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In-Situ Grouting of the Low-Level Radioactive Waste Disposal Silos at ORNL's Solid Waste Storage Area Six

C. W. Francis
C. D. Farmer
R. G. Stansfield

Environmental Sciences Division
(Publication No. 4026)

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Environmental Sciences Division

In-Situ Grouting of the Low-Level Radioactive Waste Disposal Silos at ORNL's Solid Waste Storage Area Six

C. W. Francis
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R. G. Stansfield[a]

Environmental Sciences Division Publication No. 4026

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LIST OF ACRONYMS AND INITIALISMS

BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
ESD	Environmental Sciences Division
IEA	Internal Environmental Assessment
NEPA	National Environmental Protection Act
OHSA	Occupational Safety and Health Administration
ORNL	Oak Ridge National Laboratory
PWTP	ORNL Process Waste Treatment Plant
QA	Quality Assurance
RCRA	Resource Conservation and Recovery Act
SARA	Superfund Amendments & Reauthorization Act of 1986
SWSA6	Solid Waste Storage Area 6
TDS	Total Dissolved Solids
USEPA	U. S. Environmental Protection Agency

ABSTRACT

In-Situ Grouting of Low-Level Radioactive Waste Disposal Silos at ORNL's Solid Waste Storage Area Six C. W. Francis, C. D. Farmer, and R. G. Stansfield. ORNL/TM-12283. Oak Ridge National Laboratory, Oak Ridge, Tenn.

At Oak Ridge National Laboratory (ORNL), one method of solid low-level radioactive waste disposal has been disposed of in below-grade cylindrical concrete silos. Located in Solid Waste Storage Area 6 (SWSA 6), each silo measures 8 ft in diameter and 20 ft deep. Present day operations involve loading the silos with low-level radioactive waste and grouting the remaining void space with a particulate grout of low viscosity. Initial operations involving the disposal of wastes into the below-grade silos did not include the grouting process. Grouting was started as a standard practice (in late 1988) after discovering that ~75% of the silos accumulated water in the bottom of the silos in the ~2 years after capping . Silo water (leachate) contained a wide range of types and concentrations of radionuclides. The migration of contaminated leachate out of the silo into adjoining soil and groundwater was considered to be a serious environmental concern.

This report describes how a specially designed particulate-base grout was used to grout 54 silos previously filled with low-level radioactive waste. Grouting involved three steps: (1) silo preparation, (2) formulation and preparation of the grout mixture, and (3) injection of the grout into the silos. Thirty-five of the 54 silos grouted were equipped with a 3-in.-diam Polyvinyl Chloride (PVC) pipe used to monitor water levels in the silos. A method for rupturing the bottom section of these PVC wells was developed so that grout could be pumped to the bottom of those silos. Holes (2-in. diam) were drilled through the ~18 in. thick concrete to fill the remaining 19 wells without the PVC monitoring wells. The formulation of grout injected into the silos was based on a Portland Type I cement, flyash, sand, and silica fume admixture. Compressive strength of grout delivered to SWSA6 during grouting operations averaged 1,808 lb/in^2 with a bulk density of 3,549 lb/yd^3. Injection of grout into the 19 silos without PVC monitoring wells was very poor (average of 2.5 yd^3/silo). However, for the silos with monitoring wells, an average of 11.4 yd^3 of grout were injected per silo. Considerably less grout could be injected into the silos that contained contaminated soil. For example, for those silos equipped with PVC monitoring wells, only 7.9 yd^3 of grout could be injected into silos that contained contaminated soil as compared to 12.7 yd^3 in those silos that did not contain contaminated soil.

1. BACKGROUND

Starting in 1986, one method of solid low-level radioactive waste disposal has been disposed of in below-grade cylindrical concrete silos. Located in Solid Waste Storage Area 6 (SWSA 6), each silo measures 8 ft in diameter and 20 ft deep. Current operations involve lowering the wastes into the silos, grouting the remaining void space with a particulate grout of low viscosity, and covering the silo with an 18-in. concrete cap. Initial operations involving the disposal of wastes into the below-grade silos did not include the grouting process. Grouting was started as a standard practice (in late 1988) after discovering that ~75% of the silos accumulated water in the bottom of the silos in the ~2 years after capping (Davis et al. 1989). Silo water (leachate) contained a wide range of types and concentrations of radionuclides (Appendix A). The migration of contaminated leachate out of the silo into adjoining soil and groundwater was considered to be a serious environmental concern.

To evaluate the feasibility of grouting the remaining ungrouted silos, a demonstration was conducted in 1989 (Appendix B). In this instance, silo No. 527 was grouted with ~9 yd^3 of a cement/bentonite-based grout. The ~9 yd^3 of grout injected into the silo represented ~56% of the available void volume of the silo (measured by two independent techniques). The relatively low efficiency in filling the available void volume was thought to be caused by the inability of the particulate grout to penetrate and fill the small void volumes contained in the large quantity of contaminated soil added to the silo. However, the grout readily inundated other waste forms encapsulating them into a form not favorable for leaching. Of the 66 remaining ungrouted silos, ~20 silos contained contaminated soil. Based on these results and the need to maintain or place the ungrouted silos in a condition similar to those being filled under current practices, it was decided to grout the remaining ungrouted silos.

2. METHODS AND MATERIALS

Grouting of the SWSA 6 silos involved three steps: (1) silo preparation , (2) formulation and preparation of the grout mixture, and (3) injection of the grout into the silos. However, before these steps could be implemented a general strategy needed to be developed regarding the type of grout to be used and acceptable methods for injection and their potential bearing on Resource Conservation and Recovery Act (RCRA) closure actions planned for SWSA 6. After developing this strategy, it was then necessary to obtain regulatory approval governing environmental, health, and safety implications for the grouting process.

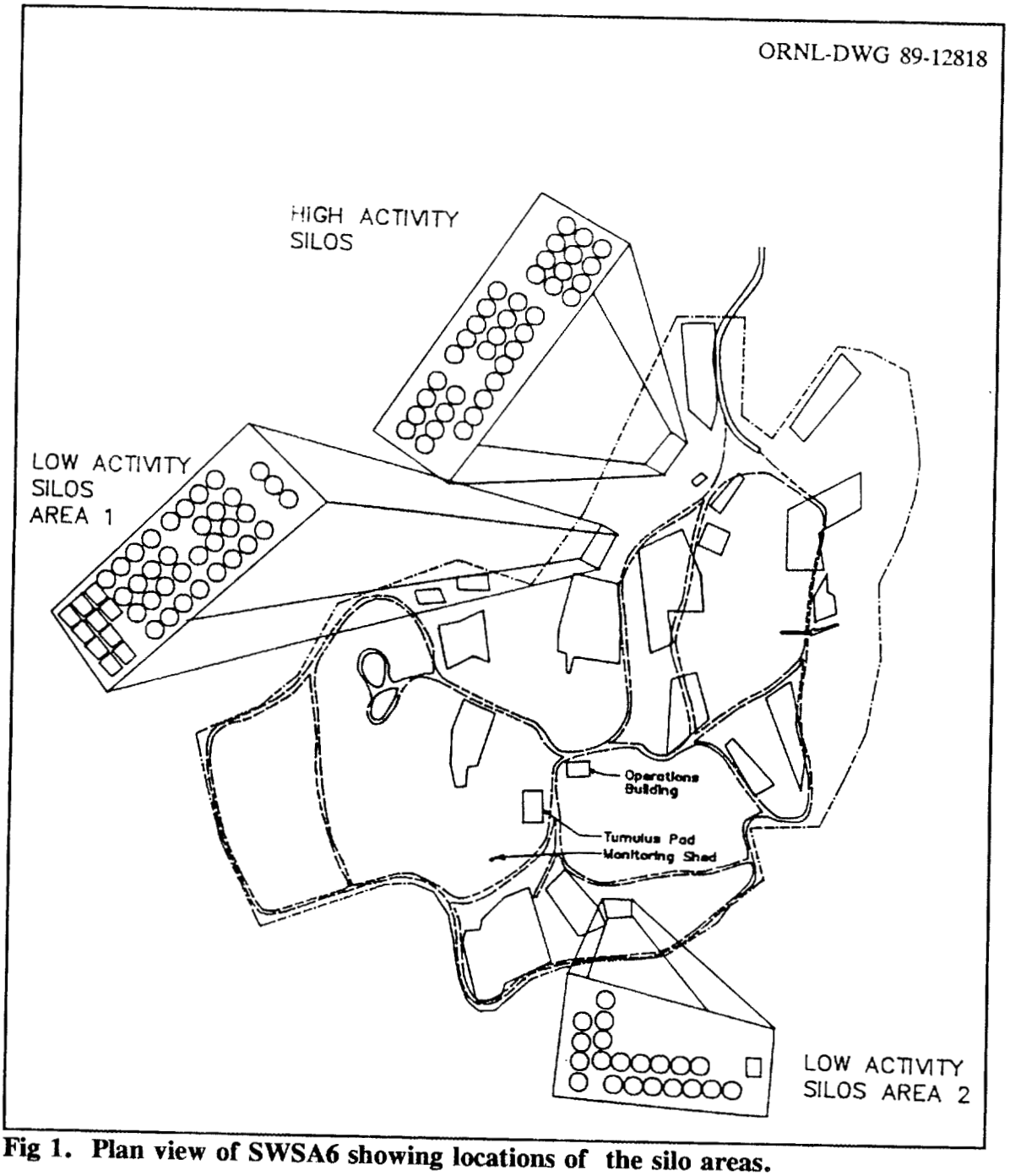


Fig 1. Plan view of SWSA6 showing locations of the silo areas.

