SUBSURFACE BARRIER DESIGN ALTERNATIVES FOR CONFINEMENT AND CONTROLLED ADVECTION

S.J. Phillips, W.E. Stewart and R.G. Alexander
Westinghouse Hanford Company
Richland, Washington

K.J. Cantrell
Pacific Northwest Laboratory
Richland, Washington

T.J. McLaughlin
Bovay Northwest, Incorporated
Richland, Washington

ABSTRACT

Various technologies and designs are being considered to serve as subsurface barriers to confine or control contaminant migration from underground waste storage or disposal structures containing radioactive and hazardous wastes. Alternatives including direct-coupled flood and controlled advection designs are described as preconceptual examples. Prototype geotechnical equipment for testing and demonstration of these alternative designs tested at the Hanford Geotechnical Development and Test Facility and the Hanford Small-Tube Lysimeter Facility include mobile high-pressure injectors and pumps, mobile transport and pumping units, vibratory and impact pile drivers, and mobile batching systems. Preliminary laboratory testing of barrier materials and additive sequestering agents have been completed and are described.

INTRODUCTION

During the past 5 decades, thousands of subsurface nuclear and hazardous waste storage and disposal structures have been used at U.S. Department of Energy (and predecessor agencies) complex sites for management of liquid and solid waste materials. These structures range in size and complexity from drainfields and reverse wells to large-volume liquid underground storage tanks to multitrench landfills. Westinghouse Hanford Company, Pacific Northwest Laboratory, and Bovay Northwest, Incorporated are investigating materials, geotechnical equipment, and construction technologies for placement of barriers to confine or interdict contaminants originating from these underground structures.

Subsurface barriers can be categorized into numerous functional types. Thermal, chemical, and physical subsurface barriers are being evaluated at the Hanford Site for use over a variety of underground structures (e.g. underground storage tanks) containing variable quantities and inventories of contaminants. Final selection of subsurface barriers, if required, will be made after waste materials, barrier function, and secondary impact to waste structures (e.g. heaving) are evaluated in detail. Two subsurface barrier preconceptual design alternatives will be discussed in this paper: direct-coupled flood barriers and controlled advection.

DISCUSSION

High-Level Radioactive and Hazardous Waste Tank Direct-Coupled Barrier

High-level radioactive and hazardous wastes are stored, in part, in underground storage tanks at the Hanford Site. From many of these tanks, residual liquids, sludges, and solids will be retrieved during the next 30 yr. To preclude leakage from the tanks as they exceed design life or leakage occurring as a result of retrieval actions, subsurface barriers may be required (6).

If implemented, subsurface direct-coupled barriers for tanks will function in the partially saturated groundwater zone from near grade to depths of approximately 20 m. Direct-coupled barriers are intended to operate for individual tanks, not assemblages of tanks. An important attribute of direct-coupled barriers is elimination or significant reduction of contaminants entering the soil that eventually could migrate to the saturated groundwater system. This results from forming a secondary confinement or redundant barrier directly in contact with the outer tank wall. The ensuing design is a primary barrier comprising a unique and durable material, with a redundant secondary material (of another unique and durable material), creating a redundancy in the number and types of barriers surrounding the tank.

Construction of direct-coupled barriers can follow myriad scenarios. Two alternative preconceptual designs are shown in Fig. 1. A primary barrier either is installed by injection (modified jet grouting process) of an hydraulic cement in a cone morphology from an elevation near the base of a tank, or it is installed from laterals (pipe-jacking process) installed through caissons constructed vertically proximal to given tanks. In each case, a steel sheet pile wall is tied into the hydraulic cement base. For the cone-shaped barrier, an inexpensive aqueous silicate is injected into the base of the cone using induced liquefaction. For the cylindrical caisson barrier, hydraulic cement is injected by displacing backfill soil materials, forming a three-layer barrier floor. Near the base of the tank and cylindrically around the tank an aqueous polymer is injected into the backfill soil. The result is a large monolithic barrier directly in contact with the tank floor and wall, which is surrounded by an exterior redundant subsurface barrier.

