STABILIZATION AND ISOLATION OF LOW-LEVEL LIQUID WASTE DISPOSAL SITES

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ABSTRACT

Rockwell Hanford Operations is developing and testing equipment for stabilization and isolation of low-level radioactive liquid waste disposal sites. Stabilization and isolation are accomplished by a dynamic consolidation and particulate grout injection system. System equipment components include: a mobile grout plant for transport, mixing, and pumping of particulate grout; a vibratory hammer/extractor for consolidation of waste, backfill, and for emplacement of the injector; dynamic consolidation/injector probe for introducing grout into fill material; and an open-void surface injector that uses surface or subsurface mechanical or pneumatic packers and displacement gas filtration for introducing grout into disposal structure access piping. Treatment of a liquid-waste disposal site yields a physically stable, cementitious monolith. Additional testing and modification of this equipment for other applications to liquid waste disposal sites is in progress.

INTRODUCTION

Treatment of underground waste disposal structures may be accomplished by consolidation and injection of grout. Treatment produces a geomechanically stable disposal structure that prohibits subsidence and differential settlement. Additionally, waste materials are encased within a large grout monolith. At U.S. Department of Energy sites, cementitious grout materials have been shown to provide significant physical stability and chemical isolation (1, 2). Consequently, low-level radioactive waste that is disposed of within and in proximity to the disposal structure are immobilized by grouting. Therefore, grout injection can provide greater confinement of waste materials than afforded by shallow land burial alone (3, 4, 5, 6, 7).

A prototype system for dynamic consolidation and simultaneous grout injection has been developed at the Hanford Site and is being tested under simulated and actual waste disposal conditions (8). The system consists of a self-contained, mobile grout plant connected directly to a crane-actuated hydraulic powered grout injector. Either direct or remote disposal-site remedial actions can be accomplished with this prototype system depending on radiological conditions. Implementation of this treatment process will follow development of appropriate criteria and standards.

This paper provides a general description of the prototype system equipment and summarizes its operational capabilities as applied to treatment of low-level liquid-waste disposal sites.

UTILIZATION

Treatment of underground liquid-waste disposal structures can be conducted using numerous grout injection alternatives depending on the disposal site design and the composition of the waste material. Treatment alternatives, ranging from pressurized or ambient pressure injection of grout into open void structures to simultaneous dynamic consolidation and grout injection into drain field structures, have been conducted. Other tested treatment alternatives include direct waste-package injection, soil injection, and internal and near-field treatment of buried piping. Specific combinations of system components are connected according to operational requirements.

A system developed for consolidation and grout injection of liquid-waste disposal cribs is shown in Fig. 1. Crib structures typically consist of a series of large timber boxes buried 3 to 5 m below grade. Gravel drain fields are attached downgradient through distribution piping. Large surge tanks upgradient from each crib provide liquid feed. Other general types of disposal structures include caissons, reverse wells, French drains, and diversion pits.

Four general system components are combined to form an integrated system for crib treatment.

- Mobile Grout Plant Component. This component provides microprocessor-controlled, continuous-flow batch mixing of particulate grout feed material to injectors or packers. The mobile grout plant component comprises particulate grout transport, shearing, mixing, and pumping units.

- Open-Void Surface Injector Component. Inert-gas packers, mechanical surface packers, and displacement gas-filtration units are used when introducing particulate grout into disposal structures under ambient or elevated pressure conditions.

- Vibratory Hammer/Extractor Component. This component is used to direct *high-frequency*, high-displacement energy into near-field soil and drain fields associated with typical liquid-waste disposal sites. The vibratory hammer/extractor component comprises hydraulic pump and eccentric driver units.

