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MARTIN MARIETTA

In Situ Grouting of a Low-Level Radioactive Waste Trench

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ABSTRACT

A shallow land burial trench containing low level radioactive waste was injected with a particulate grout to help control subsidence and radionuclide migration. The trench's accessible voids have been estimated at 20 vol %, and most of these voids appear to have been filled with grout. This injection was accomplished with a simple, labor intensive technique, and an inexperienced crew at an estimated cost of about $55,000. The grout costs $0.21/gal and 8081 gal was injected into the trench.

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1. INTRODUCTION

In August 1986, particulate grout was injected under pressure into trench 150 in the Oak Ridge National laboratory (ORNL) Solid Waste Storage Area (SWSA) 6 as a remedial action demonstration. The objective of this full-scale demonstration is to assess the effect of this type of grouting on trench subsidence and radionuclide behavior. An earlier report provided information on the development of the grout formulation.[1] This report summarizes the field injection operation. A report at the end of FY 1987 will summarize the entire operation, including the post evaluation and monitoring results to date.

Many millions of cubic feet of radioactive waste are buried in shallow trenches and pits across the United States, much of it in the humid Southeast. These radioactive burial sites have experienced the same problems as other shallow-land burial sites: subsidence, container disintegration, water and biota intrusion, waste migration, and groundwater and surface-water contamination. In situ grouting is one of the remedial actions currently being tested in an attempt to solve some of these problems. The objectives of in situ grouting (solution or particulate) can range from filling the large, accessible voids to penetrating the entire underground area (large voids, waste, containers, soil backfill, and surrounding undisturbed soil). Low-level radioactive waste (LLW) trenches have been experimentally grouted with solution (chemical) grouts with the latter objective in mind.[2] However, the typical commercial grouting of nonradioactive landfills uses particulate grouts to meet the former objective of filling the large voids. No field demonstrations of in situ particulate grouting of LLW trenches have been attempted. Besides the obvious benefit of filling the large voids and preventing subsidence, particulate grouts may immobilize and encapsulate most of the radioisotopes close to the waste, may redirect water flow paths away from the waste, and may offer the advantage of utilizing natural materials that withstand the rigors of weather and time.

2. EQUIPMENT AND PROCEDURES

2.1 SOLIDS BLENDING

Solids blending is the dry mixing of the grout solids to produce a homogeneous blend. Sometimes the dry grout components can be mixed separately with the water, but this is not recommended when bentonite is one of the components. The equipment at the New Hydrofracture Facility (NHF) at ORNL was used for blending in this operation (Fig. 1). The NHF was not designed to be used for such a small operation or to deliver the blended solids outside of the facility. However, minor modifications resulted in satisfactory operation.

The dry blend components used were those recommended by Tallent et al.:[1] Type I Portland cement, Eastern Class C flyash, and bentonite. The relative proportions of these components blended for the field operation was approximately the centroid of the acceptable range of compositions identified by Tallent et al.; the blend consisted of 39% cement, 55.5% flyash, and 5.5% bentonite. The bulk cement and flyash were purchased and stored in tank trailors at the NHF. The bentonite came from an existing stockpile of 100-lb bags of bentonite at NHF. The blending and transport operations were done pneumatically.

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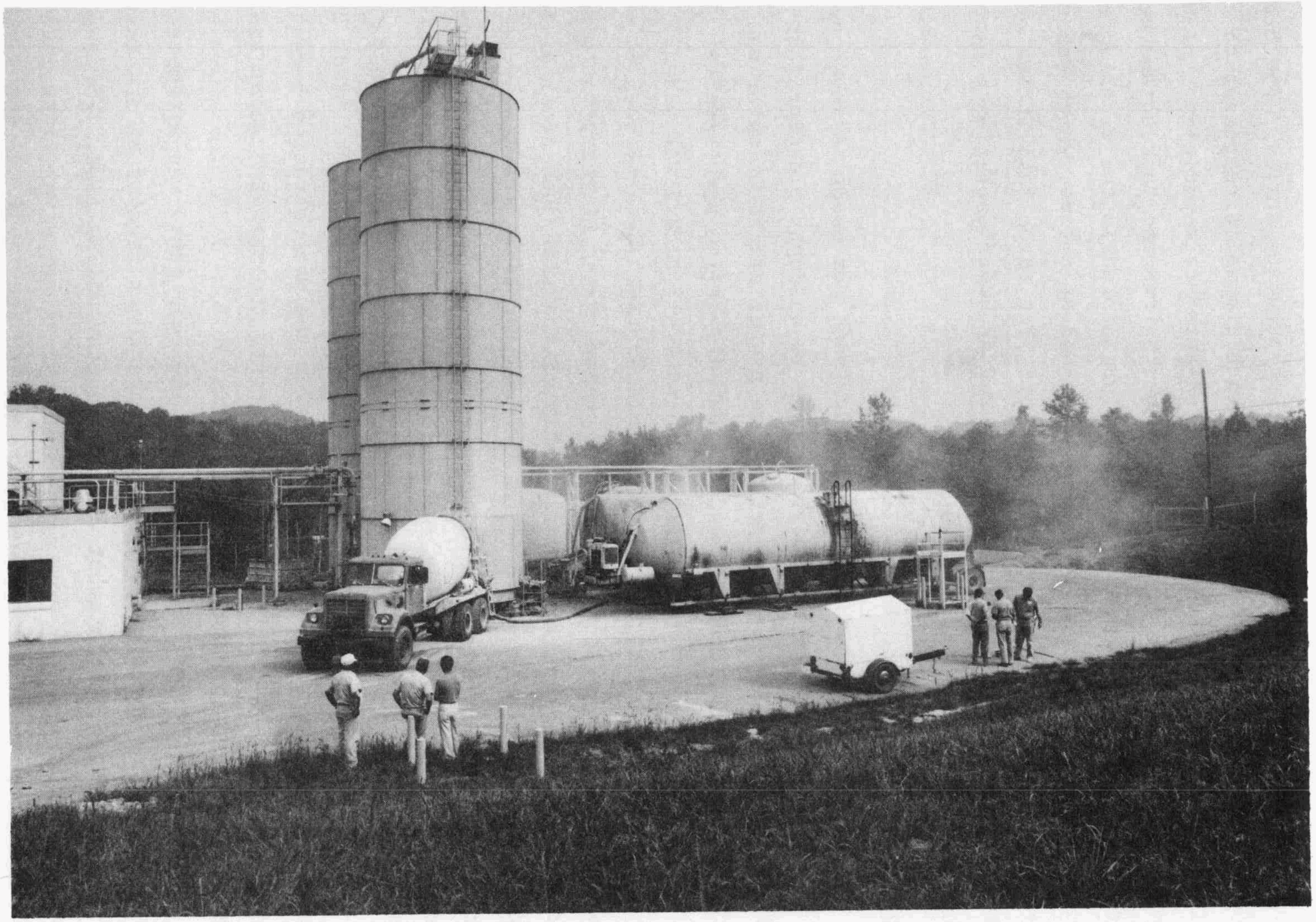

Fig. 1. Blending and mixing operation at the new hydrofracture facility.

The blending tanks at NHF consist of three pneumatic tanks, each capable of holding about 40,000 lb of dry solids. One of these tanks (the weighing tank) is mounted on a set of accurate scales. The blending procedure started with the addition of each dry solid component to the weighing tank, with the tank weight noted after each addition. Blending was done by blowing the entire tank contents from one tank to another three times. After blending, the blend was stored in the weighing tank for later use. About one tankful was blended at a time, which was enough dry blend to keep the grout injection going for three days at its optimum rate. A sample of the blend was taken and archived each time a batch of grout was mixed.

2.2 GROUT MIXING

For grout mixing, a concrete mixing truck was used. A known quantity of blend was blown from the weighing tank to an empty blending tank (the holding tank). Using a water meter, the proper amount of water was put into the truck drum; and the set retarder/dispersing agent (delta gluconolactone, marketed by Halliburton as CFR-1 sugar) was added. With the drum rotating at high speed, the holding tank contents were blown into the drum (Fig. 1). The mix ratio and proper mixing of the grout were confirmed by measuring the grout density at the site just after mixing and several times during the injection. At each stage of the operation (i.e., empty, with water, and with grout), the truck was weighed to provide another check on the weighing and mixing.

Mixing in this manner was not recommended initially because a concrete mixer depends on the aggregate to shear the mix and break up lumps. This technique, however, worked for the demonstration because the grout used was fluid enough to be slurried by the agitated water and few lumps were present in the purchased solids.