Preliminary laboratory testing of polymer injectant materials has been completed for tank wastes (4). Additional laboratory testing of natural sequestering agents also has been completed for hydraulic cement materials (5). Polymer injectants evaluated include methacrylates, polyester styrene, vinylester styrene, furfuryl alcohol, polyacrylic acid, and modified sulfur cement. Sequestering agents evaluated include ferrous sulfide, carbonate fluorapatite, mixed metal oxide/hydroxide, organic coated oxides, hydrotalcite, and clinoptilolite. The following standard tests were conducted:

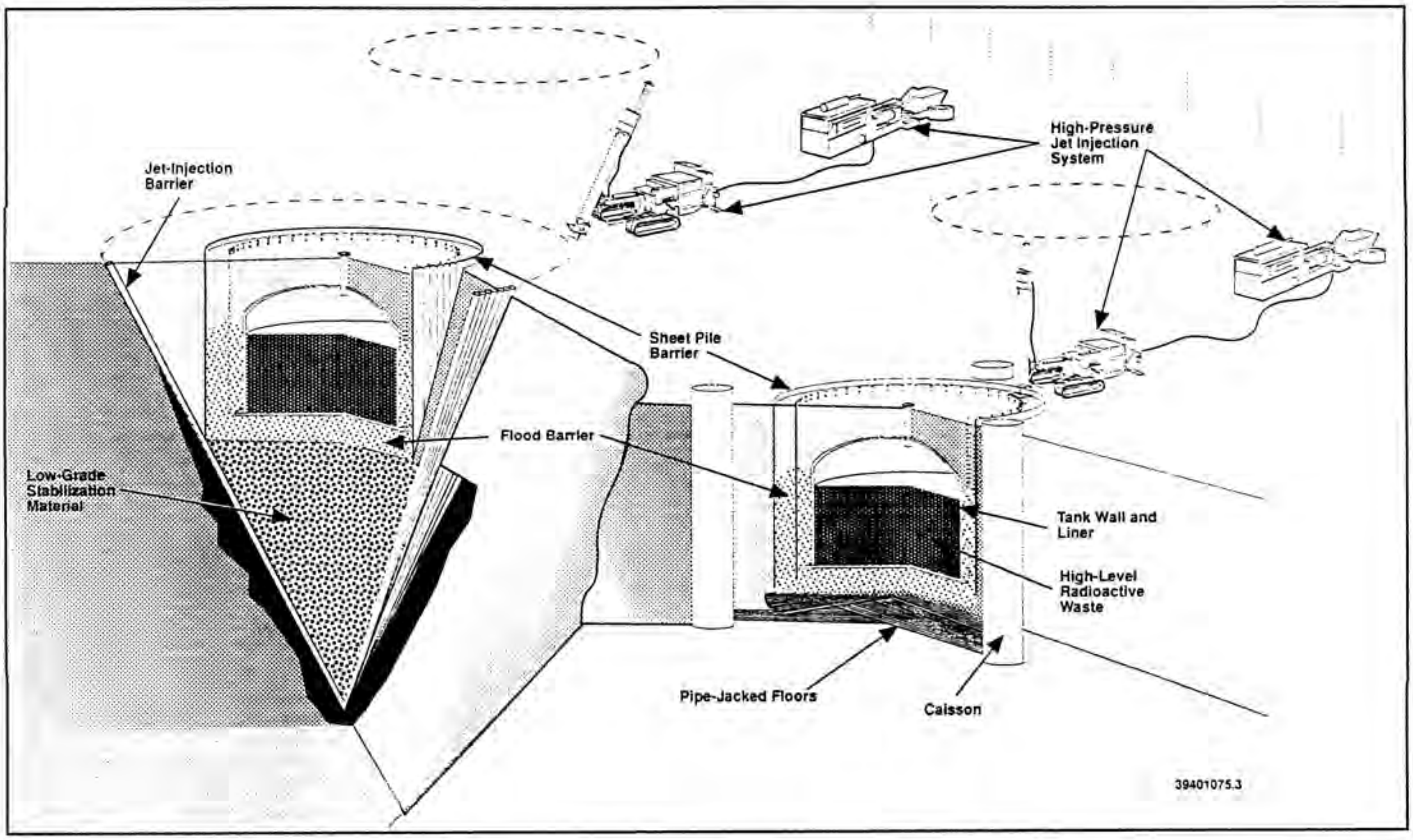

Fig. 1. Example subsurface barriers for underground storage tanks containing high-level and mixed radioactive and hazardous waste. A cone barrier with redundant direct-coupled flood confinement is shown. A vertical sheet pile wall and redundant injected floor with direct-coupled flood confinement also is shown.

1. Water immersion
2. Thermal cycling
3. Irradiation stability
4. Hot nitrate brine immersion
5. Hydraulic conductivity
6. Compressive strength
7. Contaminant diffusion.

Prequalification and regulatory approval will be required before application of any of the above materials for subsurface barrier placement.

Verification and validation of barrier placement adequacy and completeness, and the performance of the subsurface barrier during its design life is the primary concern. Monitoring access has been designed into the placement systems. Flood-injection and jet-injection piping is cleaned after each use and remains open for access to monitoring instruments and for make-up caused by sluffing. Verification/validation and performance instrumentation can vary; for example, from electrical or acoustic tomography/holography, cross hole radar, gamma and neutron activation logging, to temperature- and pressure-measuring instruments. Instrumentation can be used to measure point or diffuse source materials or parameters.

Low-Level Radioactive or Hazardous Waste Tank and Liquid waste Disposal Structure Flood Barrier