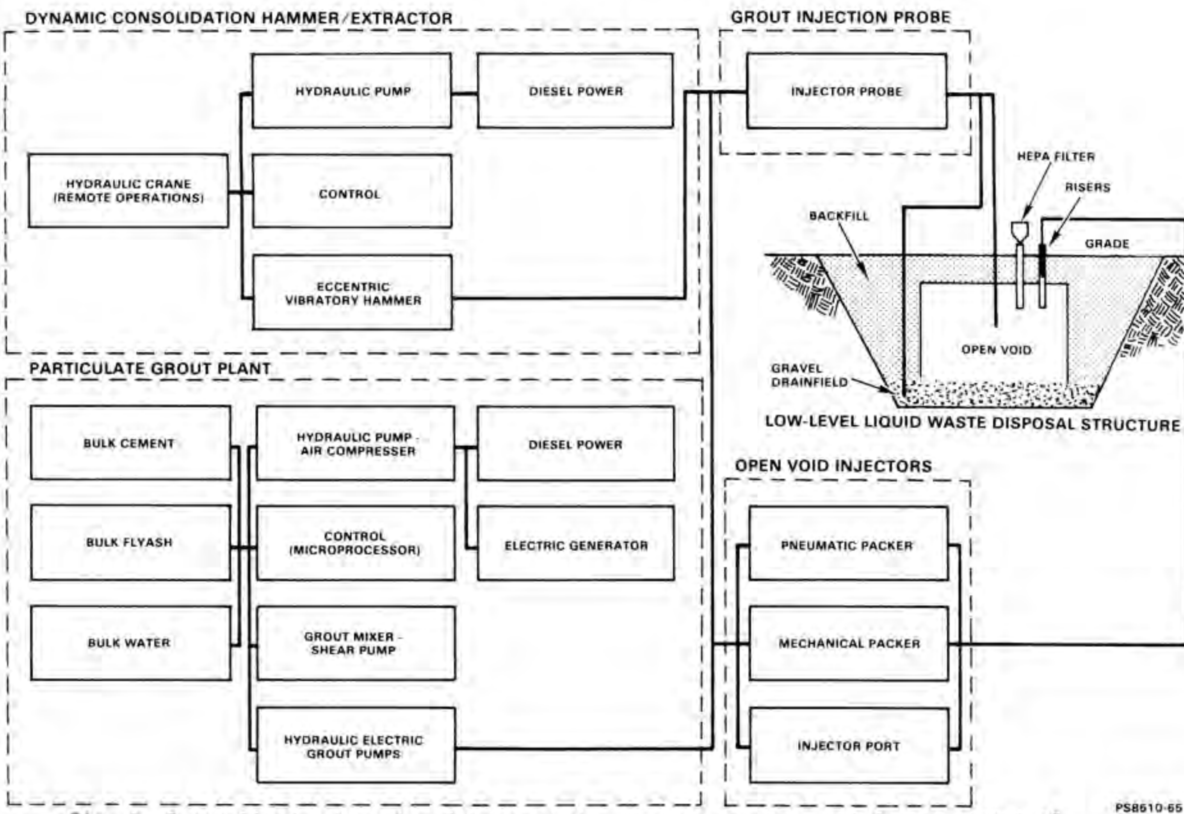

Fig. 1 Generalized schematic of integrated system components used for treatment of underground low-level radioactive waste disposal structures.

- Dynamic Consolidation/Injector Probe Component. Injector probes, composed of reinforced-coaxial piping or shielded grout-tube metal beams, are driven into fill or drain materials adjacent to or below liquid-waste disposal structures using the vibratory hammer/extractor component. Grout materials produced by the mobile grout plant component can be introduced into the waste disposal structure through coaxial or shielded tubes welded to injector probes.

These components can be used individually or can be integrated into a system based on operational needs. Simultaneous grouting and consolidation of wastes is accomplished by combining the four components.

SYSTEM DESCRIPTION

Simultaneous dynamic consolidation and grout injection, as a treatment process for contaminated liquid-waste disposal sites, depends upon the operation of several mechanical, hydraulic, and electrical devices that compose individual units within system components. These include mechanical devices such as helical augers for product transfer and feed, hydraulic devices to provide drive power to pumps and mixing modules, and electrical devices to provide drive power for pumps and for process control. These devices are shown diagramatically in Fig. 2 and 3.

Mobile Grout Plant Component

The particulate grout plant is completely mobile and self-contained so that operational activities can be initiated at field locations or directly within the confines of chemical processing plants. The trailer-mounted plant, when at its capacity of dry particulates, water, and fuel, produces a gross weight of nearly 4.9 x 10^4 kg. A 4 x 10^4 W, air-cooled engine powers the mobile grout plant and is directly coupled to a hydraulic pump and air compressor. Mixing, grout pumping, auger materials transfer, and water pumping units are hydraulically powered. Compressed air is used to drive dry-particulate material agitators. The frequency, duration, and energy of the agitators that allow transfer of dry materials can be adjusted to desired values.

Dry materials, stored in large-volume transfer bins on board the grout plant, are loaded by pneumatic air slides, augers, or gravity fill at batch plants. Flyash volume at filling is 14.2 m^3. Class C and Class F flyash feed materials have both been used in the mobile grout plant depending on application. Cement volumetric filling capacity is nominally one-third of the flyash volume or 4.6 m^3. Two Portland cement types, Type I or Type II, are used depending on application. Microfine cement has also been used for special applications. Dry-particulate additives, such as layer lattice silicates, can be added to either or both material bins during filling. Dry-particulate material may become compacted during transport so that material augering is not achievable. This condition is remedied by injecting dry, ultrapure nitrogen gas through the compacted materials to form a fluidized bed. Fluidization is controlled by gas injection through numerous ports installed throughout the bottom of each storage bin.

Water is stored on board the grout plant for mixing with dry materials. Approximately 6.4 m^3 of water is pumped on demand from a storage tank. Liquid storage, metering, and piping devices are fitted with immersion heaters and are heat traced for use under freezing conditions. Storage tanks are filled directly from hydrants or by pumping water from tank trucks.

