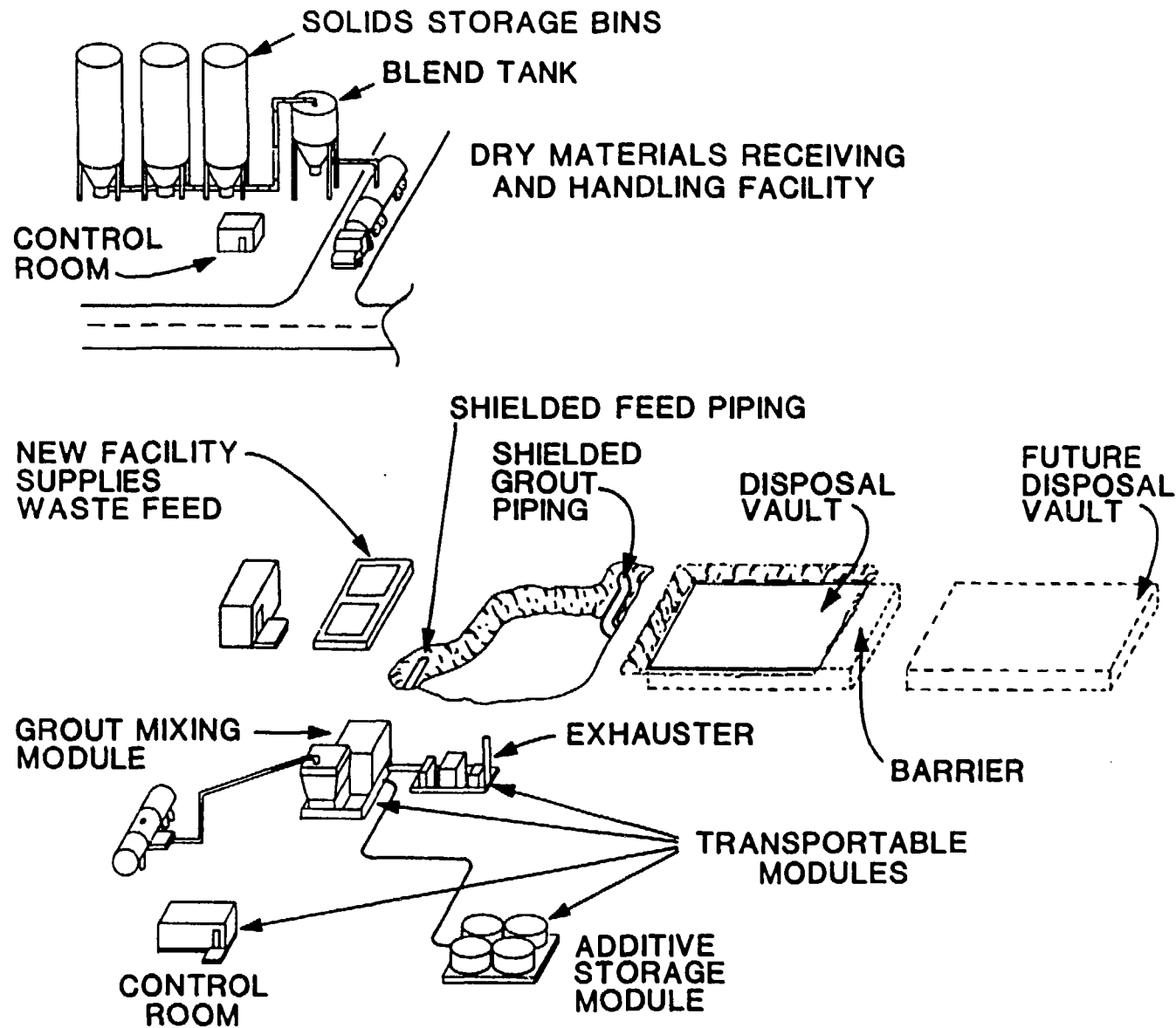


Fig. 4. Schematic of the Transportable Grout Facility.

laboratory testing will also be used in the models. The analyses being performed focus on the potential natural, human-induced, and disposal-induced events that may result in human exposure. Natural events include climatic changes, seismic activity, biotic transport, and wind erosion. Human-induced events include well drilling, excavation, and irrigation over a buried grout monolith. Disposal-induced events include structural failure of the monolith from thermal or pressure excursions.

Preliminary results show that bulk grouted decontamination and fuel storage basin filter solution, and cladding removal waste can be expected to perform adequately over the long term. Penetration of the waste zone by plants and burrowing animals would be essentially precluded by the soil and rock cover over the grout. Well drillers or excavating personnel would receive small radiation doses. Small doses would also occur to inhabitants living in the immediate vicinity of the waste material brought to the surface. Groundwater contamination would result in doses that are 30 million times lower than the average annual dose due to exposure to naturally occurring radiation. In no case would acute radiation effects on human health occur. Over the long term, no fatal cancers would be expected.