Low-level radioactive or hazardous liquids at the site were discharged to numerous underground disposal structures, i.e., drainfields, cribs, reverse wells, ponds, french drains, and trenches. These liquids originated from hundreds of waste streams generated from chemical separations, laboratory, reactor, metal finishing, decontamination, waste storage, and materials-handling facilities. Of these numerous structures, many may be decommissioned and closed in situ, near the Hanford Site chemical separations areas. Long-term closure of these structures may require in situ subsurface barriers to restrain radioactive and hazardous materials from entering environmental contaminant transport pathways.

Subsurface barriers confining low-level tank and liquid waste disposal structures are designed to function in the partially saturated groundwater zone. Typically, the depth of these barriers will not exceed 10 m while entombing the majority of contaminants discharged to the structure. In principle, the design for these barriers are equivalent to that of high-level tank subsurface barriers, a primary barrier enclosing a secondary barrier consisting of a microencapsulating flood material. As opposed to entombing the waste disposal structure, however, the design micro/macroencapsulates the entire structure and part of the underlying contaminant plume. The ensuing barrier consists of a primary and secondary redundant barrier, with each barrier constructed of a different and durable material.

Construction of the primary barrier is accomplished by driving of vertical sheet pile ends and intersecting angled (3.5×10^{-1} to 8.6×10^{-1} rad) walls. Primary barrier ends and walls also can be constructed by jet-grouting columns of the same configuration. Depending on the inventory and type of contaminants in the plume below the structure, variable microencapsulating materials can be injected. Open void-volume, piping, and interstitial aggregate void-volume within the structure, i.e., the crib (Fig. 2) can be injected with hydraulic cements containing sequestering agents. Flood injection is conducted by induced liquefaction through sacrificial injector pipes.

Sequential injection of aqueous silicate and hydraulic cements in a simulated liquid waste burial caisson has been completed at the Hanford Geotechnical Development and Test Facility. Testing of injectant materials has been completed, in part, for silicates both under laboratory conditions and under controlled and accelerated field conditions at the Hanford Site Small-Tube Lysimeter Facility.