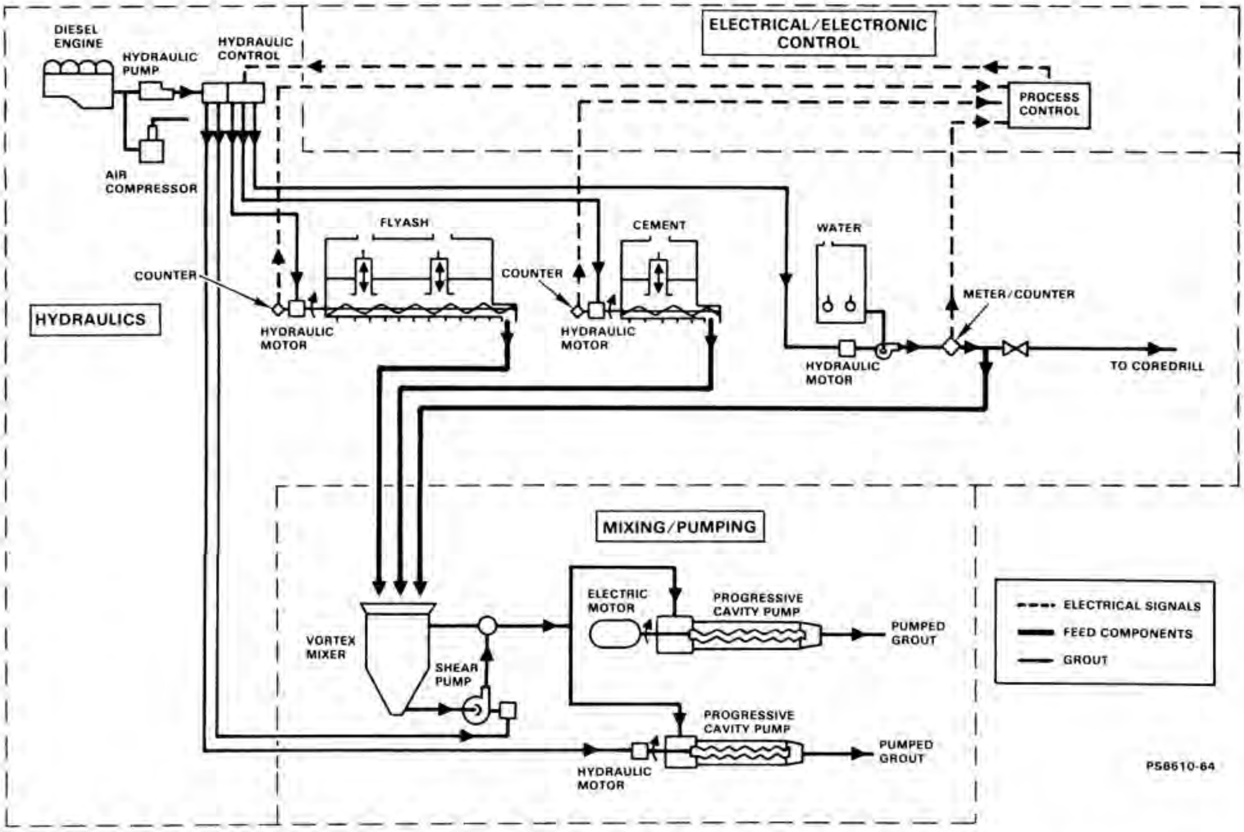

Fig. 2 Process flow schematic for electrical, materials feed, and grout pumping on board the mobile grout plant.