2.1 Silo Location

Silos have been installed in three areas of SWSA 6 (Fig. 1). These have been named "High-Activity Silos," "Low-Activity Silos Area 1," and "Low-Activity

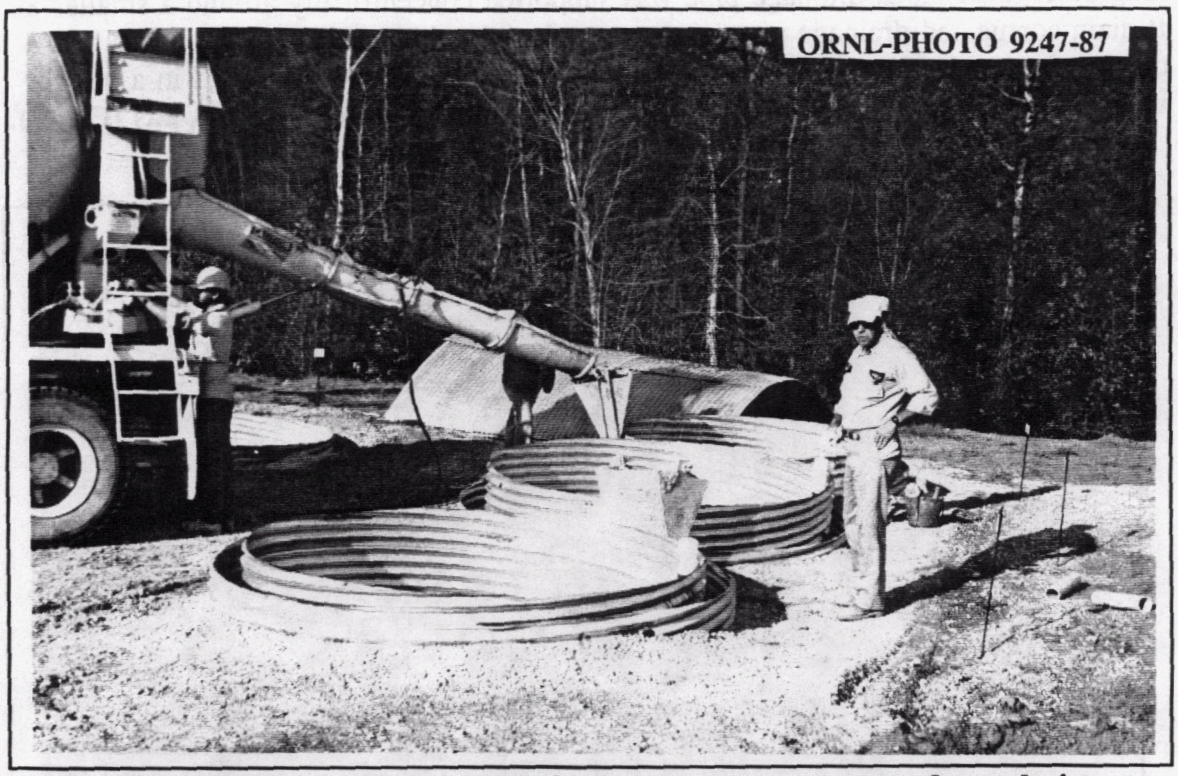


Fig 2. Pouring concrete into the annular between two corrugated metal pipes to form silo sidewalls.

Silos Area 2." As the name indicates, the higher-activity wastes (those whose surface dose rates were $\geq$200 mrem/h and $\leq$1 rem/h) were disposed of in the "High-Activity Silos" (i.e., those silos positioned higher on the ridge and further distance to the water table for better containment purposes).

2.2 Silo Construction

The first silos installed used existing precast concrete drainage pipe obtained from the Clinch River Breeder Reactor Project. The dimensions of this pipe were ~8 ft in diameter and 20 ft in length. A trench was dug such that four of these precast pipes could be set in the trench side by side in an upright position. The trench was then backfilled with excavated dirt, and a steel-reinforced concrete bottom was poured in each silo, thereby letting the walls of the pipe serve as a form for the

concrete bottom. A tar seal was then painted at the joint of the silo wall and floor. Twelve of these precast concrete silos were placed in SWSA 6.

A second silo construction technique was warranted when the supply of existing precast concrete pipe was exhausted. In this technique, a 9-ft diam by 20-ft-long corrugated metal drainage pipe was supported concentrically around a smaller 8-ft-diam corrugated drainage pipe of the same length with welded struts. Thus, two concentric metal cylinders were formed. The two cylinders were placed in a trench in an upright position and served as the forms for pouring concrete sidewalls (Fig. 2).

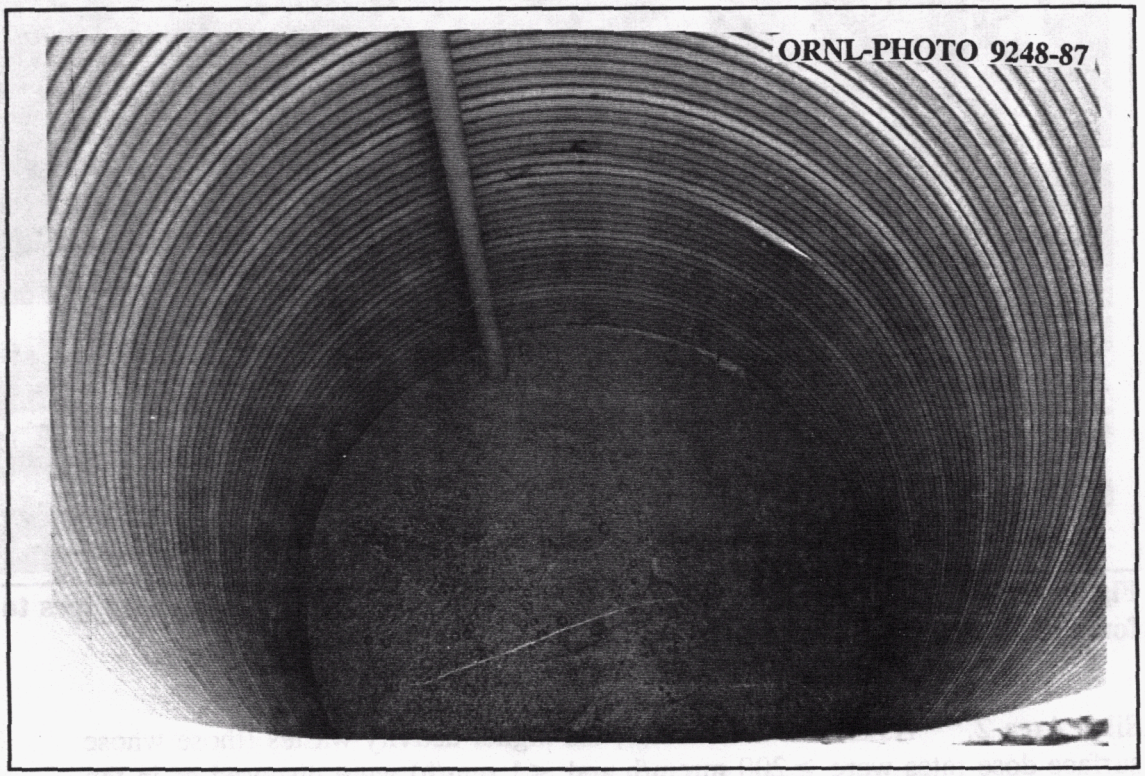


Fig 3. View looking down into silo containing a 3 in. diam. PVC monitoring well.

At the same time the sidewalls were poured, a steel reinforced concrete floor was poured by using the inner corrugated metal pipe as the form. A total of 24 such silos have been constructed in SWSA 6 by using what is referred to as the "old" corrugated metal pipe construction technique.

When water-level monitoring revealed that water was present in some of the waste silos constructed by aforementioned technique, the integrity of the joint between the concrete floor and the inner corrugated metal pipe was suspected. To correct possible leakage of groundwater into the silo through this joint, a third construction

technique was developed. In this construction, the inner 8-ft-diam corrugated metal pipe was raised ~1 ft off the trench floor before it was welded in place to the outer, larger diameter metal pipe. The raising of the inner pipe allowed the concrete used in constructing the floor to flow under the inner pipe and to be formed by the outer metal pipe. When the floor dried, the sidewalls were poured in a similar fashion to the older construction technique; however, the sidewalls rested on the concrete floor, forming a concrete-to-concrete joint instead of the former concrete-to-metal joint. Figure 3 illustrates the slight differences in the bottom joint between the old and new (currently used) construction technique.

Before placing waste into a silo, a 3-in.-diam polyvinyl chloride (PVC, Schedule 40) pipe was placed to the bottom and along the inner wall of the silo. This pipe, which was slotted at the very bottom, was used to monitor water intrusion into the silo (Fig. 4). The placement of these 3-in.-diam PVC pipes in each of the silos was intended to be a standard practice; however, a number of silos were constructed without them. Of the 66 silos (those constructed before grouting became a standard practice in the disposal of wastes into silos), 39 silos have the 3-in.-diam PVC

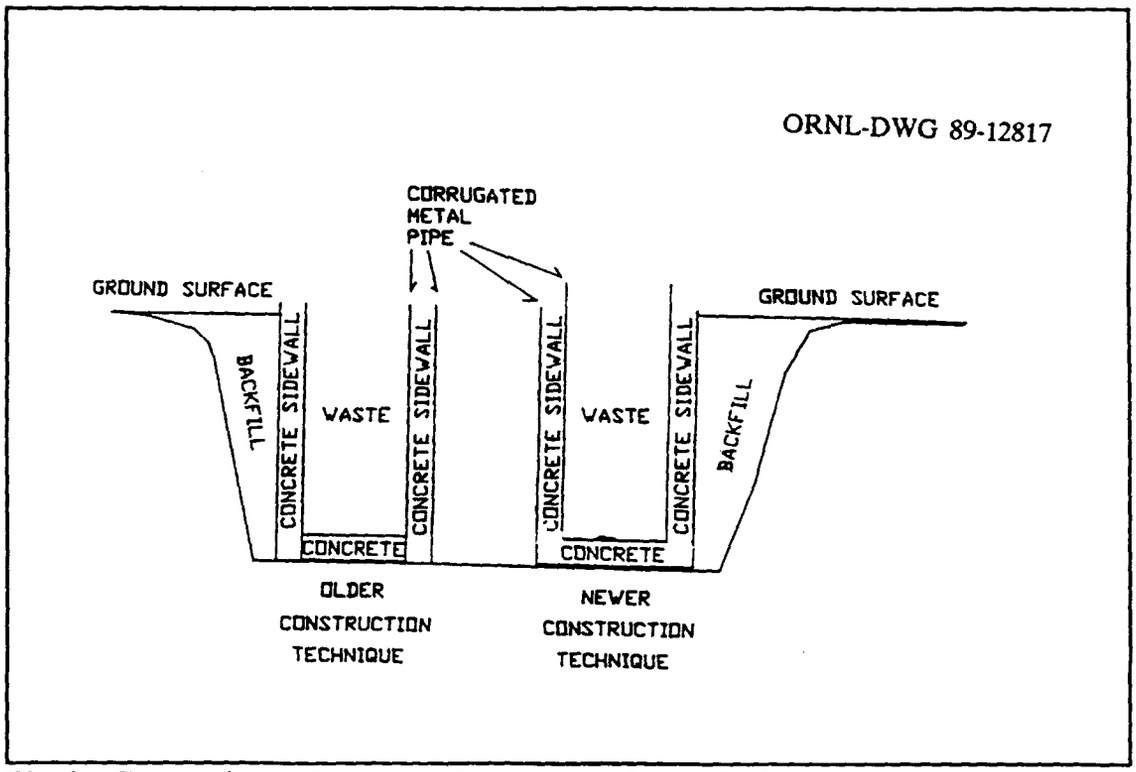


Fig 4. Comparison of the two silo construction techniques.

monitoring wells. Twenty-seven silos were not outfitted with these monitoring wells because (1) some of the silos were constructed before the practice of installing the

PVC monitoring wells began; (2) some of the silos were covered (with soil and surface liner) during the RCRA interim closure at SWSA 6; and (3) in the construction of new silos, the operating crew failed to install the PVC wells .