A different technique (mixing in a 1500-gal tank) was attempted at the beginning of the field work but was abandoned because of its inability to produce a homogeneous grout and its lengthy mixing time. For the abandoned technique, the preweighed quantity of blend was blown into the back of a dump truck covered with a tarpaulin and hauled to the injection site at SWSA-6. At the site, the proper amount of water was added to a

1500-gal tank (see the tank in the background of Fig. 2) and the CFR-1 sugar was added to the water. The blend was then scooped from the truck bed and dumped into the 1500-gal tank, where it was mixed and kept suspended by recirculating the tank contents continuously through a diaphragm pump at about 80 gpm. In addition to the agitation provided by pumping the fluid, an impeller stirrer kept the upper two-thirds of the tank agitated. One tank full of grout was sufficient for one day's operation at average rates.

In the first batch made in this manner, no operational problems were encountered. However, the second batch became too thick to pump. A check of the weighing records quickly revealed that an excessive amount of solid material had been inadvertently added; and because with this technique there was no way to reslurry the grout with more water, which was not expected, the batch was dumped. In addition, mixing using this technique took longer than was anticipated, almost half a workday.

The inherent instability of the abandoned technique was recognized prior to beginning field operations as was the possibility of mixing problems in the other technique, which involved using the concrete mixer without the presence of aggregate. Both techniques were kept as options and tried in the field operation. The concrete mixer proved to be easier, quicker, less troublesome for mixing and delivery, and less hazardous to operating personnel. Not surprisingly, neither technique duplicated exactly the mix used in the laboratory, but the grouts produced were satisfactory. The recirculating pump technique has worked well for making large batches of lime-flyash slurry, but, unlike cement grouts, such a slurry may be left unagitated overnight and still be reslurried.

2.3 LANCE PLACEMENT

The lances were sections of 1.939-in.-ID by 2.375-in.-OD (2-in.-diam schedule 80) pipe. Disposable points were placed in the end of the lances prior to driving them into the trench to enhance penetration of the backfill and to prevent soil from blocking the grout exit. A 120-lb portable air hammer was used to drive the lances into the trench (Fig. 3). A lance was driven either to the bottom of the trench or until an obstruction was encountered. Once in place, the lance was pulled up

ORNL-PHOTO 4827-86

Fig. 2. Grout injection into Trench 150.

ORNL-PHOTO 4834-86

Fig. 3. Lance placement.

6 in., the point was knocked out of the end (and left in the ground at the bottom of the hole), and the lance was pulled up another 6 in., ready for grout injection. Upon grout refusal at a given depth, the lance was pulled up 1 ft and grouting was continued. Injection into a given hole was terminated if grout appeared on the surface of the trench or if the pressure required to inject the grout was excessive (~20 psi).

Because long lances could not be handled with this manual placement procedure, segments of 7 ft or less were joined with pipe couplings to keep adding length to the lance until the desired depth was achieved. For trench 150, two 7-ft sections were more than sufficient to be able to reach the bottom of the trench. In fact, the lances usually could not be driven as much as 7 ft. The trench bottom was approached in only 4 placements out of the 36 used. In some cases, obstructions prevented penetration to the trench bottom; but, in general, the 2-in. pipes offered more resistance to being driven into the backfill than was expected. The 120-lb hammer was just not capable of forcing the 2-in. pipes through the backfill at most locations. However, this limitation did not affect the final outcome. As expected, injection into one placement gave access to a large area of the trench, including the area around several other placements.

Nevertheless, for deeper penetrations, smaller diameter pipes are suggested for any future injections using this placement technique. Lances made from 0.742-in.-ID by 1.05-in.-OD (3/4-in. schedule 80) pipe should work for the SWSA-6 trench depths and the grout uptake rates observed for trench 150. The smaller pipe would increase the frictional pressure drop through the lance, but a progressive cavity pump could easily handle the extra workload while maintaining the same flow rate.

2.4 GROUT INJECTION

For grout injection; a progressive cavity pump with a maximum rate of about 15 gpm was used. The pump was fed by two 70-gal slurry mixing tanks. While grout from one tank was being pumped, the other was being filled with grout from the concrete truck (Fig. 4). The grout was pumped through 50 to 100 ft of 2-in. high-pressure hose, past a pressure gage, through the lance, and into the trench (Fig. 2).

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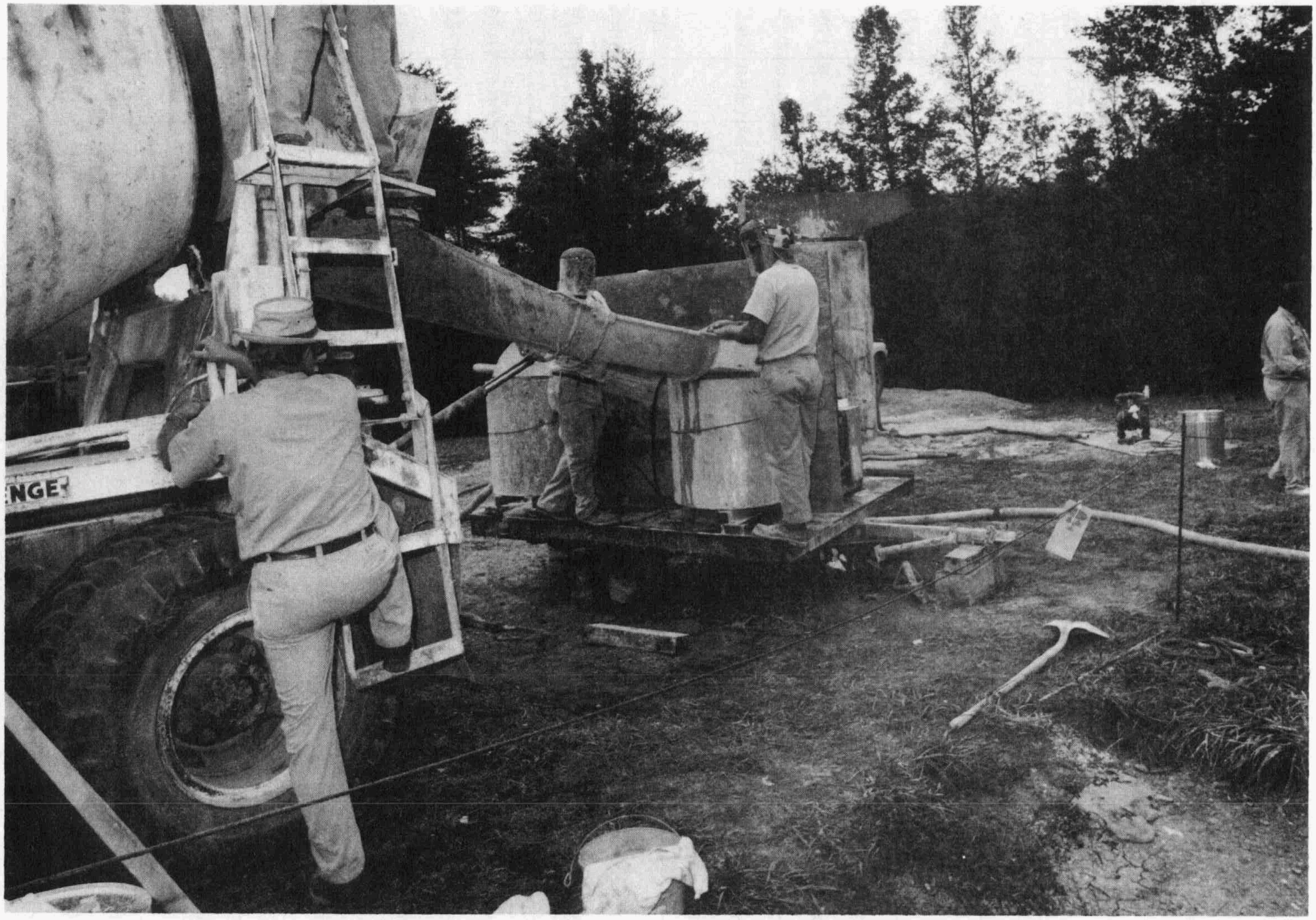

Fig. 4. Filling a 70-gal tank on the pump trailor.

A pressure of 5 to 10 psig was used as long as possible for the injection. Once the voids accessible at a given location began to fill, the pressure began to creep up and the pumping rate would be decreased. Pump rates lower than about 5 gpm resulted in operational problems for the motor and slurry agitators (the motor ran the pump and the agitators). Thus, rates at 4 gpm ± 1 were not decreased further. A slow rise in pressure indicated steady filling of the voids, and a sharp rise indicated a bottleneck to expansion or no further room for grout uptake. Injection was continued as long as possible while the pressure rose slowly. Depending on the depth and grout uptake behavior, injection was stopped at 15 to 20 psig. Sharp rises were treated more carefully. Stopping sometimes relieved the pressure, indicating that a grout flow path existed but resistance to grout movement was high. In such cases, higher pressures sometimes caused a breakthrough in the bottleneck, allowing continued operation. If high pressure was not relieved by stopping the pump, then the lance depth or location was changed. Injection was also stopped as soon as any grout broke through to the surface.