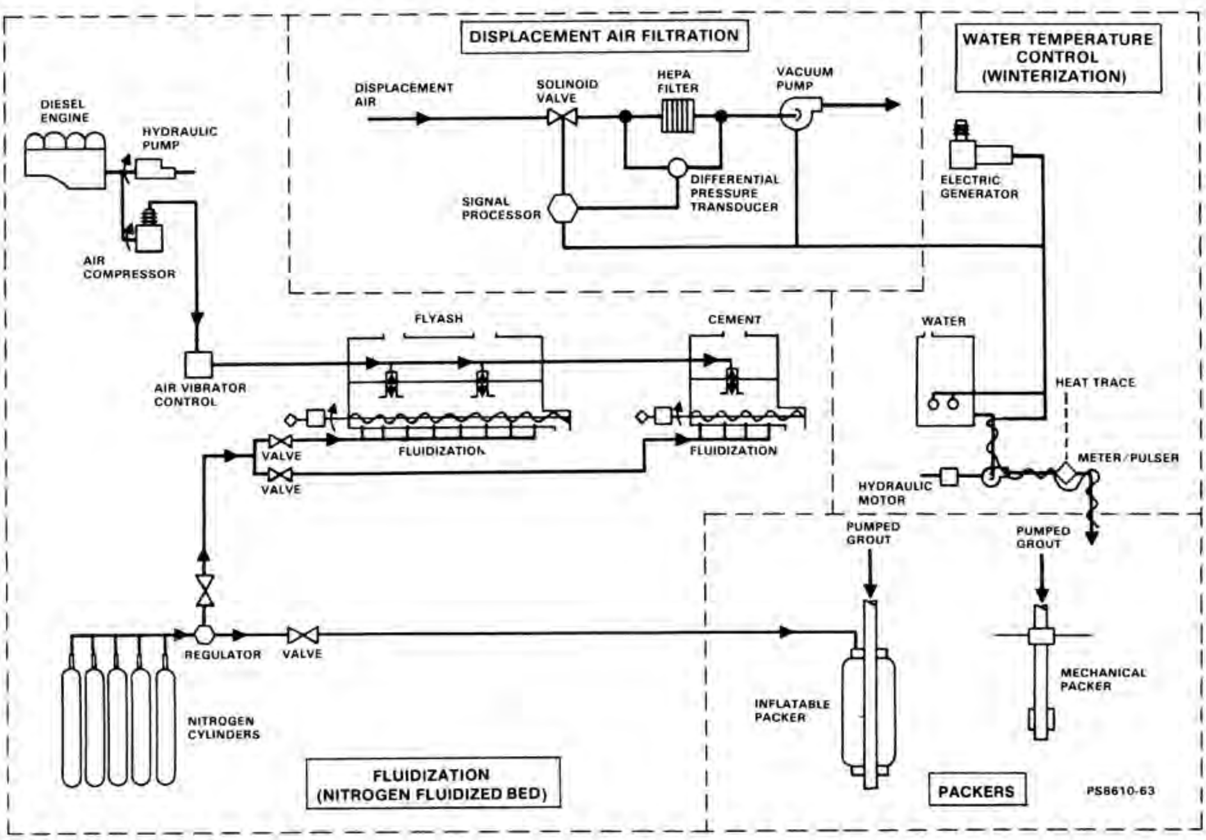

Fig. 3 Generalized schematic of cement and flyash fluidized bed, pneumatic packer inflation, and water temperature control modules used in conjunction with mobile grout plant operations.

Operation of the mobile grout plant is primarily controlled by a microprocessor. The microprocessor permits manual operation or automatic cycling. Automatic cycling is programmed for the revolution counters and totalizers used for the flyash and cement augers. Metered pulse counters and totalizers are used for automatic metering of water. In the automatic-cycle mode, the process controller sequentially transfers water, flyash, and cement into mixing and pumping units.

Flyash, water, and cement, at a mix ratio of 3:2:1, are blended and mixed in a vortex mixer actuated by a shearing pump. Numerous other mix ratios can be used at the discretion of the operator. Mix ratios can also be changed at any time during the treatment process. Shearing of grout is conducted by continuous pumping through a high-velocity, knife-blade-type centrifugal pump. Complete wetting of each particle in the grout mix results from shearing the slurry. Wetting is necessary to negate phase separation of grout materials during curing. Subsequent to high-speed shear mixing, grout slurry is transferred into a holding tank coupled to hydraulic or electric progressive cavity pumps, capable of low- to high-pressure (1.8×10^6 Pa) pumping at rates from near zero to 9.4×10^{-3} m^3/s.

Feed material transfer and product shearing and mixing are conducted as batch operations. However, product transfer and pumping is done to provide continuous flow. Hence, the process is considered as continuous flow batch mixing.

Vibratory Hammer/Extractor Component

A vibratory hammer/extractor is used as a power source to dynamically consolidate waste and soil materials within a surrounding waste disposal structure. This component can also be used to insert and withdraw injector probes within and surrounding the disposed of waste materials. The component consists of two units connected by a long umbilical. The primary unit is a skid or trailer-mounted, 1×10^5 W, diesel-powered hydraulic pump. The secondary unit is a large eccentric driver actuated by a 6×10^4 kg capacity hydraulic crane with a telescoping boom.

The eccentric driver is moved into position with respect to azimuth and lateral position of the crane for each crane position. The eccentric driver is coupled to an injector, which is initiated by starting hydraulic eccentric motors in the driver. The motors produce a driving frequency of approximately 30 Hz (nominally the natural ground frequency of unconsolidated nonindurated soil materials). Energy is transferred from the driver through the injector, producing a force of 6.3×10^5 N with an amplitude of about 8×10^{-3} m. Longitudinal, vertical and transverse orthogonal particle motion of materials through which the injector penetrates decreases with lateral distance and increases with injector depth below grade. Operation of the vibratory hammer/extractor is controlled independently by a crane operator.