2.3 Silos Available for Grouting (Number and Content)

Sixty-six silos were constructed before grouting became a standard practice in the disposal of wastes in SWSA 6 silos; however, not all of the 66 silos were available for grouting. For example, during the RCRA interim closure of SWSA 6, 17 silos were covered with either soil or the heavy-duty plastic liner used to protect the RCRA-waste-filled trenches from infiltrating rainwater. For this grouting project, soil covering the top of nine silos was removed so that the silos could be grouted. In another case, one silo (No. 527) had previously been grouted in a demonstration project (Appendix B), leaving 57 silos available for grouting (66 silos − 17 silos covered during RCRA interim closure activities + 9 silos uncovered for grouting − 1 silo previously grouted in a demonstration project).

Contaminated soils from various restoration projects at Oak Ridge National Laboratory (ORNL) have been disposed of in some of the SWSA 6 silos. The presence of contaminated soils in the SWSA 6 silos compromises the effectiveness of grouting the silos with a particulate-based grout made of Portland Type I cement and bentonite because the grout will not penetrate and fill the small pore voids contained in the fine-textured surface soils of the ORNL site. Of the 57 silos available for grouting, 20 silos contained varying amounts of soil. The presence of soil in the bottom of the silo was thought to be responsible for the relatively low effectiveness (56%) in filling the measured available void space.

2.4 Grouting Strategy

Before any plans could be developed regarding the type of grouting material or the method of grouting, two issues pertaining to grout performance and long-term monitoring of silos following the RCRA closure of SWSA 6 needed to be resolved. These were: (1) What type of grouting material should be used for the silos containing contaminated soil, and (2) What were the long-term monitoring plans for the 3-in.-diam. PVC monitoring wells in the silos?

2.4.1 Grouting Material for Silos Containing Soil

The objective of grouting the SWSA 6 silos was to fill the void spaces of the loaded silo with a material that restricted the entry and movement of water into such voids. For most wastes placed in the silos, particulate-based grouts formulated from

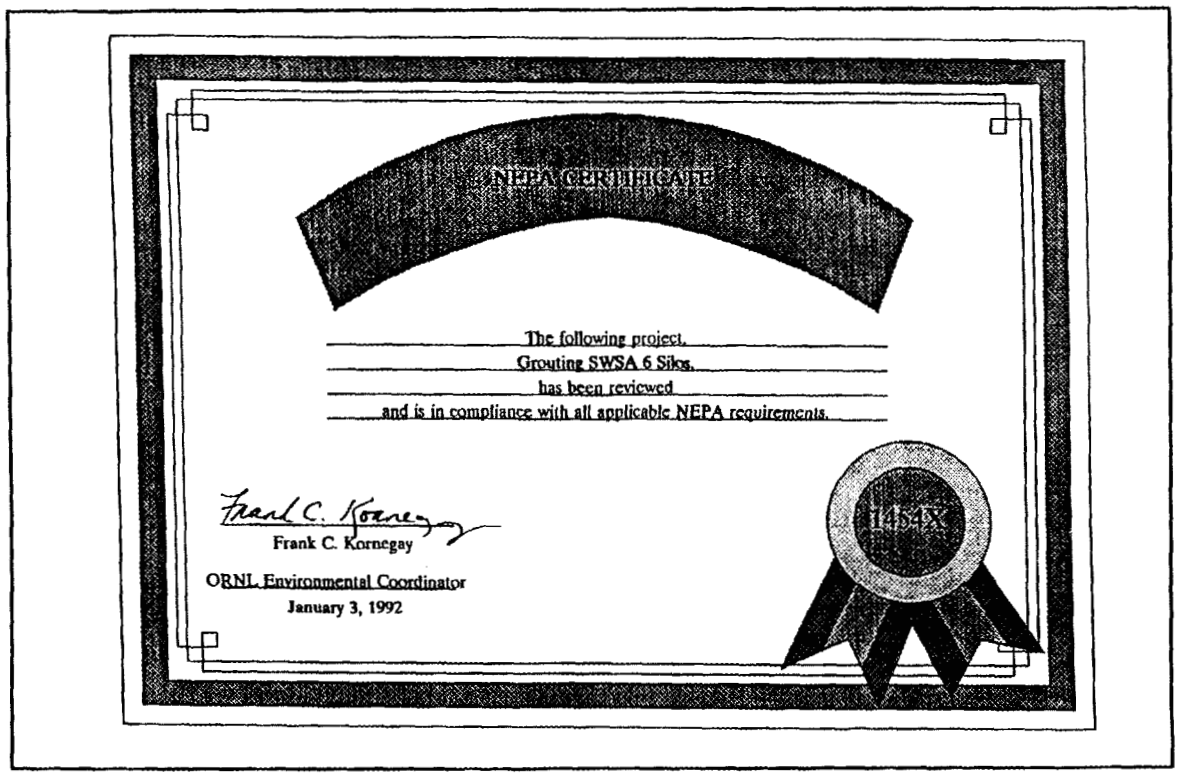
Portland Type I cements and bentonite will satisfactorily fill an adequate fraction of the voids. However, in the case in which contaminated soils have been disposed of in the silos, grout formulations based on these materials will not enter and fill most void spaces of soils. To stabilize soils by using particulate-based grouts, grouts need to be formulated with materials capable of entering void openings in the range of D_{15} = 0.12 mm (i.e., >15% of the soil voids being <0.12 mm in diameter), or in terms of the soil's hydraulic conductivity, $>3.5 \times 10^{-3}$ cm/s (Nonveiller 1989). Conventional Portland cement (Type I) based grouts are not recommended for soils having a D_{15} of <0.85 mm or a hydraulic conductivity $<2.3 \times 10^{-1}$ cm/s.

The development and current availability of microfine-cement-based grouts has made for potentially significant accomplishments in stabilization of soils. Microfine cements have a particle size distribution of D_{85} = 0.006 mm (i.e., 85% of grains <6 μm) and have been recommended for soils whose hydraulic conductivity is in the 10^{-3}-cm/s range. However, little data are available on how effective such grouting formulations are in restricting the movement of water through them. Recent use of microfine-cement-based grouts in the in situ grouting of SWSA 6 trenches indicated that hydraulic conductivities of grouted trenches were not significantly different from that measured in trenches before grouting (Francis et al. 1992). In addition, their costs are on the order of ten times that of grouts made from Portland Type I cement and bentonite.

Alternative grouting materials other than the Portland Type I cement-based grouts for the silos containing contaminated soils were chemical-based (polyacrylamide, sodium silicate, etc.) or microfine-cement-based. Chemical-based grouts are very effective in filling void spaces of soils; however, the United States Environmental Protection Agency (USEPA) has banned the use of polyacrylamide grouting in landfills. In addition, neither of the chemical grouts (polyacrylamide or sodium silicate) would give the compressive strength desired after filling the silos[1]. Microfine cement-based grouts would be a good choice because they would give excellent compressive strength (>2000 lb/in.^{2}) and they would penetrate small void spaces of soils much more effectively than the conventional Portland cement-based grouts. Material costs for microfine cement-based-grout were approximately \$500/yd^3 vs \$50/yd^3 for the Portland cement-based grouts. Assuming 18 yd^3 void space in each of the 20 silos with soil, it would have increased grouting costs on the order of \$180,000. The major impetus for using the microfine-cement-based grout would have been the higher probability of filling more of the smaller soil voids, thus restricting the hydraulic flow of leachate within and out of the contaminated soil. However, based on experiences of in situ grouting with microfine-cement-based grouts in the SWSA 6 (Francis et al. 1992), there was no assurance that the microfine

---

[1]In January of 1992, the installation of a clay cap over the trench and silo areas of SWSA 6 was a leading candidate for RCRA closure activities. There was a general concern that the grout needed to be of sufficient compressive strength to support the movement of heavy earth moving equipment.


NEPA CERTIFICATE

The following project,
Grouting SWSA 6 Silos,
has been reviewed
and is in compliance with all applicable NEPA requirements.

Frank C. Kornegay

Frank C. Kornegay
ORNL Environmental Coordinator
January 3, 1992

Fig 5. NEPA certification to proceed with grouting SWSA 6 silos.

grout would fill the small voids of contaminated soil because grout pumped upward from the bottom of the silo would likely short-circuit to the top portions of the silo via the larger (less resistance to flow) voids of the soil/waste matrix. Based on the added costs of using microfine-cement-based grout and the absence of data showing that microfine-cement-based grouts would truly restrict leachate movement significantly better than conventional Portland Type I cement-based grouts, it was decided to use the Portland Type I cement-based grouting materials.