The lance depth was changed by pulling the lance up 1 ft. At the new depth, grout injection was continued until refusal. Then the entire process was repeated. This procedure changed once the lance was within 2 ft of the surface, where effective grouting could not occur. At this point, the lance was withdrawn from the ground, and the grout injection operation was moved to a new location. The lance was pulled up either by a hydraulic jack or a small crane. The jack was small, portable, and easy to operate; but it took longer to use and was subject to contamination. The crane was used exclusively after the first two days because it was quicker, operated smoother, and eliminated the possibility of contamination. The crane was also needed to safely handle the air hammer for lance placement; it served well in both jobs.

The procedure was different once surface breakthrough occurred. Such breakthroughs can be categorized as (1) oozing around the injection lance, (2) oozing around another previously installed lance, (3) oozing up a previous injection hole, or (4) oozing out of a new pathway on the surface. Sometimes packing the exit at the surface and waiting a few minutes allowed injection to be continued. This worked especially well for oozing around the lances and occasionally worked for new pathways. Once a pathway developed at the surface with the lance at one depth, injection at a shallower depth in the hole would not work because grout would follow this same pathway to the surface. Therefore, once such a breakthrough occured, the lance was removed and the hole was abandoned. One of these four types of breakthroughs did occur at most of the injection holes, rather than the lances being withdrawn to the surface in the orderly fashion described earlier in this section.

3. INJECTION

3.1 GROUT QUANTITY AND LOCATION

Figure 5 illustrates the grout location points used. Table 1 lists the quantity of grout injected at each location and the depth at which the injection occurred. The depths referred to in Table 1 were the distances below the excavated surface; the trench bottom was at a depth of 10.8 ft (3.3 m). The total trench volume for this depth was 5564 ft^3 (41,619 gal or 157,000 L). A total of 8081 gal of grout was injected into the trench, representing 19.4% of the trench volume (excavated). The accessible void volume was estimated at 20% by T. Tamura.[3]

The injection was accomplished in two steps. The 18 primary injections were done in a diamond pattern with 10 ft, measured center to center, between injection points, (Fig. 5). The 18 secondary injections were done midway between the primary points, resulting in an injection either primary or secondary, being made about every 5 ft. Over 85% of the total volume of grout was injected in the primary injections. Note that most of the grout was injected into only a few holes (Table 1). Primary injections at F-2, C-3, I-3, and B-2 accounted for 38.4%, 21.5%, 7.7%, and 4.8%, respectively, of the total, for a cumulative total of 72.4%. Of the secondary injections, only F-1 provided a significant amount of the total (5.9%). Through these five holes, 78.3% of the grout was injected.

Based on the grout uptake locations, the trench can be roughly divided into three regions: north, central, and south. As expected, a

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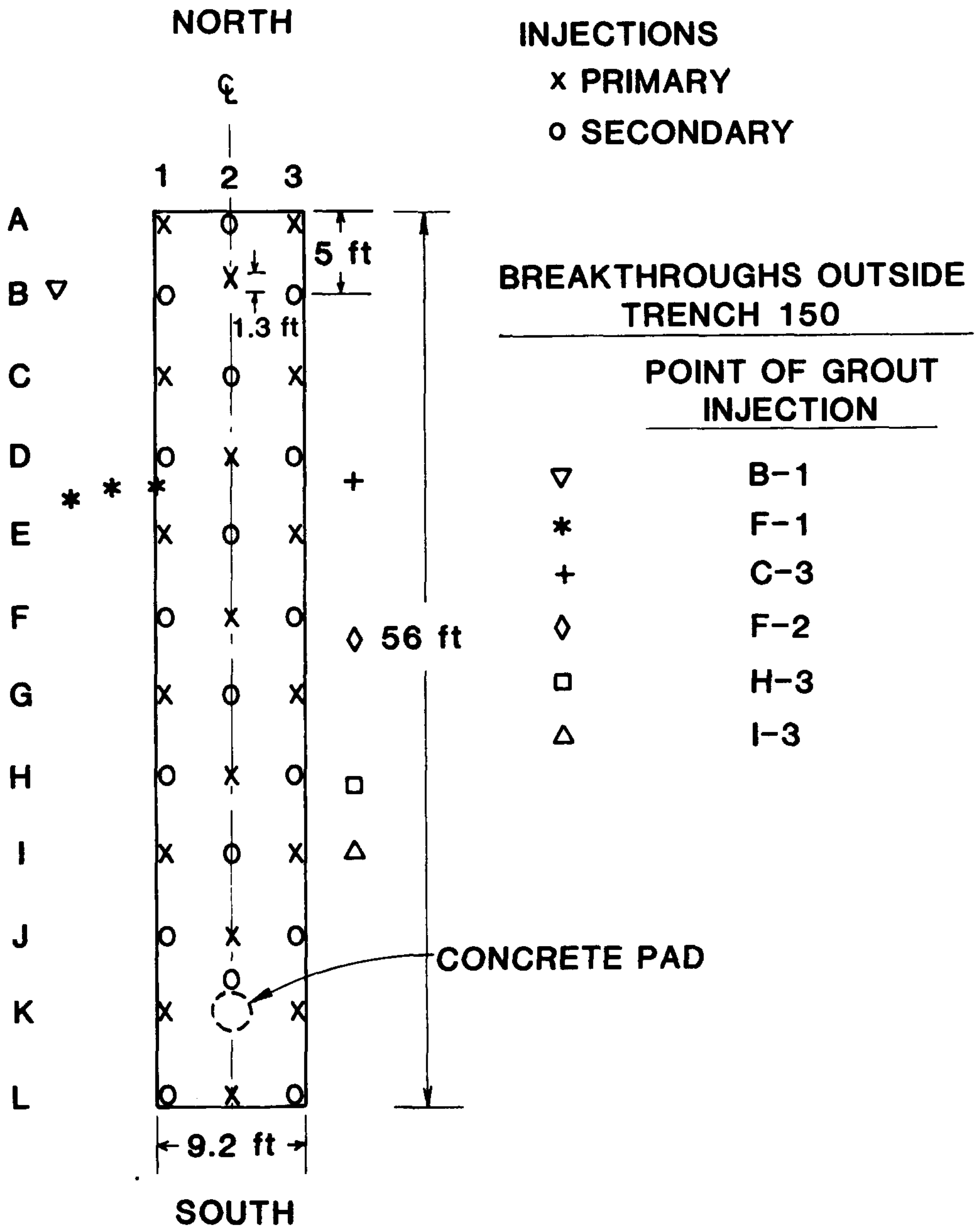

Fig. 5. Grid locations for grouting Trench 150 in SWSA-6.

Table 1. Summary of grout injection of trench 150

Injection No.	Location	Depth (ft)	Volume (gal)	Time (min)	Uptake rate (gpm)	Reason for stopping
			Primary injections			
1	B-2	9.5	360	38	9.5	Breakthru 1.7 ft S of B-1
		7.5	25	2	12.5	Changing depth no help
2	C-3	2.5	1740	300	5.8	Breakthru between 150 & 152[a]
3	C-1	6.75	207	30	6.9	Breakthru at B-2
4	D-2	5.2	0	0		High pressure
		4.0	0	0		Breakthru at C-1
5	E-3	6.0	60	5	12.0	Breakthru at C-1
6	E-1	5.5	38	5	7.6	Breakthru at D-2
7	F-2	8.5	171	64	2.7	High pressure, low pump rate
		7.5	591	80	7.4	Grout thickening
		6.5	1685	260	6.5	High pressure, low pump rate
		5.0	180	40	4.5	High pressure, low pump rate
		3.0	480	75	6.4	Breakthru between 150 & 152
8	G-3	5.9	0	0		Breakthru at F-2
9	G-1	10.0	85	10	8.5	Breakthru 3 ft S of D-2
10	H-2	4.0	0	0		Breakthru at G-3
11	I-3	6.1	625	65	9.6	Breakthru between 150 & 152
12	I-1	3.25	150	17	8.8	Breakthru within 1 ft of I-1
13	J-2	4.4	80	11	7.3	Breakthru at I-3
14	K-3	3.8	70	10	7.0	Breakthru at K-3 wall
15	L-2	4.8	150	15	10.0	Breakthru at K-1 & pad
16	K-1	7.2	30	3	10.0	Breakthru within 1 ft of K-1
17	A-1	6.0	185	45	4.1	Breakthru 1 ft N of F-1
18	A-3	6.0	7	1	7.0	Breakthru at A-1
			Secondary injections			
19	F-1	8.5	480	60	8.0	Breakthru W at 150 & S of D-1
20	F-3	8.2	80	10	8.0	Breakthru S of D-1
21	G-2	3.75	0	0		Breakthru at G-1 wall
22	H-1	5.25	20	3	6.7	Breakthru 4 ft N of H-1