Dynamic Consolidation/Injector Probe Component

Vertical probes, consisting of capped or uncapped thick-walled metal cylinders, structural beams, coaxial pipes, etc., are used to consolidate and/or penetrate waste materials below grade. Consolidation is accomplished by acceleration of the soil material adjacent to and proximal to the probe as it is driven or withdrawn from grade. Waste materials can also be consolidated by the direct energy imparted from the vertical probe as the probe is driven. Acceleration at the probe surface, under normal operating conditions, is approximately 2.3×10^2 m/s^2. The energy away from the probe is omnidirectionally and exponentially attenuated (geometrical damping) to about 10 m/s^2, 1 m outward from the probe (under conditions tested). A summary of geotechnical relationships of dynamic consolidation has been reported previously (9).

Grout materials produced by the mobile grout plant mixing and pumping units can be introduced into the waste-disposal structure and/or surrounding soil material simultaneously with dynamic consolidation. As a result, contaminated materials are compacted and cast continuously into a large cementitious monolith. Grout is pumped downward through coaxial or shielded tubes welded to the injector probe. Depending on application and disposal conditions, grout pumping can be initiated at the time of probe insertion into the ground or at any time during driving of the probe into the waste zone. Similarly, grout injection can be repeatedly halted and reinitiated at any time during the driving or withdrawal of the injector probe.

Injector probes for grout or probes used only for dynamic consolidation can be used repeatedly on a predetermined surface grid. Alternatively, disposable probes are used in cases where significant contaminant adheres to probes. Disposable probes are driven to grade, injected if required, and either removed at grade by abrasive wheel cut-off tools or backfilled with appropriate capping materials.

Open-Void Surface Injector Component

Access into liquid-waste disposal structures for grout injection can be facilitated by several techniques. Metal pipe risers about 0.1 to 0.3 m diameter, installed during construction for use as inspection ports or for venting, exist at several types of disposal structures and can be used for access. Grout injection can be accomplished by direct gravity injection downward through the riser, gravity or pressurized injection through flexible grout hose connectors welded to a capped riser, or pressurized injection of grout through pneumatic packers installed within the riser. Compressed nitrogen gas (1.3×10^7 Pa), used to form a fluidized bed in the mobile grout plant component, is used to supply inflatable packers. Displacement gas produced from injection of grout into open void structures can often be vented back to the atmosphere through high-efficiency particulate air (HEPA) filtration attached to auxiliary risers.

Several liquid-waste disposal structure designs have no direct access piping to facilitate grout injection. Diamond core drilling and mechanical packers are used in these cases to provide a channel for grout entry into the waste material. Coring is conducted by electrically powered, hollow-core diamond drills using coolant water from the bulk water storage tank on board the mobile grout plant. Power for drilling is provided from grout plant auxiliary electrical supplies. Mechanical packers are inserted in the access hole provided by the diamond bit and are rotated into place. As with the pneumatic packers, grout provides a seal whereby materials contained within the disposal structure cannot be ejected at grade for possible entrainment into the atmosphere.

SYSTEMS APPLICATIONS

The dynamic consolidation and grout components may be used independently or in combination, depending on the disposal structure and site characteristics. For example, treatment of a liquid-waste disposal crib consisting of a gravel backfilled drain field, perforated distribution piping, large open void structure, and ingress/egress piping, could proceed as follows:

- Site geophysical and radiological survey and mobilization of equipment
- Dynamic consolidation of drain-field materials with crane suspended vibratory hammer/extractor
- Injection of grout through vertical beam used for consolidation, wherein grout is injected into gravel drain field materials
- Withdrawal of injector probe beam and demobilization of vibratory hammer extractor
- Installation of surface mechanical packers within steel risers that extend above grade from the open void structure
- Installation of HEPA modules within steel risers for displacement gas filtration
- Injection of grout into the disposal structure directly from the mobile grout plant
- Pressure injection of grout through piping connecting the open void disposal structure to drain field distribution piping
- Capping of access piping and demobilization of equipment.

Figure 4 illustrates a system that can be used for treatment of a hypothetical liquid-waste disposal crib.

In preparation for actual dynamic consolidation and isolation of disposal sites, testing is being conducted at a geotechnical facility. This facility uses only simulated waste materials emplaced in controlled, specially constructed disposal structures. Numerous measurement and monitoring devices and nonradiological tracer materials are used at the site to determine the effectiveness of treatment techniques. When testing of each technique for consolidation and/or grout injection is complete, each disposal structure is exhumed and direct measurements are made to determine the effectiveness of the treatment. To date, equipment testing has been conducted on the following simulated disposal structures:

- Drainfields and wooden cribs have been tested with respect to dynamic consolidation, ambient pressure, and high-pressure grout injection. Direct injection of grout into the internal void volume of cribs accessed through surface risers was completed. Grout injection into drainfield materials was completed by simultaneous dynamic consolidation and grouting using a single injector repeatedly or by injecting through many sacrificial injectors.
- Caissons consisting of bottomless vertical arrays of end-to-end welded steel drums, large-diameter vertical steel pipes, and large vertical culverts have been treated. Staged grouting (injection and curing of grout at greater than grout cure time intervals) was necessary to alleviate the buoyancy of canned liquid-waste packages. Particulate grout was introduced into these simulated waste disposal structures with specially designed lateral diffusers and mechanical disk packers. Diffusers and packers were used to further reduce the possibility of bringing contamination to the ground surface due to waste package buoyancy.