2.4.2 Silo Monitoring Wells

The original intent of installing the 3-in.-diam PVC pipe monitoring wells was to determine if groundwater was entering the silos. Investigations by Davis et al. (1989) determined that excessive amounts of groundwater was entering the silos, and as a consequence, grouting became a standard practice in the disposal of wastes into the SWSA 6 silos. These monitoring wells were installed in 39 of the 57 silos to be grouted and were to be used to inject grout to the bottom of the silo. The manner in which grout was injected into these wells depended on the postclosure monitoring needs for these wells. For instance, if these wells were not needed in the post-closure monitoring of SWSA 6 , grout could be pumped directly into the wells. However, if

these wells were needed in the postclosure monitoring plans, then grout would have been injected via a 2-in.-diam steel pipe and a compactor installed at the bottom of the monitoring well to keep grout from filling the void annular space between the 2-in.-diam steel pipe and the 3-in.-diam PVC monitoring well. After grouting, the steel pipe would be removed, leaving an open 3-in.-diam PVC monitoring well. For these PVC monitoring wells to be effective postgrouting, the PVC casing would then be perforated along the length of the monitoring well.

An internal memorandum distributed January 9, 1992 requested input to these issues[2]. Responses were unanimously in favor of (1) grouting the soils containing contaminated soil with conventional Portland Type I cement-based grouts and (2) direct use of the 3-in.-diam PVC monitoring well for grout injection (i.e., these monitoring wells were not needed in the RCRA postclosure monitoring plans). In addition, the memorandum implemented a decision to no longer install the PVC monitoring wells in new silos being constructed.

An ancillary issue addressing the strategy to be used to grout those silos not equipped with the 3-in.-diam PVC monitoring wells also needed to be resolved. Two approaches could be taken: (1) two holes could be drilled in the ~18-in.-thick concrete caps of the silo, one for injection of grout and the other for venting and (2) a similar approach could be used in which two holes are drilled through the silo cap, but in this case a pipe would be driven to the bottom of the silo though one of the holes so that grout could be injected from the bottom of the silo upward through the waste/soil matrix. After considerable discuss with waste management and health physics personnel and a private consultant[3], it was decided that the risks involved were too great and the probability of success in reaching the bottom of the silo by driving an injection pipe to the bottom of the silos was not realistic. Instead, the best tactic would have been to install the injection pipe along the inside and adjacent to the silo wall without coming in contact with stable ridged waste forms. This option (i.e., installation without repeated coring through the top of the silo cap) did not appear to be feasible or safe from the standpoint of the potential to contaminate equipment and personnel with radioactivity. Thus, the strategy of injecting grout directly into one of the two holes drilled through the silo cap was taken.

2.5 Regulatory Approvals

Aside from in-house environmental, health, and safety approvals [i.e., Environmental Sciences Division (ESD) Project Safety Summary Form No. 9203-03

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[2]Distribution included the following: H. L. Adair, T. L. Ashwood, C. P. Manrod, C. E. Nix, T. F. Scanlan, J. E. Van Cleve, and D. D. Van Hoesen.

[3]R. G. Stansfield, Professional Geological Engineer

and an ESD Mini Waste Management Plan No. 9203-02] a National Environmental Protecton Act (NEPA) approval was required before any field work could be started. This was accomplished by documenting in an Internal Environmental Assessment (IEA-1454X) the proposed methods to do the work, locations of where the work will take place , and potential environmental impacts as a result of conducting the work. A NEPA Certificate was issued January 3, 1992 (Fig. 5) permitting the project to proceed on schedule. On March 30, 1992, a Readiness Review Meeting was held. Personnel from the Waste Management and Remedial Action and Plant Equipment divisions and the Office of Radiation Protection, Quality Assurance (QA), and Office of Safety and Health Protection of ORNL as well as representatives from Harrison Construction and Master Builders, the contractors to formulate and deliver grout, were present. During the grouting operation, full-time health physics coverage was provided by the Office of Radiation Protection. A surveillance check (July 22, 1992) by the ESD Safety Officer and personnel from the Office of Safety and Health Protection (covering industrial safety and hygiene) was also conducted.

2.6 Quality Assurance Plan

A Quality Assurance Plan (QAP-X-92-ES-077) was prepared and approved. The plan addressed training requirements [e.g., completion of 40 h of Superfund Amendments and Reauthorization Act of 1986 (SARA)/Occupational Safety and Health Adminstration (OSHA) training and the ORNL radiation worker training course], document control (Technical Notebook A-105364-G), and the development of instructions and procedures necessary to conduct the grouting operation. Technical instructions were written for the following operations: (1) collection and disposal of silo water; (2) core drilling of 2-in.-diam holes through the tops of silos constructed of concrete; (3) retrofitting 3-in.-diam PVC monitoring wells for grout injection; (4) injection of fill grout into silos, including QA testing of grout; and (5) collection and disposal of noncontaminated grout in the event of a spill from a ruptured grout pumping line.

2.7 Silo Preparation

Silo preparation included (1) pumping any standing water from the silo, (2) drilling holes through the concrete silos caps, and (3) retrofitting the PVC monitoring wells for grout injection.

2.7.1 Pumping Water from the Silos

The levels of water standing in the 39 silos equipped with monitoring wells were measured January 21, 1992. Twenty-two of the silos contained measurable

quantities of water; however, only six silos contained >2 ft of standing water. Water was pumped from the silos by using a submersible pump (outside diameter small enough to be lowered into the 3-in.-diam PVC monitoring wells) into 55-gal steel drums and a 1500-gal high-density polyethylene tank. Tubing from the wells to these containers was double-lined (with larger size tubing) to avoid leakage and potential contamination of personnel and theenvironment if it ruptured. All drums and the tank were contained within a primary container: the four 55-gal drums were contained in a specially designed steel tank and the 1500-gal tanks were set inside portable inflatable berms. After the contaminated water (silo leachate) had been pumped to the 1500-gal tank, a bulk tanker was used to transport it to the ORNL Process Waste Treatment Plant (PWTP). At total of ~740 gal was pumped from the silos. An estimate of the number of gallons pumped from each of the wells is presented in Table 1.

Table 1. Estimated quantity of water pumped from the silos

Silo No.	Depth of water (ft)	Presence of soil	Estimated water pumped (gal)
490	0	No	<1
500	0	Yes	<1
511	1.2	No	60
512	0.6	No	2
513	0.7	No	1
514	2.2	No	2
516	0	No	<1
517	0	No	4
518	1.9	No	<1
519	0	No	<1
521	0	Yes	<1
522	0	Yes	<1
523	1.8	Yes	470
524	0	Yes	<1
525	0	Yes	<1
526	3.5	Yes	5

Silo No.	Depth of water (ft)	Presence of soil	Estimated water pumped (gal)
527	0	Yes	<1
528	3.5	Yes	<1
529	1.6	No	<1
530	0	No	<1
531	2.8	Yes	<1
536	0.1	No	<1
537	0.2	No	3
538	0.3	No	6
540	0.6	No	1
541	5.3	Yes	1
542	<0.1	No	<1
551	0	No	<1
552	<0.1	No	0
553	0	No	<1
554	1.9	No	130
556	0.8	No	40
557	0	No	3
558	15.1	No	3
559	0	No	4
560	0	No	<1
561	0.4	No	<1
562	1.0	No	<1
563	1.0	Yes	2

2.7.2 Drilling Holes in the Concrete Silo Caps

A portable Minuteman® drill rig (Mobile Drilling, Indianapolis, Iindiana) was used to drill 2-in.-diam holes through the concrete caps of the silos. This is a lightweight drill rig powered by a 7-hp air-cooled 4-cycle gasoline engine. A crew consisting of two men drilled these holes, and a Health Physicist to monitor for possible contamination (Figs. 6 and 7). In many instances, it was necessary to drill multiple holes in the silo caps to obtain two holes that were fully open. The major obstacle in obtaining a fully open hole was the soil, in some cases Wyoming bentonite clay, located directly under the silo cap. These materials were present under the cap because they were placed on top of the wastes to form a footing for pouring the concrete cap. Thus, for some silos it was necessary to drill several holes until a hole was formed that directly linked to an open void space in the top of the silo.

2.7.3 Retrofitting PVC Monitoring Wells for Grout Injection

The 3-in.-diam PVC pipe installed to monitor water levels in the silos was used in this project to inject grout to the bottom of the silo. Several modifications to these monitoring wells were necessary before they could be used for this purpose. First, an opening at the bottom of the well had to be made (Fig. 8). The PVC pipe when installed as a monitoring well was slotted (using a saw to make several 2- to 3-in. slots) ~6 in. from the bottom of the well to ensure that water entered the well casing. These slots were <0.2 in. wide and not large enough to allow grout to be pumped into the silo; thus, it was necessary to make an opening at the bottom of these wells for grout injection. After the water was pumped from each of the silos, an electrically powered hydraulic pump, connected by a 30 ft length of hydraulic hose to a hydraulic spreader, was used to rupture the PVC pipe at the bottom of the silo. The hydraulic spreader is a jaw-like device developed to expand pipe. It is ~6.5 in. in length and has the capacity to expand to ~6 in. at its maximum open jaw state. This procedure worked very well, and a PVC well could be ruptured in <30 min in most cases. This procedure was also used to rupture the PVC wells in silos into which grout had previously been injected so that the silos could be filled on a day to day basis rather than a single continuous pour basis. Details regarding this procedure are presented in Sect. 2.9.

2.8 Grout Formulation

The grout formulation used in the initial grouting of SWSA 6 silos (standard practice at the time of this report) and in the grouting demonstration conducted in 1989 (Appendix B) was based on 85% cement and 15% Wyoming bentonite admixture (dry weight basis) suspended with water on a 1:1 basis. It was prepared by Harrison Construction Division, APAC-Tenn, Inc. at the Oak Ridge plant by mixing

Fig 6. Holes drilled in silo caps for grout injection and venting.