Monitoring of construction placement and long-term performance of the these barriers follows the same design as the direct-coupled tank subsurface barrier. Access for instrumentation is provided by tubing and piping used for construction.

Controlled Advection Barrier

Large quantities of low-level liquids bearing radioactive and hazardous contaminants have been discharged into the groundwater system. Highly mobile contaminants have migrated from these structures through the partially saturated zone to the saturated groundwater zone and in some cases transported many kilometers to publicly accessible areas albeit in very low concentrations. If left untreated, contaminants may continue to migrate and result in excessive exposure. Subsurface barriers capable of diversion and selective sorption of contaminants from advective groundwater may be capable of reducing contaminant exposure (1, 2).

Controlled advective flow barriers (Fig. 3) are being preconceptually designed to intercept and selectively reduce contaminant flow (3). These barriers differ from those mentioned previously in that they function exclusively in the saturated groundwater zone. As contaminated groundwater at or below the water table is advected through the barrier, contaminants are removed from the water and are contained within the barrier materials. Removal of contaminants may occur by any or combinations of the following processes:

1. Microfiltration
2. Precipitation/coprecipitation
3. Ion exchange
4. Degradation

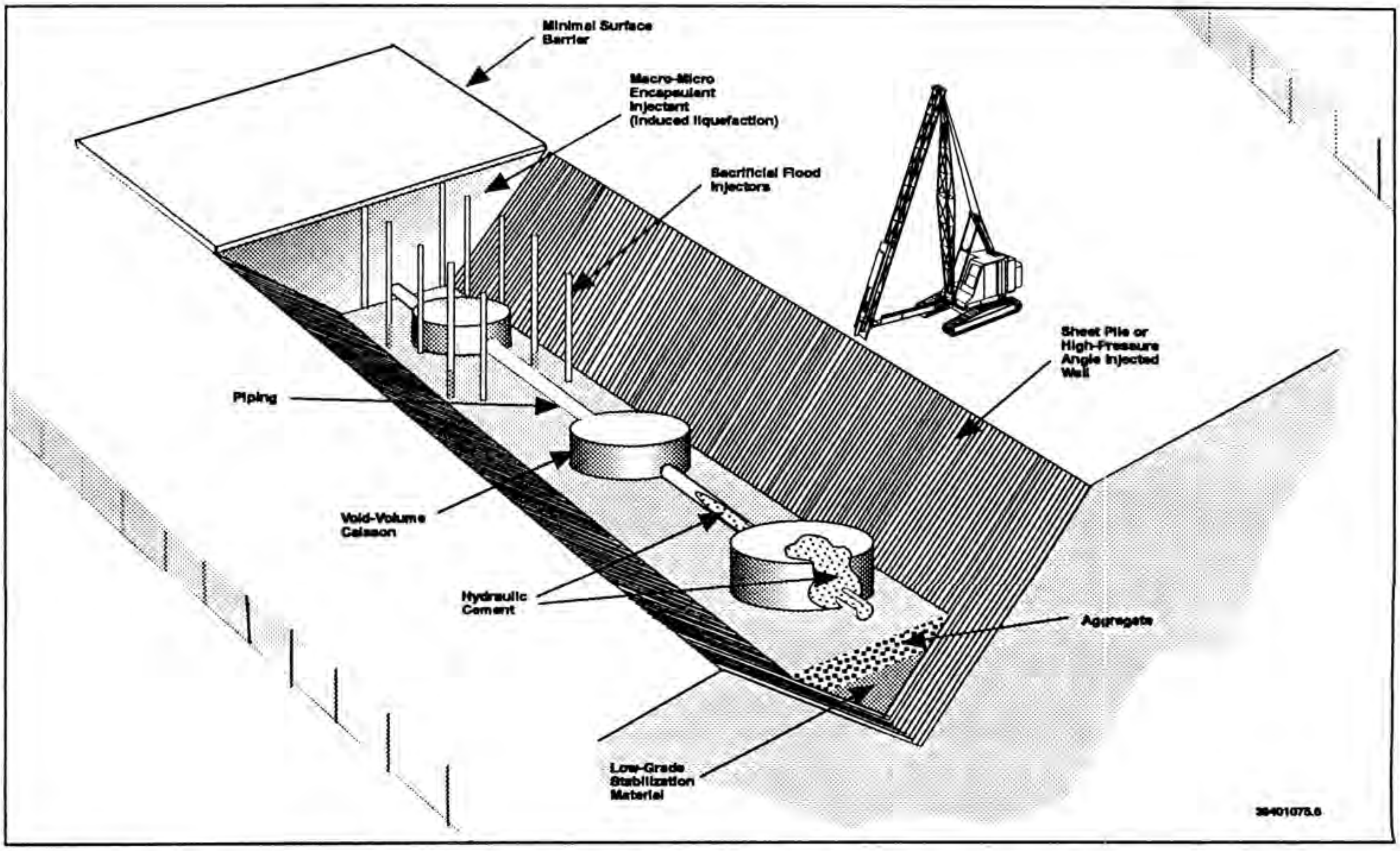

Fig. 2. Direct coupled redundant barrier encapsulating a low-level liquid drainfield. Low-grade stabilization material is flooded below the drainfield to encapsulate the contaminent plume. The structure is flooded with, for example, polymers using induced liquefaction technology. The structure plus primary contaminent plume is enclosed in a sheet-pile barrier.