Table 1. (Continued)

Injection No.	Location	Depth (ft)	Volume (gal)	Time (min)	Uptake rate (gpm)	Reason for stopping
			Secondary injections			
23	H-3	4.6	110	15	7.3	Breakthru between 150 & 152
24	E-2	5.3	10	2	5.0	Breakthru at F-3
25	D-3	1.0	0	0		Too shallow
26	D-1	2.5	10	2	5.0	Breakthru at D-3
27	A-2	4.7	20	12	1.7	Breakthru 2 ft N of C-2 & C-3
28	B-1	4.1	25	7	3.6	Breakthru W of 150
29	B-3	4.1	55	15	3.7	Breakthru at C-2
30	C-2	5.75	125	29	4.3	Breakthru at B-3
31	I-2	3.0	30	6	5.0	Breakthru 1 ft S of H-1
32	J-1	6.6	40	8	5.0	Breakthru 1 ft N of L-1
33	J-3	3.4	10	2	5.0	Breakthru at J-3, 1 ft S of K-3
34	K-2	2.8	5	1	5.0	Same as J-3
35	L-3	2.3	135	45	3.0	Breakthru 3 ft W of L-3
36	L-1	2.0	7	2	3.5	Too shallow
		Total	8081	1325	6.1 av	

[a]Breakthrough occurred between trench 150 and 152.

great deal of hydraulic interconnection exists within the trench and partially defines these three regions. Once a region was saturated with grout, further addition resulted in upwelling of grout from another hole or a previous breakthrough. The northern region was saturated by the injections into B-2, C-3, and C-1. The central region was saturated by the injection into F-2, and the southern region, by the injection into I-3. Of the secondary injections, only the first injection, in the middle portion of the trench at F-1, took a large amount. However, the remaining 30 injections still accounted for 20% of the grout injected and cannot be disregarded.

Based on the results of this demonstration, the initial injections could have been made on 20- to 25-ft centers. Also, stopping at the end of the workday when a given hole was still taking grout at a good rate may have caused some accessible voids to be sealed off when the grout set overnight (only the injections into C-3 and F-2 were not completed in one workday). To prevent this in the future, operation should be stopped only after grout refusal of a given hole. Once a region is saturated, further injection while the injected grout is still fluid is usually pointless because the regions are so hydraulically connected that forcing in grout at one point just forces grout out at another point. A more effective method for the future would be to allow the grout to set after saturation is reached in a given region before injecting more grout into the region. This should plug the previous hydraulic connections and force grout into new areas.

3.2 TIME AND RATE

The time and rate of injection can be defined in several ways. For example, based on total time and volume and average uptake rate in Table 1, it took 22 h to inject 8081 gal of grout into trench 150 at an overall rate of 6.1 gpm. However, this can be misleading since the job took a total of 11 days. The values reported in Table 1 represent only the times when injection was occurring and do not include support operations such as blending, mixing, and lance placement. In general, grout uptake rates started high and had to be reduced as the voids filled and pressure increased, but the rates reported in Table 1 are overall averages for the given injections. Spot checks of the pump rate agreed with these overall rates, so the times and rates reported in Table 1 are indicative of the grout uptake rate for a given injection.

If an average injection rate is based on number of days worked (11), an average of 735 gal/day was injected into trench 150. However, this period includes some time when little or no grout was injected. The first two days were used to set up the operation and the equipment. The next two days were spent familiarizing the personnel with the operation and equipment and trying the recirculation mixing technique; only 385 gal was injected during these two days. Thus, the daily rates can be summarized as 0 gal/d for the first two days, about 200 gal/d for the next two days, and about 1100 gal/d for the remaining seven days.

The field operation was designed around an 8-h workday and a 1500-gal batch of grout. It was expected that 1500 gal of grout could be mixed and injected into the ground within a normal 8-h workday, with time left for cleanup and setting up for the next day. Thus, the workday was defined around the grout batch, with the hours remaining flexible, (i.e., the workday ended when the batch was injected and the equipment was cleaned). At the beginning, 1500-gal batches were used; and, as expected, an entire batch could be injected in close to the desired time. As the trench became saturated and the grout uptake rate slowed, the batch size was cut in half (to 750 gal). The workday hours remained about the same because mixing the smaller batch took just as long as mixing the larger batch, the injections took longer, and much more time was required for moving from hole to hole and driving lances.

In the transition period between larger and smaller batches, when 1500-gal batches were still being used but the time for injection was significantly longer, the grout thickened unexpectedly early toward the end of a batch. Laboratory tests had demonstrated that the grout would set overnight but would not thicken for 8 h or more if agitated. However, thickening occurred in the field after only 7.5 h, probably because direct sunlight and higher temperatures speeded up the cement reactions. All of the equipment was cleared of the rapidly thickening grout except for two sections of lance pipe. Operation around 7 h after grout was mixed was avoided for the rest of the project.

4. ANALYSIS OF THE LANCE TECHNIQUE

4.1 SMALL-SCALE MANUAL EFFORT

The grouting technique used in this demonstration was simple and straightforward and was easily learned by inexperienced crew. The equipment needed was inexpensive and readily available. Driving the pipe was hindered by the large pipe size (2-in. diam), but using a smaller pipe (3/4-in. diam) would have solved this problem.

This technique was labor intensive. A minimum of two men could have performed all the operations, but time would have been sacrificed. Only the mixing and injection had to be done sequentially; blending and lance placement were done at the same time as other operations. Ten workers were used for this field demonstration, more when blending or truck driving was required; but this was more than was necessary. The work was performed by craft workers; and because no craft exists for "grout worker" at ORNL, two or more different crafts were required in situations that one worker could handle for commercial grouting firms. Also, some manpower duplication was necessary to continue operation during breaks and meals. Two workers can handle all the tasks if the grout batch can be used over a period of several days, as in the case of lime-flyash grouts. Cement grouts must be injected in a matter of hours, and more workers are necessary to handle tasks that need to be done simultaneously. If all the workers can work interchangeably, then a minimum number of four or five could perform the operation. This would supply enough workers to blend, mix, place lances, and inject and still provide coverage for staggered breaks and meals.

Maneuvering around buried objects is more time consuming and complex with this technique than it would be for a mobile lance machine. Several steps involving two or more workers are required: (1) driving the lance down until an obstruction is met, (2) removing the hammer and attaching the puller, (3) pulling up the lance, and (4) repositioning the lance and driving at the new location. The actual driving takes only a few minutes, but relocating can take 15 min or more, especially if a hydraulic jack is used to pull up the lance.

The grouting operation could be speeded up by using a header system and injecting into more than one lance at a time. Initially, when grout uptake rates are close to the pump maximum, dividing the flow would not help much. As the voids fill and the rate for an individual lance decrease, the benefit becomes obvious.

4.2 COMPARISON TO A MOBILE LANCE MACHINE

The mobile lance machine is not a standard grouting machine routinely available from the typical grouting vendor. Rather, it consists of a lance or lances mounted on a machine that is able to quickly and easily position itself at any point desired, quickly insert the lance to the desired depth, quickly stop or reposition a lance if an obstruction is encountered, and inject grout as soon as a lance is in place. Such machines have not been routinely used with cement-based grouts. They were originally developed for lime-flyash injections into railroad beds. Companies such as Woodbine, Inc., Ft. Worth, Texas, have machines with up to four independent lances that go as deep as 40 ft. The lances are not as rugged as the thick-walled pipe used in this demonstration, but they proved to be rugged enough in the loose trench backfill for a demonstration conducted by Woodbine in a nonradioactive trench at SWSA-6. With such a machine, the grouting of trench 150 could have started with four evenly spaced, simultaneous injections along the north-south axis. Based on the results reported in Table 1, 75% to 80% of the trench could have been grouted from this initial set of injections. Next, as many injections as desired, wherever desired, could have been made to ensure topping off the trench.