Simulated crib disposal structures were internally encased in a cementitious monolith. The monolith has substantial compressive strength, incorporating the disposal structure and proximal soil within the cement matrix. Dye injection tests showed negligible fissuring or phase separation, and leaching of dye from the monolith did not occur. Subsequent analysis of stress-strain relationships and of radionuclide and hazardous chemical leach resistance will be conducted to further quantify site stability and isolation.

Simulated caisson disposal structures have been grouted. On exhumation of these structures, physical and chemical laboratory analyses well be made equivalent to those for exhumed crib materials. Similar results are expected.

Development, testing, and demonstration of system components have been completed on simulated liquid waste disposal structures. The system described previously has been adapted to accommodate treatment of each structure. The following uses of equipment are proposed or are in progress:

- Engineering development activities for injection of grout into a large burial box containing a condenser from a radiochemical separations plant will be completed in place during backfilling. Cementitious grout (1.8×10^2 m^3) will, on authorization, be injected into the box to fill the space between the concentrator and the box walls. This operation will be conducted after the box is placed in a burial trench and backfilled to provide shielding. Grouting in several pours was necessary due to anticipated buoyancy of the condenser within the burial waste package. An auxiliary vacuum system will be used during grout pumping to minimize overpressurization of the box. Airborne particulates within the box will be removed by filters attached to the box and installed at a depth of 2.5 m, and another attached to the vacuum pump in line at grade.
- Pressure grout injection of classified nuclear reactor components within large steel shipping and disposal vessels, which will provide long-term stability is in progress. Grouting will be conducted with minimal physical access to the shipping and disposal vessels. An injector module is being fabricated to facilitate pressurized particulate grout injection into the vessels.

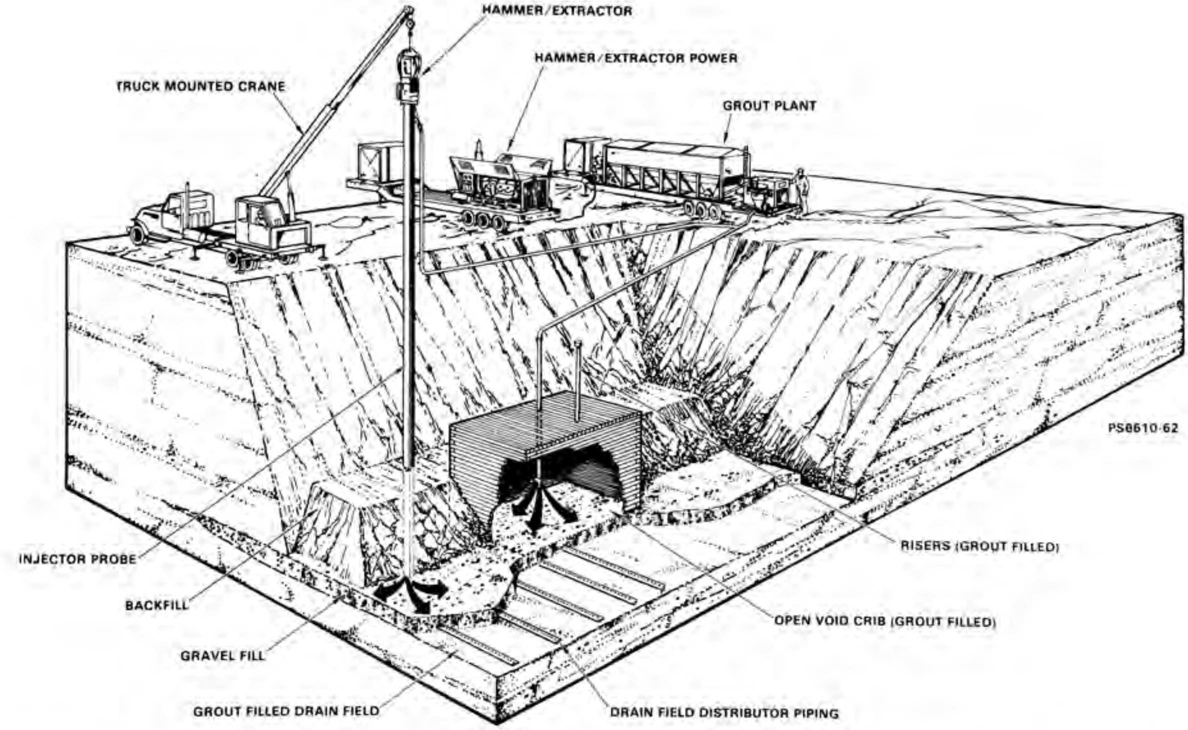

Fig. 4 Perspective view of mobile system used to stabilize and isolate a low-level liquid waste disposal structure. Large monoliths incorporating wastes and providing long-term strength and isolation are produced.