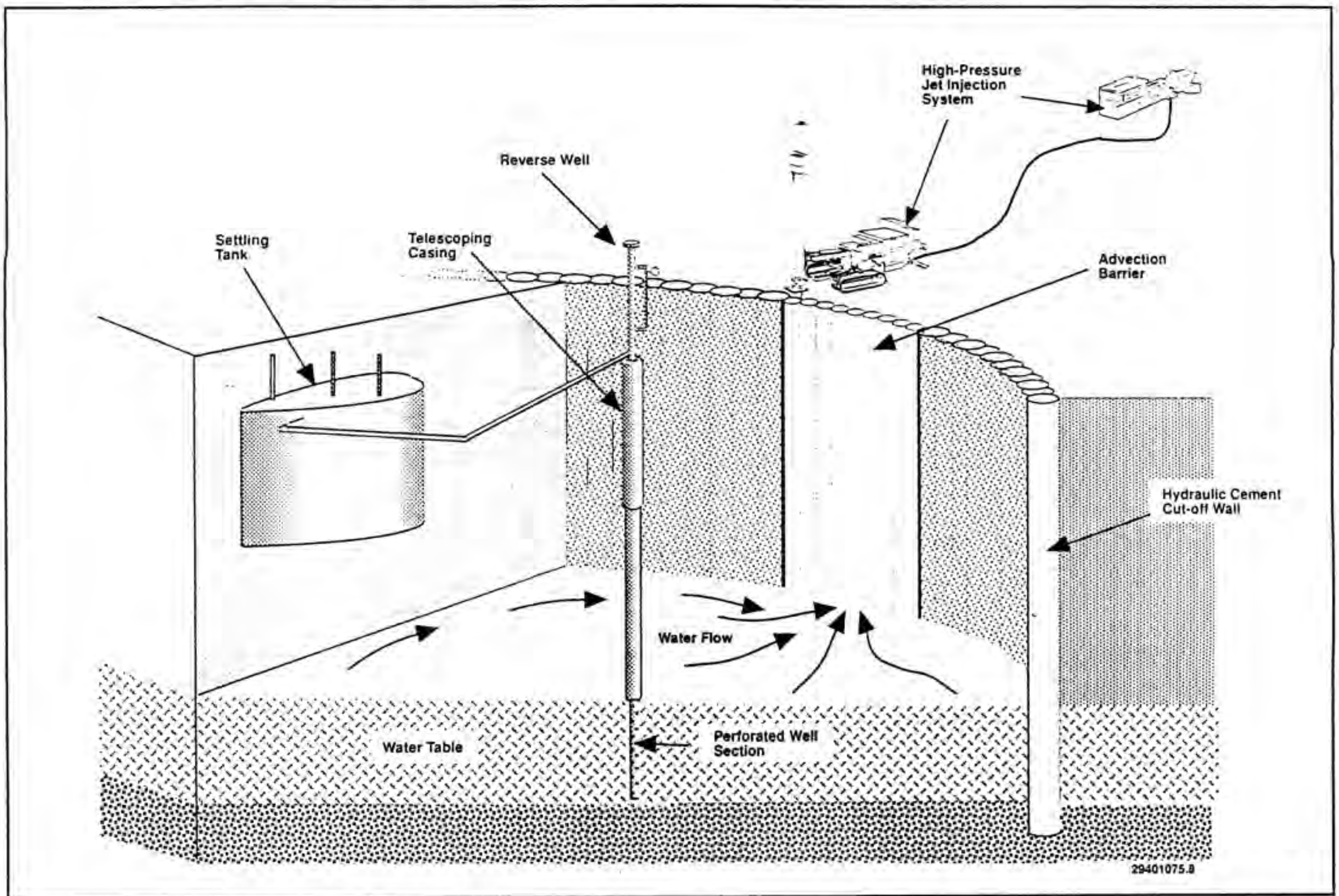

Fig. 3. Advection (flow-through) barrier in saturated porous media. Contaminated groundwater is diverted through a barrier containing sequestering or reactive agents resulting in, in situ treatment of radioactive and hazardous wastes.

5. Adsorption
6. Chelation
7. Biodegradation/biofixation.

Contaminants are held in situ within the barrier at or below loading limitations. If loading is exceeded, functional barrier materials must be refreshed.

Construction of the controlled advection subsurface barriers can follow numerous designs. Vertical barriers consisting of low-hydraulic-conductivity hydraulic cement surrounding a contaminated subsurface waste storage or disposal structure can be emplaced with a high-hydraulic-conductivity segment down gradient. Other alternatives being considered include cutoff-wall configurations made of low-hydraulic-conductivity hydraulic cement, placed down gradient from a contaminant-storage or disposal structure with a higher hydraulic-conductivity segment at the apex of the cutoff walls that contain contaminant-removal agents. Placement of vertical cutoff walls is being considered using a high-pressure low-volume injector system modified to operate in low-to-moderate radiation fields. Placement of removal agents in a *vertical column* within the controlled advection barrier is following the preconceptual design of a metal particulate and colloidal pneumatic/hydraulic injector.

Validation and verification of the placement of controlled advective barriers are much the same in design as those of the previous barriers. However, another aspect can be included wherein up- and downgradient performance monitoring of contaminants can be continually or periodically determined outside of the expanse of the subsurface barrier. Monitoring performance in the saturated groundwater can be used to determine performance as well as temporal indication of contamination loading and the need for refreshing the sequestering agents in the active volume of the barrier.

Laboratory analysis of sequestering agents for *controlled* advection barriers is proceeding for liquid waste disposal structures. Preliminary testing for the following agents has been completed: 1) iron, magnesium, and aluminum oxides; 2) hydrotalcite; 3) organic coated oxides; and 4) sulfur reducing compounds. These agents or combinations may prove effective in removal of both radioactive and hazardous material contaminants in groundwater at the Hanford Site.