The concept appears feasible and offers the advantages of quicker, less labor-intensive operation over the technique used in the demonstration. Difficulties do exist in acquiring the services of such a machine. The lime-flyash vendors possess the most advanced machines, but they have had little experience in grouting with cement grouts. The cement grout vendors have had little experience with such machines. The few vendors that claim experience with both may not wish to work in areas contaminated with radioactivity. The advantages of this technique over the labor-intensive technique are much more apparent for larger jobs, such as grouting all the trenches in SWSA-6. For small jobs, such as grouting Trench 150, the time advantage may be small or nonexistent. Use of a mobile lance machine on small jobs may cost more due to the large mobilization effort needed to move the machine to the site.

5. ECONOMIC ANALYSIS

5.1 DRY BLEND COMPONENTS

Table 2 reports the cost of the dry blend components. No bentonite was purchased for this demonstration because plenty 100-lb bags were available for use at NHF. The cost for bentonite given in Table 2 is the cost quoted in the economic analysis of in situ grouting done for EG&G Idaho.[4] For only a few tons of bentonite, the shipping charges are higher

Table 2. Cost of dry blend components

Component	Source	Quantity (t)	Cost	
			$/t	Total $
Type 1 Portland cement	Dixie Cement Company, Inc., Knoxville, Tennessee	23.5	61.31	1441
Eastern class C flyash	American Flyash Company Des Plaines, Illinois	50	40	2000
Bentonite	Black Hills Bentonite Mills, Wyoming		38[a]	

[a]Price without freight costs from Mills, Wyoming, to Oak Ridge, Tennessee.

than the material cost. From Table 2, the purchase price of bentonite was about $0.02/lb ($0.044/kg). Assume that the delivered cost was $0.05/lb ($0.11/kg). From Table 2, the delivered costs of cement and flyash were $0.03/lb ($0.066/kg) and $0.02/lb ($0.044/kg), respectively. The target mix ratio of 12.5 lb dry blend per gallon of water had a resultant density of about 13.5 lb/gal of grout (1.62 kg/L). Therefore, each gallon of grout was calculated to contain 3.2. lb of cement, 4.5 lb of flyash, and 0.4 lb of bentonite. Ignoring water costs, each gallon of grout costs $0.10 for cement, $0.09 for flyash, and $0.02 for bentonite, for a total of $0.21/gal of grout ($0.055/L). Thus, the total cost of the grout injected into trench 150 was $1697. About 300 gal, representing $630, was dumped or wasted because of learning errors.

5.2 EQUIPMENT AND LABOR COSTS OF DEMONSTRATION PROJECT

Table 3 shows the cost of renting grouting equipment from a local grouting firm. The total equipment costs were $3449. Discounting the 4-d learning and experimental period and the cost for the technical advisor leaves $1773 for equipment costs during the period of active injection. As shown in Table 4, a total of about 1217 work-hours was used to grout trench 150 at an estimated cost of about $50,000. Based on total equipment costs of $3449 and total labor costs of $50,000, the per-day cost of manpower and equipment was about $4800. Of the 11 d of operation, 4 d were spent in setting up, instructing the workers, and experimenting with the mixing procedure; during the remaining 7 d, the bulk of the grouting was done. Using the estimated daily cost of $4800, these 7 d cost $33,600. Based only on the 7-d period, about 1150 gal of grout was injected per day into trench 150 at a cost of $242/d for the grout; a total daily cost of manpower, equipment, and grout was $5,042.

The work-hours reported in Table 4 include some overtime and some duplication of personnel. Based on the work-hours used and an 8-h workday, the job averaged 14 people, including the foreman, the engineer, and the blending operators (hydrofracture).

5.3 ESTIMATE OF COMMERCIAL OPERATION COSTS

An estimate of cost for a commercial operation to perform this job is useful for comparison purposes. As expresssed in Sect 4.1, a commercial operation probably could use a working crew of five (including the foreman) plus a part-time engineer. ORNL would still need to provide some support [e.g., a health physicist (HP)]. Therefore, a crew of six (including the HP and excluding the engineer), working 48 work-hours per day at an estimated $40 per work-hour costs $1920/d. Equipment costs are estimated to run $219/d, based on the daily costs listed in Table 3 (excluding the technical advisor and driver bullets). An estimate of grout cost is $242/d (any unused grout must be discarded at the end of each day). Total estimated costs to this point are (1) manpower, $1920/d; (2) equipment, $219/d; and (3) grout, $242/d. Overhead and profit for the commercial vendor would increase the price by about 25% to $3000/d, or about $2.60/gal of grout injected.

A commercial operation would require one day to set up, and the smaller crew would likely take longer to complete the job. The job could take 11 d, as in the demonstration, but without the learning time. This assumption gives an expected cost of about $33,000 for a vendor to grout trench 150 using the same technique as used in the demonstration. If a mobile lance machine is used, a mobilization cost of several thousand dollars would be charged with little advantage in time or money for a small job such as this one. Thus, the total cost could be $40,000, or

Table 3. Cost of renting grouting equipment from Rembco Engineering Corp., Knoxville, Tennessee

Equipment	Cost $/unit	Cost Total $ for 11 d
Pump and tanks	65/d	715
Casing puller	20/d	220
Casing driver	20/d	220
1500-gal tank and pump	50/d	550
Mixer	50/d	550
Casing sections (98 ft)	14/d	154
Driver bullets (40)	6 ea	240
Technical advisor (5 d)	160/d	800
Total		3449

Table 4. Estimates of manpower used for grouting trench 150

Worker	Work-hours[a]	Cost ($) @ $40/work-hours[b]
Laborers	473	18,920
Truck drivers	191	7,640
Pipe fitters	135	5,400
Power equipment operators	132	5,280
Engineer	88	3,520
Foreman	88	3,520
Health physicist	60	2,400
Hydrofracture operators	50	2,000
Total	1217	48,680

[a]Work Order A3018EG1.

[b]Nominal work-hour costs chosen arbitrarily but typical of current ORNL costs.

more, for a single trench. The benefits of using the machine would become more apparent as the size of the proposed job increased.

6. LESSONS LEARNED

1. The accessible voids in a shallow-land burial can be grouted with a fluid slurry grout.

2. Up to a third of a trench the size of trench 150 can be fairly saturated with a fluid slurry grout from a single injection hole, a linear distance of about 20 ft.

3. Such single injection points can grout up to 80% of the trench. The remaining 20% requires several scattered injection points.

4. After a single-point injection to saturation of a given area, any immediate attempts to grout in the same area usually push grout out of a previously used hole or a previous breakthrough zone. A better strategy is to allow the grout to set (to seal the hydraulic connections) before attempting more injections in the same area.

5. The simple lance technique can be quickly learned and used to grout trenches.

6. Two-inch-diam pipe is too large to be easily driven into the loose backfill of the trench. The hydraulic connections among the trench voids still allow grouting, even with only partial insertion of the lance; but smaller pipes would allow easier insertion to the trench bottom.

7. A concrete mixing truck can be used to mix a fluid slurry as long as the dry powders do not contain excessive amounts of lumps.

8. If too much solid is added to the mix using the recirculating tank, the solid will not remain suspended, and subsequent adjustment to the proper mix ratio becomes difficult or impossible. This recirculating tank should be avoided, or the operators should be aware of proper solids addition. In addition, mixing in this tank is much slower than mixing in the concrete mixing truck.

9. On the average, the grout uptake rate was 6.1 gpm, with an average of 1154 gal/d injected. Thus, only about 40% of an 8-h workday was used in grout injection. The remainder of the time was used in mixing the grout, driving and pulling the lances, and cleaning up.

10. Grout thickening may occur quicker in field operation than in the laboratory, and temperature effects on setting time should be known.

11. Grouting operations should be conducted on a 24-h/d basis if the grout uptake justifies it; that is, an injection should not be stopped overnight if the hole is still taking grout.

12. No grout returning to the surface was contaminated with radioactivity.

7. SUMMARY

In August 1986, trench 150 was grouted with a particulate grout. The grout consisted of a blend of cement, flyash, and bentonite mixed with water at a ratio of 12.5 lb of blend per gallon of water. The solid components were blended pneumatically in equipment available at NHF. This blend was mixed with water in a concrete mixing truck to make the particulate grout. Another mixing technique was judged inferior to using the concrete mixing truck and was abandoned. The grout was injected into the trench through lances. These lances, which were 2-in.-diam pipes with a disposable point in one end, were driven into the trench with a pneumatic hammer. A progressive cavity pump forced the grout through the pipe and into the trench.

A total of 8081 gal of grout was injected into trench 150 at an average rate of 6.1 gpm. The entire operation took 11 d. About 80% of the grout was injected into only 5 holes out of the 36 used. The injected grout volume, 8081 gal, is 19.4% of the total trench volume (not counting the overburden excavated prior to grouting). The estimated accessible void volume of the trench is 20%; thus, 8081 gal is 97% of the accessible void volume. Because some grout breakthroughs occurred outside the trench, not all of the injected grout is in trench 150; the amount of grout outside the trench and the exact location of the injected grout are unknown at this time. Future assessment and monitoring will give a better idea of the grout location and any benefits from the grouting.