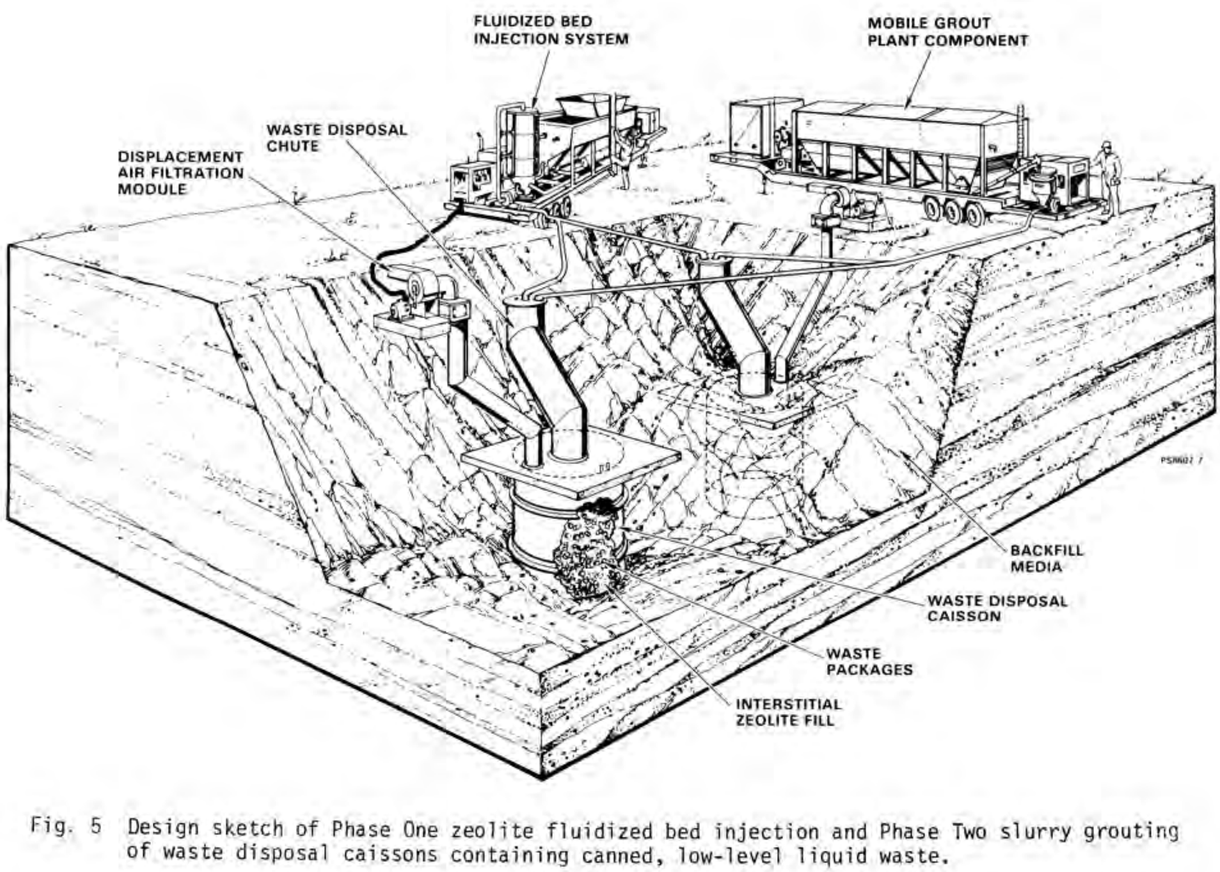

Fig. 5 Design sketch of Phase One zeolite fluidized bed injection and Phase Two slurry grouting of waste disposal caissons containing canned, low-level liquid waste.

- Consolidation and grouting of a liquid-waste disposal crib, drain field, and associated diversion tanks and piping is proposed. Development of unique disposable injector probes for this and similar structures is in progress. The total injection volume for treatment of the entire structure is anticipated to be approximately 4.5 x 10^3 m^3.

- Grouting of large glove boxes, which are to be disposed of in solid waste burial trenches, is also in progress. The mobile grout plant will be used to stabilize these boxes during trench backfilling. A penetrator is being designed to attach grout lines directly to glove boxes. The penetrator device also serves to vent displaced gases via coaxial tubing through a HEPA filter bank.

PROCESS MODIFICATION/ADDITION

A substantial volume of grout is required to fill large void volume disposal structures such as tanks, cribs, and vaults. To minimize grout volume requirements, a fluidized bed or equivalent system for injecting dry bulk materials into disposal structures has been proposed. This system will be connected to the existing waste stabilization and isolation system and will be used for preliminary operational filling of large void-volume disposal structure treatment.