1444 lb of Portland Type I cement and 262 lb of Wyoming bentonite (cement grade, CAS No. 1318-93-0, 80% passing through a 200 mesh screen) with 202 gal of water. The following procedure used to mix the formulation. The required amount of waterdelivered to a ready-mix truck and the cement was added while the load rotated in the ready-mix truck (using their bulk loading facilities). After the load was mixed ~10 min, the bentonite was added in bag lots to the suspension of water and cement. It was difficult to impossible (even with mixing times of 5 min between adding the 80-lb bentonite bags) to obtain a suspension that did not have lumps of bentonite (see Appendix B). The preferred method of mixing bentonite and water is that used in the oil drilling industry to prepare drilling muds (Francis et al. 1992); however, Harrison Construction did not have these capabilities. Furthermore, the compressive strength of this formulation would probably not be that desired if SWSA 6 closure involved the movement of heavy equipment across the top of the silos. The cracking of this

Fig 7. Core drilling in the silo cap.

mixture on setting and drying also indicated that a better formulation needed to be used. Rather than developing a new grout formulation of cement and bentonite, private industry was consulted concerning cement-based formulations that would be applicable for our use. One of these was Master Builders, Cleveland, Ohio, who has had considerable experience in the development of grouting materials. This is the same company that made the grouting formulation for the overpacking of drums at the Oak Ridge K-25 site.

The formulation for the grout injected into the SWSA 6 silos is based on a cement, flyash, sand, and silica fume admixture (Table 2). The uniqueness of this grout formulation over that used in the past in other grouting operations at ORNL (Francis et al. 1992, Tamura et al. 1987) is the use of silica fume instead of bentonite clay. Silica fume is a pozzolan that reacts chemically within the grout to increase the

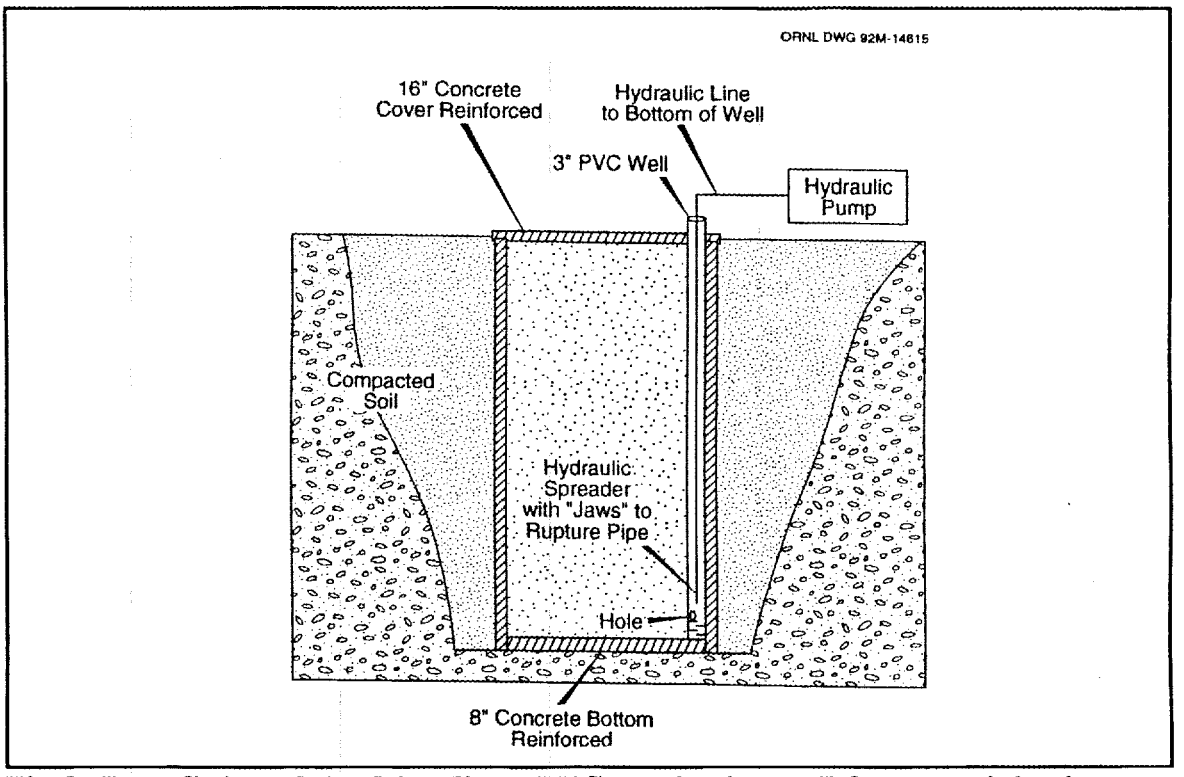

Fig 8. Retrofitting of the 3 in. diam. PVC monitoring well for grout injection.

2.9 Grout Injection into a Capped SWSA 6 Silo

Grout was mixed at the vendors bulk plant in Oak Ridge and brought to the site in the vendor's ready-mix truck. The grout was then poured into the hopper of a Mayco® grout pump and pumped through 2-in.-diam pressure hose into the silo. At the silo, the pressure hose was connected to the 3-in.-diam PVC monitoring well. A tee module was constructed to fit directly on the monitoring well. A rupture disc (set at 150 lb/in.^{2}) was installed on one side of this tee to prevent the rupture of the hose in the event of a sudden pressure surge. For the silos without the 3-in.-diam PVC monitoring wells, the 2 in. pressure hose was connected directly to one of the 1¾ in. PVC pipes mounted into the 2-in.-diam holes drilled through the silo cap.

Grout was delivered to the site in 6-yd^3 loads (one ready-mix truck load). To ensure that sufficient grout was on hand to fill a silo (~ 18 yd^3), at least three truck loads were ordered on a daily basis. After gaining some experience, it became standard practice to order six loads, staggered ~ 1 hr apart throughout the day. All the ready-mix trucks were in radio contact with their bulk plant and loads could be ordered and cancelled based on need.

In most cases, the silos were filled with a continuous pour (i.e., sufficient grout was on-site so that the silo would be filled). The exceptions were some of the

silos with the 3-in.-diam PVC monitoring wells. In these instances, the silos could be partially filled if the PVC well was cleared of grout before pumping was stopped. The wells were cleared of grout by inserting a sponge in the grout pump line and moving the grout to the bottom of the silo with compressed air. To inject grout into the partially filled silos, the 3-in.-diam PVC pipe was ruptured (as described in Sect. 2.7.3) immediately above the grout level so that more grout could be injected into the well.

Fig 9. Flowability demonstration of the grout formulation into a 55-gal drum.

A section of clear plastic tubing was connected to the venting hole of the silo during injection of grout. The end of this tubing was submerged in approximately 15-gal of water contained in a 55-gal drum. This served two purposes: (1) to trap particulate that might be entrained in the outflow gas and (2) to monitor the injection of grout by observing the bubbling of gas displaced as grout was added to the silo void space. If venting (measured as bubbling of the vent line submerged in water) did not take place, the injection of grout was stopped to avoid the possible compression of gas within the silo.

Grouting began July 7, 1992, and was finished September 29, 1992. Grout was injected into the silo until (1) grout emerged from the vent pipe or (2) venting did not occur. Gage pressure was generally <20 lb/in.^{2} during the grouting operation. Grouting was discountinued for silos Nos. 502, 503, 504, 505, 506, 522, 526, 542, and 554 because venting was not observed. Bentonite clay placed between the cap and open void spaces at the top of the silo in silos No. 52 through 506 limited venting. Grout injection into silo No. 536 had to be discontinued because of the entrainment of radionuclides into the water trap connected to the vent line.

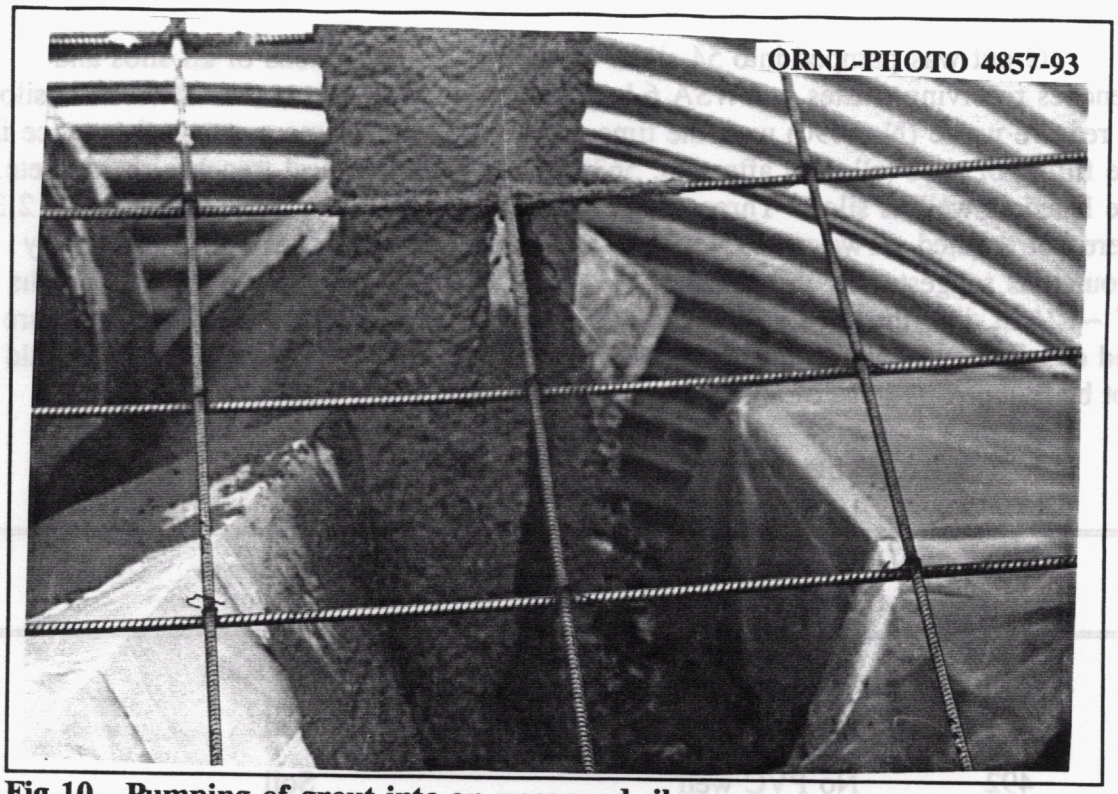

Fig 10. Pumping of grout into an uncapped silo.