The technique used to grout this trench was labor intensive but simple and straightforward. A mobile lance machine would respond quicker to hidden obstructions and would be less labor intensive than the technique used. For a single trench the size of trench 150, the advantages of the lance machine are offset by the small size of the job and the higher fixed costs of the machine.

The grout used for this job cost about $0.21/gal; for a total cost of $1697. A total of 1217 work-hours was used for this grouting operation, and renting the grouting equipment cost $3449.

REFERENCES

1. O. K. Tallent, E. W. McDaniel, R. D. Spence, and T. T. Godsey Initial Formulation Results for In Situ Grouting of a Waste Trench at ORNL Site No. 6, ORNL/TM-10299, Oak Ridge National Laboratory, January 1987.

2. Natural Resources and Environmental Protection Cabinet, Department for Environmental Protection, Maxey Flats Branch, Commonwealth of Kentucky, In Situ Waste Grouting Technology Demonstration Maxey Flats Nuclear Waste Disposal Site, Frankfurt, Kentucky, prepared for the U.S. DOE, January 1985.

3. T. Tamura, Oak Ridge National Laboratory, private communication, August 1986.

4. R. D. Spence, Cost Estimate of Grouting the Proposed Test Pits at Idaho National Engineering Laboratory Using the ORNL-Recommended Grouts, ORNL/TM-10025, Oak Ridge National Laboratory, August 1987.

APPENDIXES

Appendix A

CALCULATED GROUT POSITION FOR THE HIGH UPTAKE HOLES

The grout positions were calculated by assuming a 20% grout volume and assuming that grout filled the trench depth of 10.8 ft. Thus, only areas for the five largest grout uptakes were calculated (Figs. A.1 through A.5). These assumptions are flawed, but the figures give some idea of the coverage achieved from these five injections. Figure A.6 speculates on the combined coverage of the five injections.

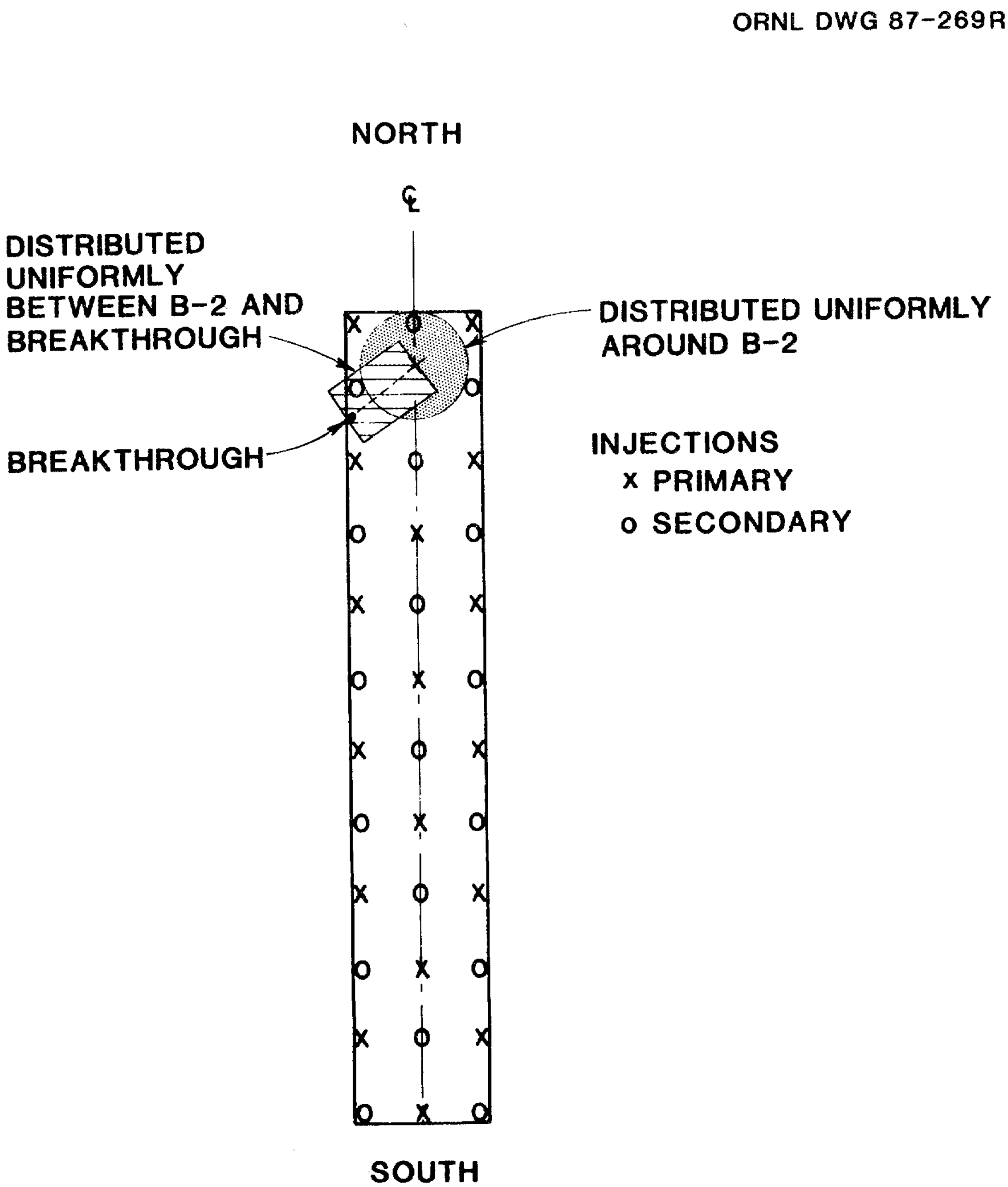

Fig. A.1. Estimated position of grout for injection B-2.

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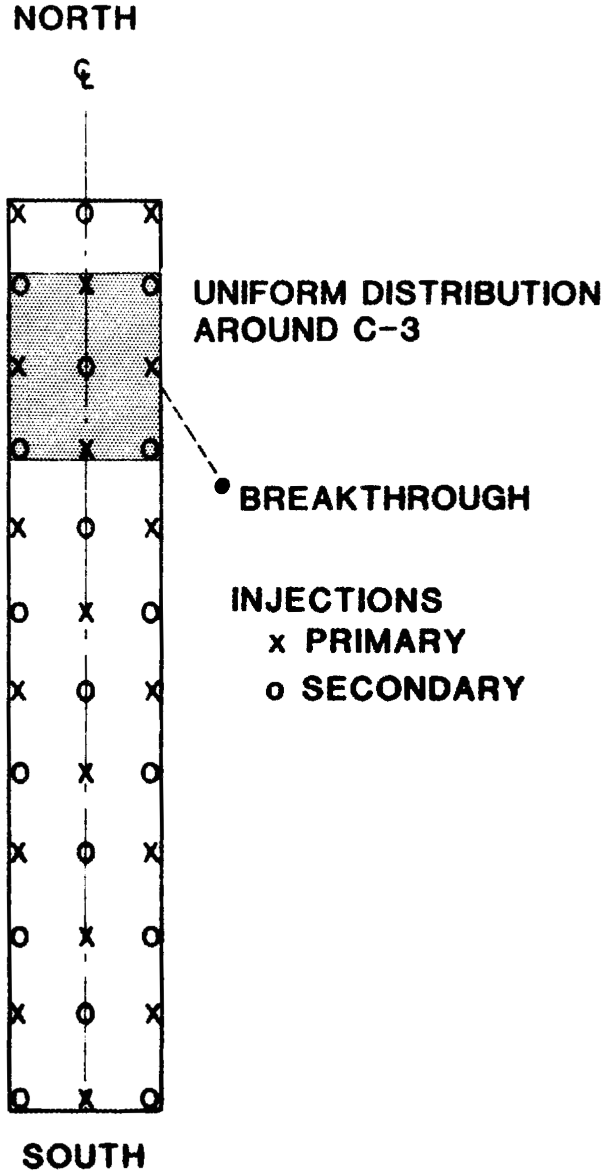

Fig. A.2. Estimated position of grout for injection C-3.