Grout System Cost

The costs associated with implementing low-level liquid radioactive waste disposal by producing grout are given in Table 2.

Table 2. Grout Disposal System Costs

Equipment	Costs (10 ⁶ \$)
Dry Materials Receiving and Handling Facility	3.8
Transportable Grout Equipment	4.0
Near-surface disposal site	3.4
Miscellaneous capital expenditures (in-tank mixer, blended dry solids, delivery trucks, etc.)	1.0
Expense funded	<u>15.0</u>
TOTAL	27.2

Expense costs include: engineering, formulation development, performance assessment, analytical capability development, and construction of the first disposal trench.

GROUT TESTING, CHARACTERIZATION, AND SHALLOW-LAND BURIAL TRENCHES AT THE IDAHO NATIONAL ENGINEERING LABORATORY

An investigation⁴ was conducted to test and define conditions for the use of grout to stabilize low-level and TRU waste in Idaho National Engineering Laboratory (INEL) shallow-land burial trenches. The types of grouts investigated were soil, ordinary particulate, fine particulate, and solution (or chemicals) grouts. Soil grouts were found suitable for disposal in trenches or drums, and particulate grouts were found to be suitable for filling voids in closed-trench soil/waste matrices and for establishing grout soil barriers around trenches. The question concerning suitability of chemical grouts in INEL soil has not been resolved. The recommended grout compositions listed in Table 3 are based on results from phase separation, compressive strength, freeze/thaw, density, penetration resistance, hydraulic conductivity, apparent viscosity, gel strength, soil column, and other miscellaneous tests. The following is a list of performance requirements imposed on grout formulation studies:

Study	Requirement
1. 7-d drainable water	0 vol %
2. 28-d compressive strength	≥ 50 psi, expected 200 to 800 psi
3. Compressive strength after freeze/thaw	> 200 psi
4. Hydraulic conductivity	$\leq 1 \times 10^{-7}$ cm/s
5. 10-min gel strength	≤ 100 lb _f /100 ft ²
6. Shrinkage during curing	< 1 vol %

With the exception of 10-min gel strength, all requirements were met satisfactorily for seven tested soil grout mixes (Table 3). The 10-min gel strength tests were not attempted on the soil grouts because of the

Table 3. Summary of recommended grout compositions

Grout type	No. of samples	Uses	Type I,II Portland cement (wt %)	INEL soil (wt %)	Class C fly ash (wt %)	Bentonite Clay (wt %)	Microfine cement (wt %)	Water-to-cement (weight ratio)	Additives
Soil	7	Open trench and drum disposals	22.5-38.5	30-40	10-20	-	-	0.67-1.00	a
Ordinary particulate	3	Fill large voids in closed trench soil/waste matrices	35-40	-	15-25	5	-	0.78-1.00	b
Fine particulate	3	Fill small voids; establish grout soil barrier around closed trenches	-	-	-	-	50-56	0.83-1.00	c

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a 0.2 to 0.8 wt % Dowell D-65 fluidizer.

b 0.5 to 0.7 wt % Dowell D-65 fluidizer.

c 0.2 wt % CFR-1 set retarder.

thickness of the mixes. The mixes exhibited the approximate thickness of conventional concrete that can be pumped.

The three ordinary particulate grouts listed in Table 3 passed all requirements satisfactorily. Six additional ordinary particulate mixes were prepared from dry-solid blends containing 20 wt % Type I, II cement. These latter grouts were not considered completely satisfactory, primarily because of the softness exhibited after 18-d curing which disallowed hydraulic conductivity tests.

All three fine grout mixes that were tested (Table 3) passed the requirement tests satisfactorily.

IN SITU TRENCH GROUTING

One of the major problems with shallow landfill trenches has been subsidence. In situ grouting⁵ would prevent subsidence by filling the large accessible voids in the trench with a cheap, coarse grout. This remedial action would also help to minimize water intrusion and to reduce the overall hydraulic conductivity of the trench. In turn, radionuclide migration would be retarded, hopefully to a negligible level. A typical field operation is shown in Fig. 5.

CONCLUSIONS

As can be seen in the previous sections a large number of cement-based grouting techniques are available, but no single grout type provides an ideal solution for all situations. The user must select the grout and equipment type based on required performance. However, the following equipment list is common to most types of grouting:

1. batching and weighing stations;
2. mixing equipment;
3. injection pumps;
4. auxiliary equipment such as volume measuring devices, flow meters and data recorders; and
5. source of water.

Some elements of cost in a typical grout injection are:

(1) site characterization, sampling, and analysis; (2) selection of grouting type and equipment; (3) drilling injection well, if required;

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Fig. 5. In situ trench grouting; a typical field operation.

(4) equipment procurement, operating time, standby time, mobilization and demobilization charges; (5) support labor; (6) supervision; and (7) verification of performance.

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