3. RESULTS AND DISCUSSION

Grout was pumped into 54 silos. Table 3 lists descriptions of all silos and trenches receiving wastes in SWSA 6 beginning with the construction of the first silo to receive waste (No. 490) until the time when grouting became a standard practice in the filling of silos (all silos after No. 563). Note that biological trenches, boxes, etc. are listed as well as silos. Three of the 57 silos available for grouting (see Sect. 2.3) were not grouted. Two silos (Nos. 552 and 553) appeared to have been previously grouted as suggested by the presence of grout-like materials in cores taken to depths of ~ 24 in. into the silo cap. These materials were not concrete but had the texture and consistency of the cement-bentonite grout. Another silo (No. 490), grout could not be pumped because of an obstruction in the monitoring well.

Table 3. Description of all silos and trenches

Silo No.	Description	Presence of soil
490	PVC well	No soil
491	No PVC well	Soil
492	No PVC well	Soil
493	No PVC well	Soil
494	Covered-uncovered	Soil
495	Covered-uncovered	Soil
496	Covered-uncovered	Soil
497	Covered-uncovered	No soil
498	No PVC well	Soil
499	No PVC well	Soil
500	PVC well	Soil
501	No PVC well	Soil
502	Covered-uncovered	No soil
503	Covered-uncovered	No soil
504	Covered-uncovered	No soil
505	Covered-uncovered	No soil

Silo No.	Description	Presence of soil
506	Covered-uncovered	No soil
507	Covered	No soil
508	Covered	No soil
509	Covered	No soil
510	Covered	No soil
511	PVC well	No soil
512	PVC well	No soil
513	PVC well	No soil
514	PVC well	No soil
515	Trench-asphalt	No soil
516	PVC well	No soil
517	PVC well	No soil
518	PVC well	No soil
519	PVC well	No soil
520	Trench-biological	No soil
521	PVC well	Soil
522	PVC well	Soil
523	PVC well	Soil
524	PVC well	Soil
525	PVC well	Soil
526	PVC well	Soil
527	PVC well	Soil
528	PVC well	Soil
529	PVC well	No soil
530	PVC well	No soil
531	PVC well	Soil
532	No PVC well	Soil

Silo No.	Description	Presence of soil
533	No PVC well	No soil
534	No PVC well	No soil
535	No PVC well	No soil
536	PVC well	No soil
537	PVC well	No soil
538	PVC well	No soil
539	Trench-biological	No soil
540	PVC well	No soil
541	PVC well	Soil
542	PVC well	No soil
543	Trench-box	No soil
544	Trench-box	No soil
545	Trench-box	No soil
546	Trench-box	No soil
547	Covered	Soil
548	Covered	No soil
549	Covered	No soil
550	Covered	No soil
550	Trench-cast	No soil
551	PVC well	No soil
552	PVC well	No soil
553	PVC well	No soil
554	PVC well	No soil
555	Trench-box	No soil
556	PVC well	No soil
557	PVC well	No soil
558	PVC well	No soil

Silo No.	Description	Presence of soil
559	PVC well	No soil
560	PVC well	No soil
561	PVC well	No soil
562	PVC well	No soil
563	PVC well	No soil

[a]Measured 01/22/92.

Table 4 lists the descriptions of depth of water (measured January 22,1992), whether the silo contained soil, date of grouting, and quantity of grout injected for the silos with the PVC monitoring wells.

Table 4. Description of silos that have PVC monitoring wells

Silo No.	Depth of water (ft)	Presence of soil	Date of grouting	Grout injected (yd^3)
490	0	No soil	07-20-92	
511	1.2	No soil	08-14-92	17.5
512	0.5	No soil	08-14-92	18.0
513	0.6	No soil	08-13-92	12.5
514	2.1	No soil	08-13-92	11.5
516	0	No soil	07-28-92	11.0
517	0	No soil	07-24-92	18.0
518	1.8	No soil	07-28-92	20.0
519	0	No soil	07-27-92	24.5
529	1.6	No soil	07-29-92	11.5
530	0	No soil	08-06-92	8.5
536	0.1	No soil	08-25-92	1.0
537	0.2	No soil	08-20-92	8.0

Silo No.	Depth of water (ft)	Presence of soil	Date of grouting	Grout injected (yd^3)
538	0.3	No soil	08-20-92	12.0
540	0.6	No soil	07-22-92	22.0
542	0.1	No soil	07-21-92	18.0
551	0	No soil	08-21-92	7.0
552	0.1	No soil	Grouted	
553	0	No soil	Grouted	
554	1.9	No soil	09-29-92	9.0
556	0.8	No soil	08-19-92	8.0
557	0	No soil	08-19-92	10.0
558	15.1	No soil	08-18-92	19.0
559	0	No soil	08-18-92	11.0
560	0	No soil	07-22-92	3.0
561	0.4	No soil	07-16-92	18.0
562	1.0	No soil	07-23-92	15.0
563	1.0	No soil	07-23-92	4.0
500	0	Soil	07-27-92	4.5
521	0	Soil	08-21-92	10.5
522	0	Soil	08-21-92	1.5
523	1.8	Soil	08-20-92	8.5
524	0	Soil	08-20-92	6.5
525	0	Soil	08-06-92	9.5
526	3.5	Soil	08-06-92	1.5
527	0	Soil	Demo	
528	3.5	Soil	07-29-92	9.5
531	2.8	Soil	08-06-92	11.0
541	5.3	Soil	07-22-92	16.0

Table 5 lists a similar descriptions of silos that don't have the PVC monitoring wells. The quantities of grout injected into the various types of silos (with and without the PVC monitoring wells and those that did or did not contain contaminated soil) are summarized in Table 6.

Table 5. Description of silos that don't have PVC monitoring wells

Silo No.	Presence of soil	Date of grouting	Grout injected (yd^3)
497	No soil	08-21-92	3
502	No soil	08-27-92	5.5
503	No soil	08-27-92	0.5
504	No soil	08-27-92	0.1
505	No soil	08-27-92	0.1
506	No soil	08-27-92	0.1
533	No soil	07-16-92	1
534	No soil	07-16-92	0.5
535	No soil	08-24-92	3.5
491	Soil	07-21-92	5
492	Soil	07-21-92	2
493	Soil	07-21-92	3.5
494	Soil	08-24-92	2
495	Soil	08-24-92	4
496	Soil	08-21-92	2
498	Soil	07-21-92	0.5
499	Soil	07-21-92	4.5
501	Soil	07-27-92	1.5
532	Soil	07-17-92	9

Table 6. Summary of quantities of grout injected

Type of silo		Number of silos	Quantity of grout injected		
With monitoring well	Presence of soil		Av. (yd^3)	Max. (yd^3)	Min. (yd^3)
Yes		35	11.4	24.5	1
	No	25	12.7	24.5	1
	Yes	10	7.9	16.0	1.5
No					0.1
		19	2.5	9.0	
	No	9	1.6	5.2	0.1
	Yes	10	3.4	9.0	0.1
All silos		54	8.3	24.5	0.1

As expected, the silos that had the PVC monitoring wells and did not contain contaminated soil accepted the greatest quantity of grout. These 25 silos accepted an average of 12.7 yd^3 of grout. One silo (no. 519) accepted nearly 25 yd^3 of grout. If one assumes the total volume of the silo to be approximately 35 yd^3 (assumes a 19 ft depth available to place waste), the 25 yd^3 of injected grout represents approximately 71% of the silo's volume. The average amount of grout injected into these silos (12.7 yd^3) was approximately 36% of the silo's total volume, meaning that these silos have an average void volume of 36%, assuming all the voids contained grout. For those silos equipped with the PVC monitoring wells, considerably less grout was injected (an average of 7.9 yd^3) into the silos that contained contaminated soil compared with that injected (an average of 12.7 yd^3) in silos that did not contain contaminated soil (Table 6).

The quantity of grout injected into the 19 silos not equipped with the PVC monitoring wells was very poor (an average of only 2.5 yd^3). The presence of contaminated soil in these silos did not appear to influence the quantity of grout injected. For example, the average volume of grout injected into silos with contaminated soil was twice that injected into those not containing soil, 3.4 vs 1.6 yd^3, respectively. The limiting factor in quantity of grout injected into these silos was the method by which grout was injected. For example, grout could not be injected from the bottom of the silos as it was in the silos equipped with the PVC monitoring wells. In the silos without the PVC monitoring wells, grout injection depended on gravity flow of the injected grout to the bottom of the silos. Another complicating factor was the manner in which the concrete silo caps were constructed.

In most cases, loose soil (or bentonite clay) was loaded on top of the wastes to form a base for the concrete cap. Thus, many of voids or channels to the lower part of the silo were obstructed by this soil or clay, making the downward flow of injected grout immediately beneath the silo cap difficult. Consequently, as pressure mounted, grout often short-circuited to the vent hole, preventing the injection of additional grout.

4. REFERENCES

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APPENDIX A

CHARACTERISTICS OF SWSA 6 SILO LEACHATES

A.1 BACKGROUND

Two unpublished data sets from studies addressing the characteristics of SWSA 6 silo leachates exist. One involves the assessment of radionuclide concentrations in the leachates, and another addresses the feasibility of treatment of such leachates.

A.1.1 Radionuclide Concentrations

To determine the range in concentrations of radionuclides contained in the SWSA 6 leachates, in early March of 1989 leachate from 28 silos were sampled and analyzed for radionuclides by using gamma spectrometer and gross alpha and beta counting technologies. A summary of this study is presented in Table A.1. A wide range in concentration of radionuclides was observed. Leachates from most silos contained levels of ^{90}Sr, ^{3}H, and ^{137}Cs (i.e., 28, 26, and 21 of the 28 silos, respectively). Leachate from one silo (No. 518) contained 1.5×10^6 Bq/L of ^{3}H, and leachate from another silos (No. 502) contained 1.7×10^5 and 4.0×10^4 Bq/L of ^{90}Sr and ^{137}Cs, respectively. Concentrations of radionuclides measured in each of the 28 silos are presented in Table A.2.