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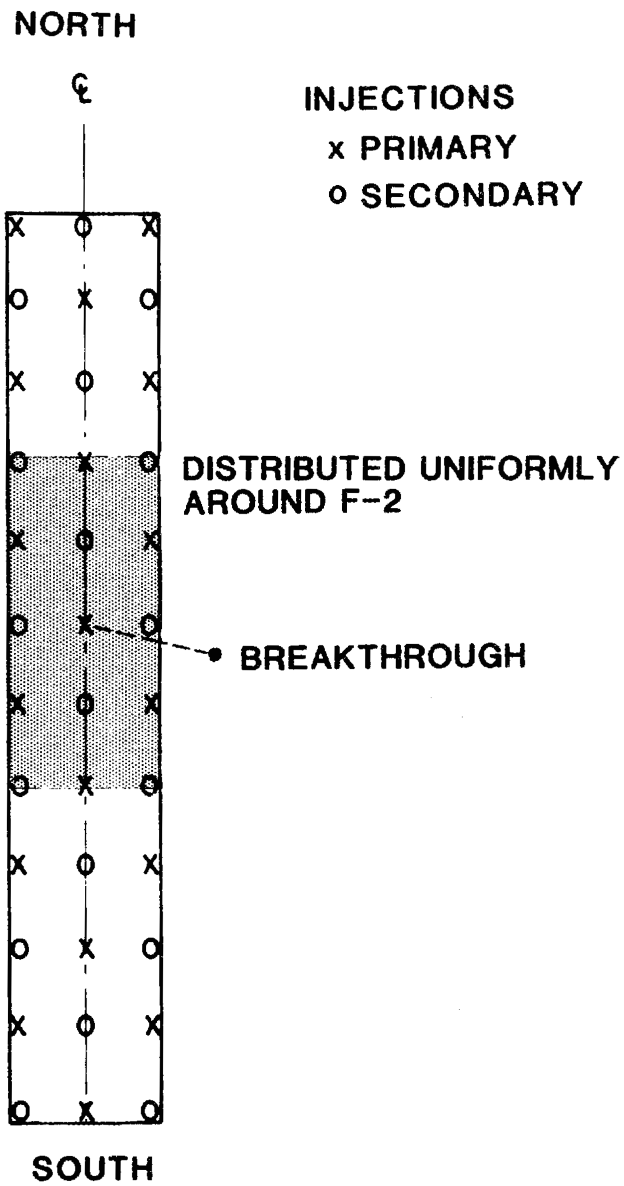

Fig. A.3. Estimated position of grout for injection F-2.

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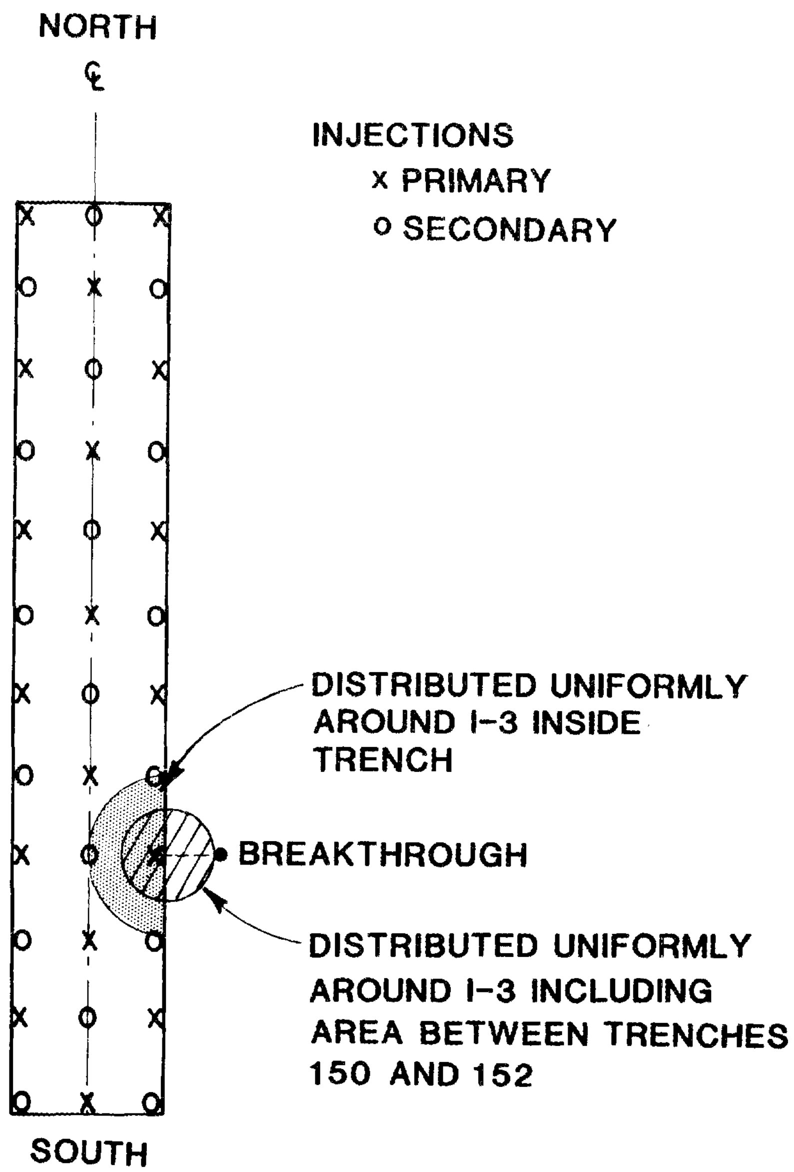

Fig. A.4. Estimated position of grout for injection I-3.

ORNL DWG 87-274R

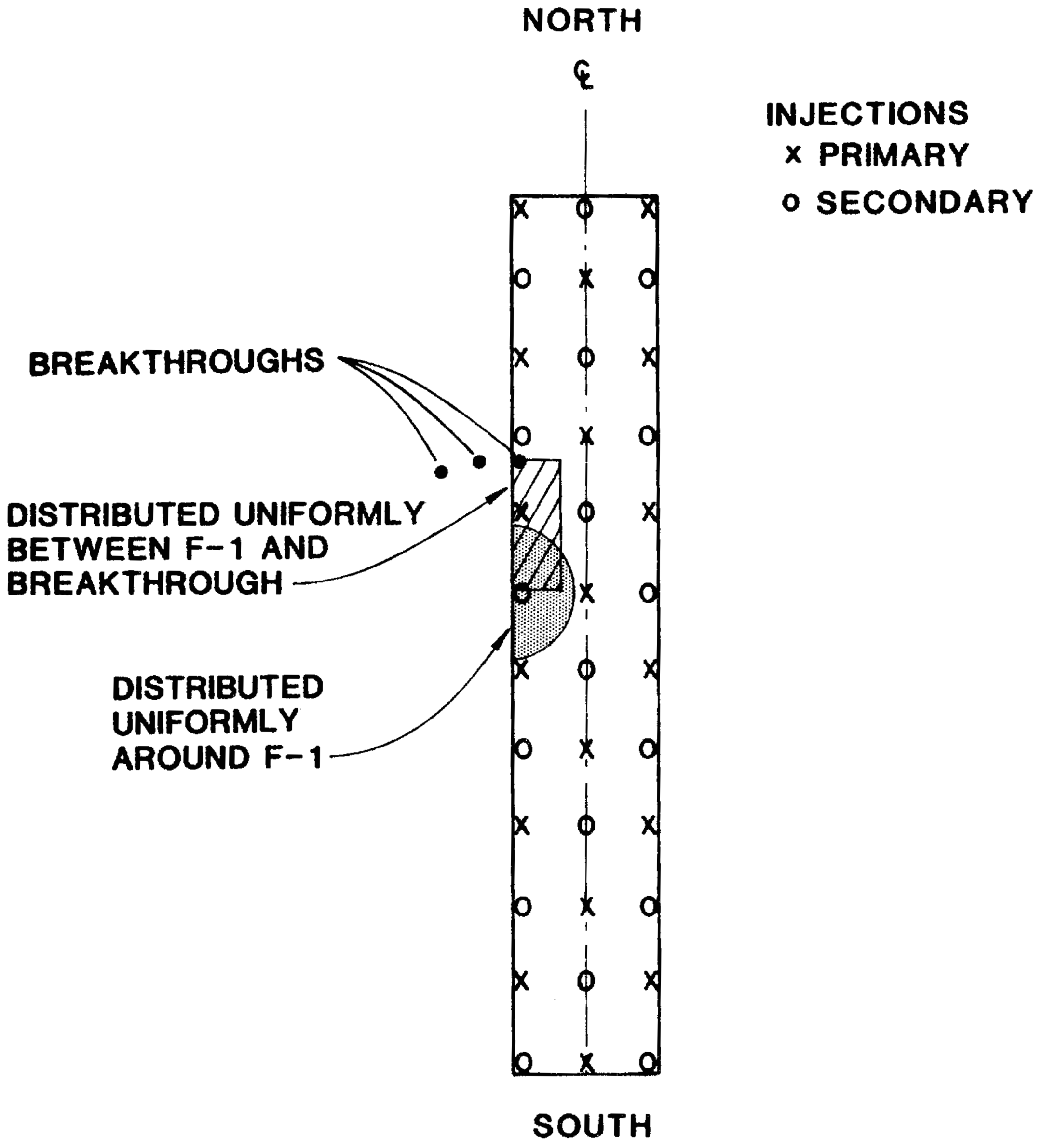

Fig. A.5. Estimated position of grout for injection F-1.