PROTOTYPE GEOTECHNICAL EQUIPMENT

Construction of direct-coupled barriers, injection of materials into low-level tank, and liquid waste disposal structures as well as construction and materials injection into controlled advection subsurface barriers are completed by a self-propelled chassis-mounted injector module. The module injector assembly (Fig. 4) consists of a counter-rotating percussion/rotation unit attached to swivel and nonreturn valves and a downhole high-pressure cutting and injection tool actuated from a (4.2 m) mast-and-winch assembly. Displacement air and cuttings, if produced, are treated with a collector and high-efficiency particulate air filtration system (38.4 m^2), modified for concurrent injector operations. The module is

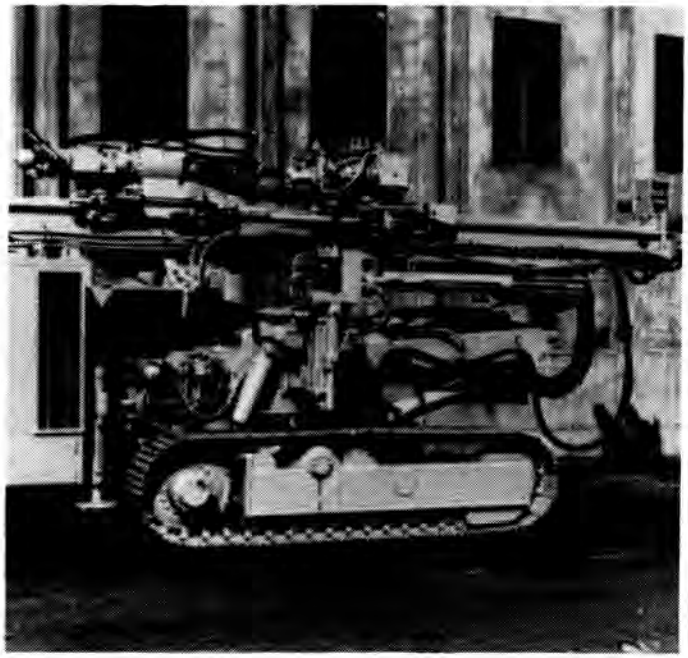

Fig. 4. Hydraulic-pneumatic, rotation-percussion injector module used for subsurface materials placement.

powered by a 6.6×10^3 W diesel hydraulic system and operated by programmable microprocessor electronics. This module is used with a stand-alone high-pressure pump or with a mobile transport and pumping module.

A high-pressure injector-pump module joined with the injector module may be required for direct-coupled, low-level tank and liquid waste disposal, and for advective flow through barriers. This pump module is required to form primary barriers surrounding secondary flood barriers. This pump is capable of producing a sustained pressure at the injector of 5.2×10^7 Pa for liquids or slurries. Controlled throughput of negligible volumes to approximately 5×10^{-3} $m^3 \cdot s^{-1}$ are required to form acceptable-diameter vertical or inclined-interconnected barrier columns.

Controlled advection barriers will require injection of granular filtration and sequestering materials into the working convective segment of the barrier. This is facilitated by a mobile transport and pumping of module. This module, mounted on a semi-truck trailer (Fig. 5), carries both liquid and dry (granular or power) feed materials in tanks and bins of 3.5 and 1.8×10^1 m^3, respectively. Powder and granular materials are fluidized with pressurized dry nitrogen gas to promote materials handling and metering. Dry materials are metered through augers, and liquids are metered through mechanical meters actuated by programmable microprocessors for batch or continuous batch operations. Aqueous or slurry materials produced by the module are recirculated and pumped through colloidal mixers, shearing pumps, and either progressive cavity or piston rock valve pumps. Variable pump configurations permit high-volume low-pressure throughput or the inverse. Maximum capacity throughput and pressure for progressive cavity pumps is 4.4×10^{-3} and 2.6×10^{-3} $m^3 \cdot s^{-1}$, and piston pumps 5.3×10^{-3} $m^3 \cdot s^{-1}$ at pressures of approximately 2.0×10 and 2.8×10^7 Pa, respectively. The module is powered by a 1.7×10^5 W diesel power plant providing hydraulic, pneumatic, and electrical power to module components as required.