A.1.2 Leachate Treatability Study

The objective of this study was to sample some representative silos for leachate and characterize the leachate with respect to various treatability options. The principal analytical characteristics of leachate differed from the above study in that the information sought was analyte concentrations and chemical characteristics other than radionuclides that might govern methods of treatability; namely, those affecting conventional waste water treatment facilities, such as chemical and biological oxygen demand (COD and BOD respectively) and concentrations of potentially toxic metals, cations, and anions. Leachate from four silos (Nos. 518, 526, 528, and 531) was sampled January 11, 1990.

A summary of the general leachate characteristics are presented in Table A.3. Alkalinity ranged from 288 to 2300 mg/L and was similar to alkalinity values tabulated by Lu et. al. (1985) for landfill municipal waste leachates. On the other hand, BOD and COD levels in the silo leachates (mean values measured in the four silo leachates of 39 and 103 mg/L, respectively) tended to be much lower than that typical of municipal waste leachate which usually ranges from 10,000 to 50,000 mg/L. The relatively low total organic carbon content of the silo leachate (range from 10 to 73 mg/L) also reflects a weak leachate compared with that of municipal waste, which often is in excess of 3000 mg/L. Also, the pH of the SWSA 6 silo leachates

was nearly neutral wheras the pH of municipal waste leachates are generally more acidic (usually <6). Total dissolved solids (TDS) municipal waste leachates generally are in excess of 10,000 mg/L, much higher than that measured in the silo leachates (range from 380 to 1900 mg/L. These data collected on a single sampling of leachate from four silos indicate that the leachate is much less concentrated in terms of organic load and suspended solids than municipal waste leachate and would be significantly easier to treat than municipal waste leachate. Thus, from this viewpoint, treatment methods used for municipal waste leachate would also be applicable for leachate from the SWSA 6 silos.

A.1.3 Metal Concentrations

The potential for elevated levels of toxic metals in SWSA 6 silos leachates does not appear to be a concern. For example, mean concentrations of Ag, As, Cd, and Pb were all below primary drinking water standards. The detection level for Se was in excess of the drinking water standard, and the leachates were not analyzed for Hg. Similarly, concentrations of Ca, Fe, Mg, and Na in the silo leachates were significantly below those normally found in municipal waste leachate (Lu et al. 1985). A summary of metal concentrations in silo leachate is presented in Table A.4.

A.1.4 Anion Concentrations

Anion concentrations in the silo leachates were low compared with municipal waste leachate (Lue et al. 1985). For example, chloride concentrations in municipal waste leachate generally average between 500 and 1000 mg/L and levels of nitrate and phosphate often exceed 10 mg/L. Concentrations in the silo leachates were below detection for nitrate and phosphate, and no single leachate contained <50 mg/L of chloride (see Table A.5).

A.2 SUMMARY AND CONCLUSIONS

Analyses of the leachates from SWSA 6 silos have shown that the leachate is considerably more dilute with respect to general leachate characteristics (e.g., organic carbon, BOD, COD, and pH). It also contains considerably lower concentrations of metals and anions than are normally found in municipal waste leachate. Thus, from this viewpoint, treatment methods used for municipal waste leachate would be applicable for SWSA 6 silo leachates. As expected, the major concern appears to be the levels of ^{137}Cs, ^{90}Sr, and ^{3}H radionuclides. The levels of ^{90}Sr and ^{137}Cs (usually <5000 Bq/L) can probably be controlled by conventional precipitation and sorption treatment processes used in low-level radioactive waste treatment processes.

However, the very high concentrations of ^3H observed in some of the leachates ($>2 \times 10^6$ Bq/L) may require unique treatment processes, depending on the acceptance criterion established for the release of ^3H.

Table A.1 Mean and distribution of radionuclide concentrations in leachates collected from SWSA 6 silos

Radionuclide	Mean (Bq/L)	Max (Bq/L)	Min (Bq/L)	No.of observations
Co-58	24	24.00	24	1
Co-60	531	0.40	5,800	11
Cs-134	390	390.00	390	1
Cs-137	1,979	0.20	40,000	21
Eu-152	8,200	8,200.00	8,200	1
Eu-154	3,600	3,600.00	3,600	1
Eu-155	1,500	1,500.00	1,500	1
G-ALPHA	69	0.10	910	24
G-BETA	17,920	1.10	490,000	28
H-3	59,712	14.00	1,500,000	26
Ru-106	7,900	7,900.00	7,900	1
Sb-125	310	310.00	310	1
Sr-90	6,436	0.00	170,000	28
Zn-95	95	95.00	95	1

Table A.2 Concentrations of radionuclides in SWSA 6 silo leachate

Silo No.	Radionuclide	Concentration (Bq/L)
502	Co-58	24
	Co-60	5800
	Cs-134	390
	Cs-137	40000
	Eu-152	8200
	Eu-154	3600
	Eu-155	1500
	G-Alpha	910
	G-Beta	490000
	H-3	250
	Ru-106	7900
	Sb-125	310
	Sr-90	170000
	Zn-95	95
511	Co-60	4.4
	Cs-137	0.23
	G-Alpha	23
	G-Beta	47
	H-3	2400
	Sr-90	4400

Silo No.	Radionuclide	Concentration (Bq/L)
512	Co-60	0.9
	Cs-137	0.79
	G-Alpha	3.5
	G-Beta	27
	H-3	1400
	Sr-90	7
513	Co-60	7
	Cs-137	1
	G-Alpha	3.9
	G-Beta	7100
	H-3	2200
	Sr-90	3800
516	Co-60	0.8
	Cs-137	1
	G-Alpha	0.37
	G-Beta	5.1
	H-3	2300
	Sr-90	0.75
517	Co-60	0.42
	Cs-137	220
	G-Alpha	1.7
	G-Beta	240
	H-3	380
	Sr-90	94

Silo No.	Radionuclide	Concentration (Bq/L)
518	Co-60	7.5
	Cs-137	140
	G-Alpha	1.2
	G-Beta	130
	H-3	15000
	Sr-90	25
519	Co-60	0.2
	Cs-137	0.8
	G-Alpha	0.1
	G-Beta	7
519	H-3	940
	Sr-90	1
523	Co-60	1.4
	Cs-137	1.9
	G-Alpha	0.48
	G-Beta	56
	H-3	8900
	Sr-90	7.7
526	Co-60	1
	Cs-137	1
	G-Alpha	0.8
	G-Beta	21
	H-3	960
	Sr-90	8.5

Silo No.	Radionuclide	Concentration (Bq/L)
527	Co-60	1
	Cs-137	0.94
	G-Alpha	0.62
	G-Beta	28
	H-3	31000
	Sr-90	16
528	Co-60	1
	Cs-137	2.8
	G-Alpha	1.2
	G-Beta	170
	H-3	110
	Sr-90	550
529	Co-60	1.3
	Cs-137	8.8
	G-Alpha	13
	G-Beta	340
	H-3	120
	Sr-90	170
530	Co-60	0.9
	Cs-137	1
	G-Alpha	0.15
	G-Beta	2.4
	H-3	200
	Sr-90	0.08

Silo No.	Radionuclide	Concentration (Bq/L)
531	Co-60	1
	Cs-137	25
	G-Alpha	0.53
	G-Beta	84
	H-3	190
	Sr-90	20
537	Co-60	0.6
	Cs-137	1.1
	G-Alpha	0.14
	G-Beta	6.2
	H-3	100
	Sr-90	0.11
538	Co-60	14
	Cs-137	110
	G-Alpha	3
	G-Beta	110
	H-3	14
	Sr-90	160
541	Co-60	0.9
	Cs-137	0.9
	G-Alpha	0.16
	G-Beta	1.7
	H-3	30
	Sr-90	0.17

Silo No.	Radionuclide	Concentration (Bq/L)
542	Co-60	1
	Cs-137	6.1
	G-Alpha	0.1
	G-Beta	24
	H-3	33
	Sr-90	0.64
547	Co-60	1
	Cs-137	3.7
	G-Alpha	1
	G-Beta	69
	H-3	510
	Sr-90	23
551	Co-60	0.8
	Cs-137	0.9
	G-Alpha	0.28
	G-Beta	1.8
	H-3	30
	Sr-90	0.11
553	Co-60	5.2
	Cs-137	3.1
	G-Alpha	680
	G-Beta	1.1
	H-3	29
	Sr-90	60

Silo No.	Radionuclide	Concentration (Bq/L)
554	Co-60	0.8
	Cs-137	0.99
	G-Alpha	0.3
	G-Beta	11
	H-3	280
	Sr-90	1.7
556	Co-60	0.7
	Cs-137	0.7
	G-Alpha	3.9
	G-Beta	11
	H-3	69
	Sr-90	1.3
558	Co-60	0.8
	Cs-137	15
	G-Alpha	0.65
558	G-Beta	89
	H-3	22
	Sr-90	0.48
561	Co-60	0.8
	Cs-137	0.9
	G-Alpha	0.05
	G-Beta	1.5
	H-3	18
	Sr-90	0.025

Silo No.	Radionuclide	Concentration (Bq/L)
562	Co-60	0.64
	Cs-137	19
	G-Alpha	2
	G-Beta	649
	H-3	63
	Sr-90	310
563	Co-60	0.42
	Cs-137	6.1
	G-ALPHA	0.1
	G-Beta	24
	H-3	33
	Sr-90	0.64

Table A.3. Summary of SWSA 6 silo's general leachate characteristics[a]

Analyte	Units	Concentration		
		Mean	Max	Min
Alkalinity	mg/L	1046	2300	288
Biological oxygen demand	mg/L	39.2	122	9
Chemical oxygen demand	mg/L	103	200	24
Conductance	mmho/cm	2.02	3.91	0.62
Oil and grease	mg/L	5.7	15	2.0
pH	pH	7.04	7.50	6.48
Phenols	mg/L	0.05	0.19	0.001
Residue, filterable (TDS)	mg/L	1212	1900	380
Total organic carbon	mg/L	50.5	73	10
Residue, nonfilterable (TSS)	mg/L	89.2	140	15

[a]Sampled from four silos, for the purpose of statistical analyses, detection limits were taken as concentrations in the leachates.