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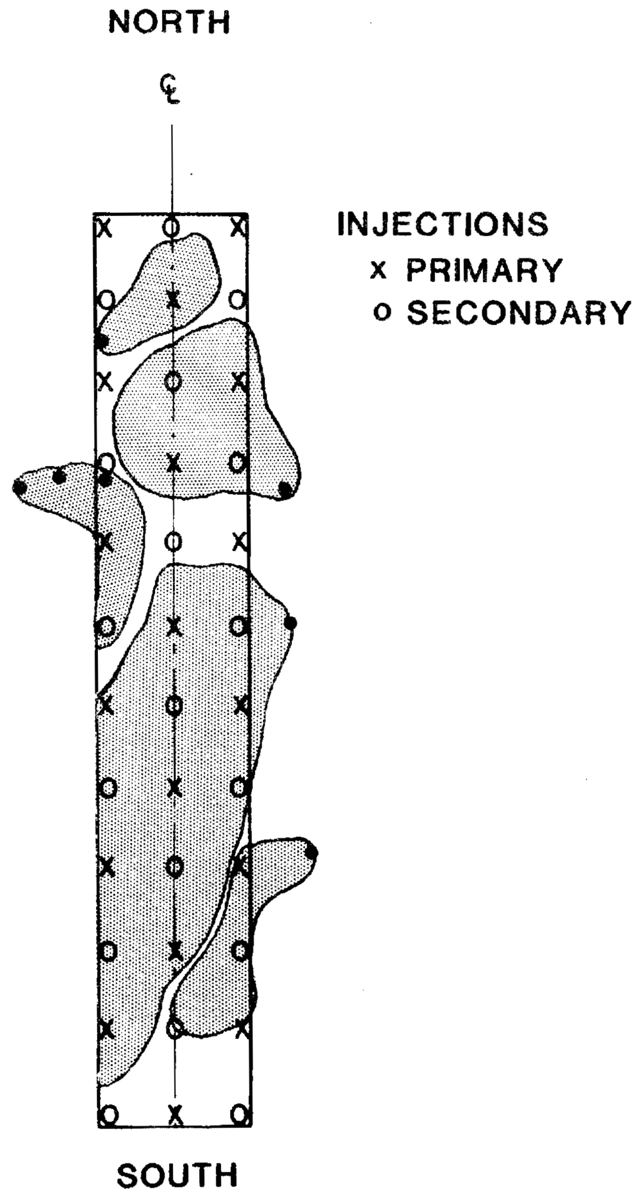

Fig. A.6. Possible distributions of grout for injections B-2, C-3, F-2, I-3, and F-1.

Appendix B

GROUT THICKENING

Grout thickening was studied in the laboratory by agitating the grout using the Hobart mixer and measuring the apparent viscosity (300 rpm on the Fann viscometer or 511/s) over time. The results are presented in Fig. B.1. The 10-min gel strength after 8 h was 17 $lb_f/100\ ft^2$ as compared with the 22 lb_f/ft^2 reported in ref. 1. (Gel strengths are measured at 3 rpm on the Fann viscometer). At 600 rpm (1022.04/s), the gel strength was 216 $lb_f/100\ ft^2$ after 8 h. The viscosity appears to begin an exponential increase at about 8 h. However, operation up to 8 h appears safe. Only one batch experienced grout thickening in the field operation when a slow grout uptake rate extended the operation to 7.5 h after grout mixing. Thus, the field operation could not safely operate up to 8 h. Likely differences in temperature and agitation require an additional time safety factor when scaling up to field operation.

The fluidity of the grout was also measured in the field with a flow cone (ASTM C 939-81). The standard for water is 8 s. Water was measured to be 8 s, and the grout was 11 s.

REFERENCE

1. O. K. Tallent, R. D. Spence, T. T. Godsey, and E. W. McDaniel, Initial Formulation Results for In Situ Grouting of a Waste Trench at ORNL SWSA-6, ORNL/TM-10299, Oak Ridge National Laboratory, January 1987.

ORNL DWG 87-275

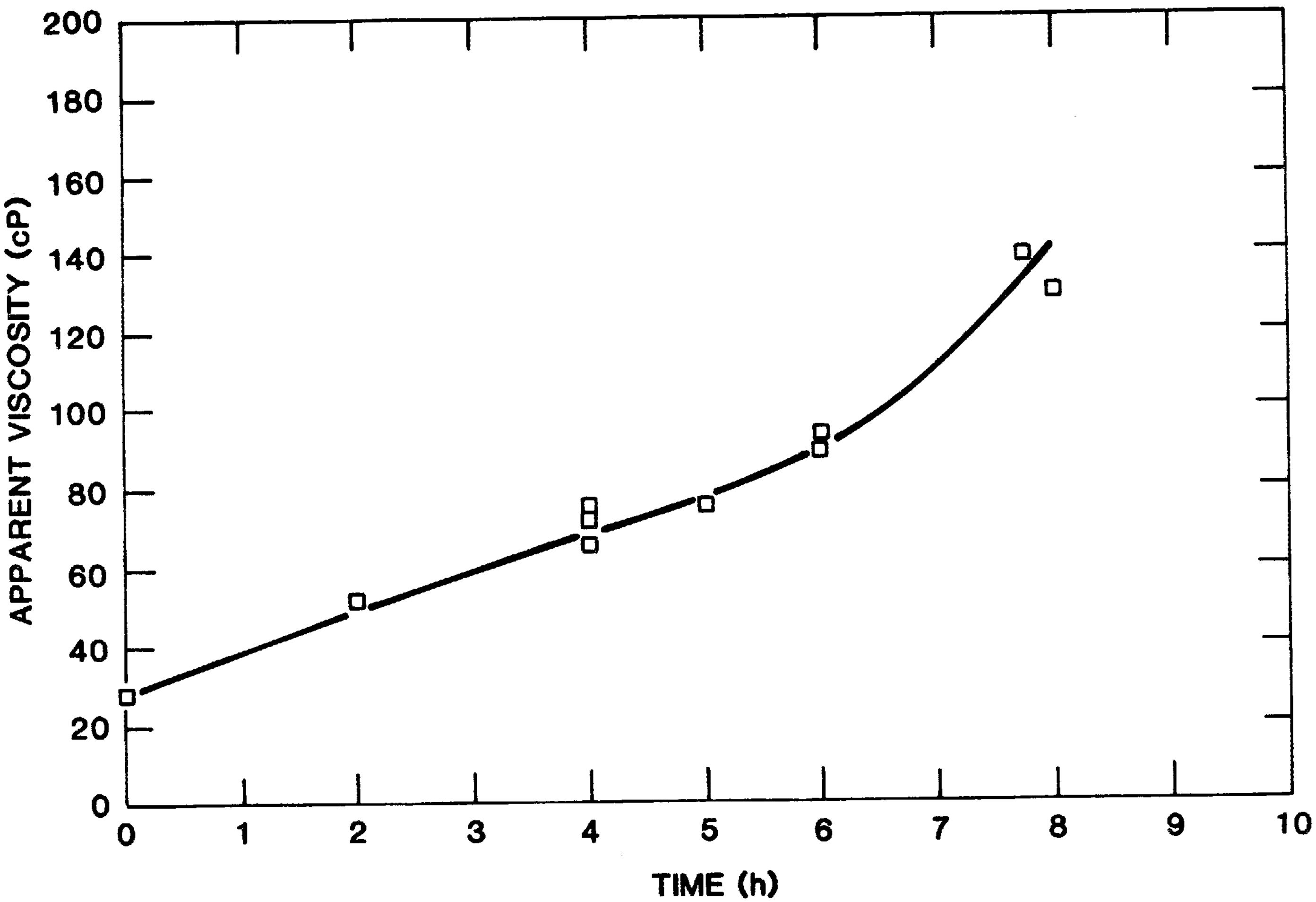

Fig. B.1. Apparent viscosity with time (measured on FANN viscometer at 300 rpm).

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