The fluidized-bed equipment will inject materials capable of sorption of liquid radioactive and hazardous waste. Sorbent materials for injection include coarse textured particulates from zeolites (hydrated aluminosilicates of univalent or bivalent bases), to glauconite (monovalent or bivalent base silicates), to phyllosilicates (layer lattice aluminosilicates). These sorbents will be mechanically or pneumatically injected directly into the disposal structure. Auxiliary equipment is used to transfer and process particulates prior to fluidized-bed injection. Free liquids, sludges, or other deposited contaminants within the disposal structure are mechanically mixed with sorbent material. Ion exchange, chemical precipitation, or equivalent processes will then incorporate contaminants on or within the mineralogical structure of the sorbent agent (10).

After injection of dry bulk materials within an open-void disposal structure, the structure is grouted. Contaminants within the structure are incorporated into the sorbent material. The structure will then be grouted to provide a final product with excellent radionuclide retention capabilities. Injecting the slurry grout into the sorbent material and filling the disposal structure void will to provide significant geomechanical strength. Hence, the disposal structure is stable, and the contaminants are confined and isolated over time.

Figure 5 illustrates application of a fluidized-bed zeolite injection system for treatment of a caisson disposal structure. This system is shown in conjunction with the existing mobile grout plant component currently in use.

SYSTEM DEVELOPMENT RESULTS

Equipment for in-place remediation and possible final closure of obsolete low-level liquid waste disposal sites is being developed and tested at the Hanford Site to meet this objective. The following prototypic equipment has been developed:

- A dynamic consolidation component for in-place compaction of buried waste
- Injectors and packers to place grout slurries into high void-volume disposal structures
- A mobile particulate grout plant to transport, mix, and pump grout slurry.

The following systems, which will be connected to the above equipment, are proposed:

- A mobile fluidized-bed (or equivalent) component for coupled pneumatic and mechanical injection of sorbent materials into high void-volume disposal structures
- Auxiliary materials transfer equipment for the fluidized-bed component.

After development of these components and their integration into existing simultaneous dynamic consolidation and grout injection systems is complete, the equipment and methodology used to operate the equipment will be transferred to cognizant site operations personnel at various U.S. Department of Energy sites for potential application at their disposal locations.

REFERENCES

1. TALLENT, O. K., T. L. SAMS, T. TAMURA, T. T. GODSEY, C. L. FRANCIS, and E. W. MCDANIEL, "Characterization for Shallow-Land Burial Trenches at INEL," ORNL/TM-9881, Oak Ridge National Laboratory, Oak Ridge, Tennessee, (1986).

2. ARORA, H., and D. DAYAL, "Leaching of Cement-Based Low-Level Radioactive Waste Forms," NUREG/CR-4756 BNL/NUREG-52026, Brookhaven National Laboratory, Upton, New York, (1986)

3. COLUMBO, P., and R. M. NEILSON, Jr., " Properties of Radioactive Wastes and Waste Containers," NUREG/CR-0619, BNL-NUREG-50957, Brookhaven National Laboratory, Upton, New York, (1979).

4. FUHRMANN, M., R. M. NEILSON, Jr., and P. COLUMBO, "Survey of Agents and Techniques Applicable to the Solidification of Low-Level Radioactive Wastes," BNL-51521, Brookhaven National Laboratory, Upton, New York, (1981).

6. PHILLIPS, S. J., R. A. CARLSON, H. E. MCGUIRE, "Geotechnical Reduction of Void Ratio in Low-Level Radioactive Waste Burial Sites: Treatment Alternatives," RHO-SA-220, Rockwell Hanford Operations, Richland, Washington, (1981).

7. GRAF, E. D., "Compaction Grouting Technique and Observations," *Journal of the Soil Mechanics and Foundations Division, ASCE*, Vol. 95:1151-58, (1969).

8. SPALDING, B. P., L. K. HYDER, and I. L. MUNRO, "Grouting as a Remedial Technique for Buried Low-Level Radioactive Wastes," *Journal of Environmental Quality, ASA*, Vol. 14:389-96, (1985).

9. PHILLIPS, S. J. and T. W. GILBERT, "Liquid Disposal Site Void Fill and Isolation: Systems Description," *Proc, Seventh Annual Participants Meeting DOE Low-Level Waste Management Program*, CONF-8509121, EG&G Idaho Co., Idaho Falls, Idaho, (1985).

10. PHILLIPS, S. J and T. W. GILBERT, "Near-Field Evaluation of Geotechnical Remedial Actions at Hazardous or Radioactive Materials Disposal Sites," RHO-RE-EV-82 P, Rockwell Hanford Operations, Richland, Washington, (1986).

11. FREEMAN, H.D. and J.L. BUELT, "Engineered Sorbent Barrier Screening Studies," *Proc, Seventh Annual Participants Meeting DOE Low-Level Waste Management Program*, CONF-8509121, EG&G Idaho Co., Idaho Falls, Idaho, (1985).