Table A.4 Summary of metal concentrations in SWSA 6 silo leachates[a]

Analyte	Concentration (mg/L)		
	Mean	Max	Min
Ag	0.003	0.004	0.003
Al	0.16	0.47	0.010
As	0.044	0.057	0.040
B	2.08	7.86	0.066
Ba	0.23	0.44	0.048
Be	<0.001	<0.001	<0.001
Ca	115	262	40.2
Cd	0.004	0.007	0.003
Ce	0.02	0.02	0.02
Co	0.01	0.039	0.002
Cr	0.005	0.006	0.004
Cu	0.004	0.01	0.002
Fe	16.6	31.9	0.71
Ga	0.01	0.01	0.01
K	172	306	61
La	0.003	0.003	0.003
Li	3.99	15	0.03
Mg	33.5	89.8	10
Mn	5.88	18.5	0.35
Mo	0.026	0.04	0.006
Na	201	565	5.0
Nb	0.01	0.01	0.01
Ni	0.015	0.036	0.008
P	0.91	2.58	0.22
Pb	0.023	0.03	0.02

Analyte	Concentration (mg/L)		
	Mean	Max	Min
Ag	0.003	0.004	0.003
Sb	0.05	0.05	0.05
Sc	<0.001	<0.001	<0.001
Se	0.04	0.04	0.04
Si	3.3	3.3	3.3
Sn	0.05	0.05	0.05
Sr	.0.46	0.74	0.20
Th	0.01	0.01	0.01
Ti	0.007	0.02	0.002
V	0.004	0.004	0.004
Zn	17.1	62.9	0.036
Zr	0.007	0.02	0.002

[a]Samples from four silos [except for K and La, where number of samples were three]. For statistical analyses purposes, detection levels were taken as concentrations in leachates.

Table A.5 Summary of anion concentrations in SWSA 6 silo leachates[a]

Anion	Concentrations (mg/L)		
	Mean	Max	Min
Cl	23.8	39.0	7.4
F	2.7	5.0	1.0
NO_3	5.0	5.0	5.0
PO_4	5.0	5.0	5.0
SO_4	98.7	380	5

[a]Samples from four silos. For statistical analyses purposes, detection levels were taken as concentrations in leachate.

APPENDIX B

SILO GROUTING DEMONSTRATION–1989

B.1 BACKGROUND

Silo no. 527, located in the low activity silo area in the south central section of SWSA 6, was selected to demonstrate the feasibility of using a particulate-based grout to grout a capped silo containing low-level radioactive wastes. Grouting was accomplished by pumping the grout from ready-mix concrete trucks to the bottom of the silo via the 3-in.-diam PVC monitoring well already installed in the silo. Grout was partitioned between the inside of the 3 in. diam. PVC monitoring well and the silo by using a well packer. This allowed utilization of the monitoring well postgrouting if continued monitoring was desired. Before grouting the silo, the available pore volume within the silo was determined by two independent methods. One involved the pumping of high-purity carbon dioxide gas, which is heavier than air, to the bottom of the silo and monitoring its breakthrough at the top of the silo. The other involved a gas pressurization technique using nitrogen gas (Francis et al. 1992). The purpose of determining the available pore volume in the silo was to evaluate the effectiveness of a particulate-based grout to fill this space.

B.2 COMPLIANCE ACTIONS

To ensure that the environmental, health, & safety, as well as quality assurance, issues were addressed, the following were completed.

1. Preparation of an Environmental ALARA Memorandum entitled "Cement Grouting of Silo Demonstration, SWSA 6 (0776X) issued August 3, 1989

2. Preparation of a Quality Assurance Plan (QAP-X-89-006)

3. An Environmental, Safety and Health Review, July, 1989

4. An Environmental Sciences Division Project Safety Summary

5. An Environmental Sciences Division Mini Waste Management Plan

B.3 METHODS

B.3.1 Void Volume Determinations

A summary of the void volume determinations by the two independent methods is presented in Table B.1. Both methods gave void volumes of ~15 yd^3.

Table B.1 Summary of silo void volume measurements by two independent techniques

Technique	Flux (L/min)	Estimated void volume (yd^3)
Carbon dioxide injection	10.1-12.2	13.5-16.2
	28.9-31.9	13.6-15.0
	48.2-50.5	14.5-15.2
		Mean 14.6±1.0
Nitrogen pressurization	14.3	14.2
	22.6	14.8
	25.1	17.4
	31.0	17.2
		Mean 15.9±1.6

B.3.2 Grout Formulation and Delivery

The grouting formulation was based on 85% Portland Type I cement and 15% Wyoming bentonite admixture (dry weight basis) suspended in water on a 1:1 basis. It was prepared by Harrison Construction Division, APAC-Tenn, Inc. at the Oak Ridge plant by mixing 1444 lb of Portland Type I cement and 262 lb of Wyoming bentonite (cement grade, 80% passing through a 200 mesh screen) with 202 gal of water. The following procedure was used to mix the formulation.

The required amount of water was delivered to a ready-mix truck after which the cement was added while rotating the load in the ready-mix truck, and the cement was added while the load was rotated in the ready-mix truck. After ~10 min of mixing, the bentonite was added in bag lots to the cement suspension. This procedure was not satisfactory in that the grout contained a large number of "lumps" of bentonite (see Fig. B.1). There were so many lumps in the grout, some of which were as large as 4 in. in diameter, that it was difficult to pass the grout through the ~2-in. slotted grid on the feed hopper of the grout pump. Delivery of this load was rejected and a nonconformance report was issued (NCR-X-89-ES-002). When preparation of grout was conducted under survillance of the QA inspectors (Report No. 101289-S, 10/12/89), significant reductions in the number of large "lumps" of bentonite resulted; however, numerous small lumps of bentonite remained. The

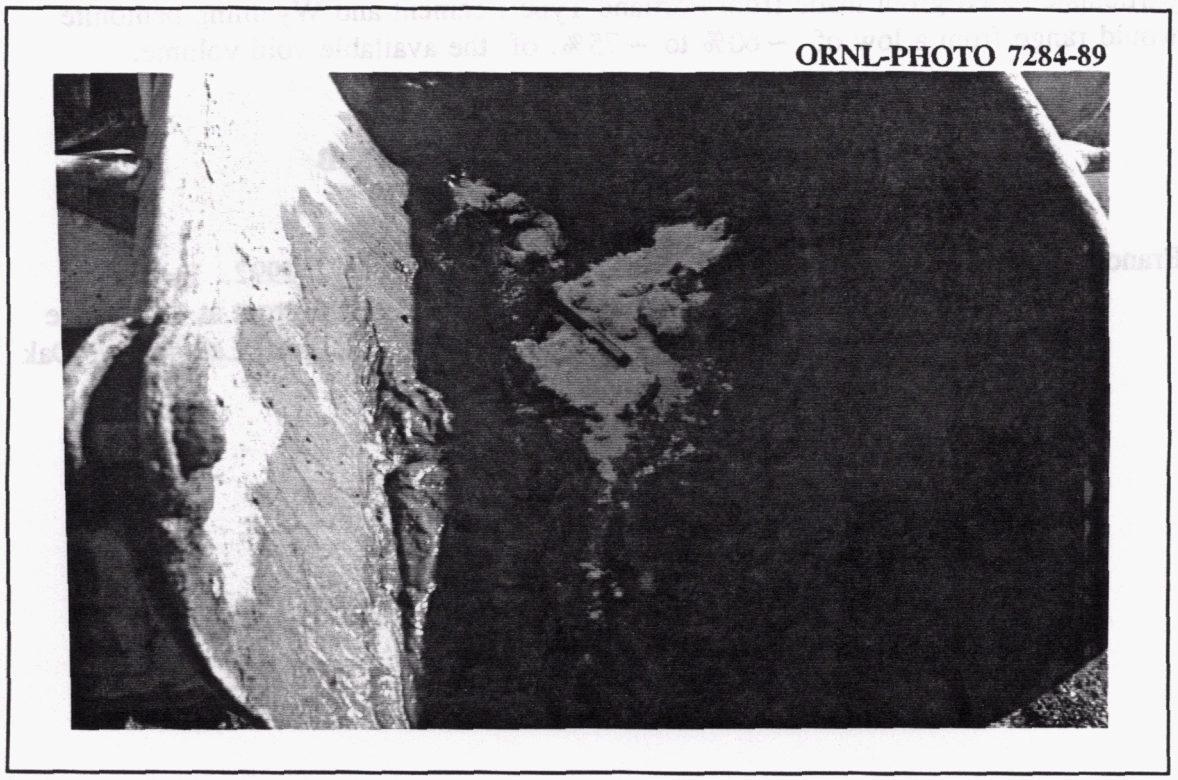

Figure B.1 Photograph of 'lumps' of bentonite clay in cement-bentonite grout formulation.

surveillance exercise, which required the addition of the 100 lb bags of bentonite in >1 min intervals, resulted in a grout that could be pumped and thus could be accepted. A total of 8.9 yd^3 of grout was pumped into the silo before grout emerged from the vent hole drilled through the top of the silo cap.

B.4 SUMMARY

The total volume of the silo (assuming 8 ft diam and 19 ft depth) is ~35 yd^3. Available void volume of silo no. 527, as determined by the two independent methods of measurements, was ~15 yd^3. Total volume of grout pumped into the silo was 8.9 yd^3, ~ 60% of the measured available void volume. The complicating element is that the silo contained ~7.5 yd^3 of contaminated soil (according to SWIMS data records), the voids of which were probably not filled by this grouting formulation but were measured as "available" by the two gaseous phase methodologies.. Thus, the effectiveness of the grout to penetrate or fill voids other than soil voids was probably greater than the measured 60%. For example, if one assumes a bulk density of soil to be 1.5 g/cm^3, then ~3.2 yd^3 of the measured available void volume might be related to soil voids, which are not accessible to this type of grouting formulation. Thus, it appears that the effectiveness of grouting the ungrouted SWSA 6 silos with a

particulate based grout made from Portland Type I cement and Wyoming bentonite would range from a low of ~60% to ~75%. of the available void volume.

B.5 REFERENCE FOR APPENDIX B

Francis, C. W., R. D. Spence, T. Tamura, and B. P. Spalding. 1992. In situ grouting of low-level burial trenches with a cement-based grout at Oak Ridge National Laboratory. ORNL/TM-11838, Oak Ridge National Laboratory, Oak Ridge, Tenn.

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