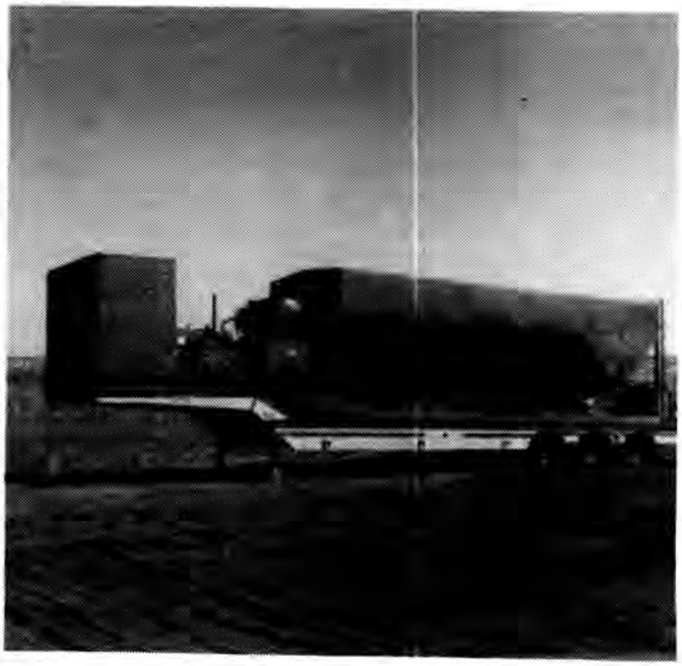

Fig. 5. Mobile transport, shearing, and pumping module for dry powder and liquid feed homogenization and pressure injection.

Batching of materials used to form direct-coupled confinement barriers requires a mobile batch-plant/silo module capable of either wet or dry operations. This prototype module currently has the additional capability to produce thermal setting injectant materials. Maximum throughput of 3.3m x 10^{-2} $m^3 \cdot s^{-1}$, storage capacity of 96.5 m^3, and homogenization capacity of 9.2 m^3 is controlled by a programmable microprocessor allowing continuous or batch operations. An axillary 8.0×10^5 W diesel onboard generator is required for operation of this module.

Construction of low-level liquid tank and waste disposal structure barriers may also require installation of sheet or H-piling, or template structural steel members below grade, proximal to the disposal structure. A 9.8×10^4 J single-action, diesel pile hammer and leads (23.3 m) (Fig. 6) have been field tested adjacent to small-volume subsurface tanks for template construction. This unit is inappropriate for construction of direct-coupled barriers because of the excessive force on the tank structure, floor, wall, and footings Construction of cylindrical pile using a diesel hammer also can be used to place subsurface barrier columns that consist of hydraulic cement and advective flow-sequestering materials.

Direct-coupled and low-level liquid tank and waste disposal structure barriers may use a vibratory hammer extractor for construction of sheet piling primary barriers enabling placement of flood materials. Field testing of these hammer modules has efficient barrier placement in nonindurated backfill materials. Limited success has been demonstrated in coarse and indurated geologic media. A skid-mounted 1.1×10^5 W diesel/hydraulic power plant and eccentric driver (30 Hz) unit, which is actuated by a large capacity hydraulic crane, is used to drive sheet piling using a ground-surface driving template. The same unit has been used to drive

Fig. 6. Diesel single-action pile hammer and leads for primary barrier construction.

cylindrical piling, potentially useful in advective flow and sequestering agent barrier columns. The drive unit can be directly attached to the 23.3-m leads used for diesel hammer pile construction and actuated from vertical to approximately 7×10^{-1} rad.

These geotechnical unit operations used singularly or in combination are capable of placement of numerous subsurface barrier configurations constructed of a wide variety of materials. Further development, testing and optimization of equipment function will follow U.S. Department of Energy direction for confinement of waste materials in retired underground waste storage or disposal structures.

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