The Circulating Air Barrier: Effective Prevention of Liquid Contaminant Movement Through Soil

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CONTRACT INFORMATION

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OBJECTIVES

K&M Engineering and Consulting Corporation (K&M) supported by BDM Federal, Inc. (BDM), completed a study in June, 1993, for DOE's Morgantown Energy Technology Center (METC). In the study, the K&M/BDM team evaluated alternative drilling technologies and subsurface barriers which would be used at the Hanford site for confinement of contaminated materials which might leak from the buried single shell tanks. Specifically, the C Tank Farm was targeted for consideration because of the presence of two high-heat tanks (radiogenic heat source) and the suspected leaking of seven of the 12 tanks in the farm. The study culminated in the conceptual development of seven integrated subsurface barrier systems and associated implementation plans.

Following the completion of that study, K&M was assigned a task to further evaluate two of the most promising barrier systems identified, the Circulating Air Barrier (CAB), and a Permeation Cone Grouting Barrier. In this more recent study, K&M was supported by BDM Federal, Inc. and Arctech, Inc. Objectives of the task included design, modeling, selection of drilling and surface processing equipment, and development of test procedures and cost estimates for conducting a cold test demonstration of the CAB process. The demonstration configuration is scaled to a prototype CAB system designed specifically for the C Tank Farm at the Hanford Site. The design methodology is also applicable for application of the CAB system at other sites within the DOE weapons complex.

BACKGROUND INFORMATION

The Hanford Site, located near Richland, Washington was used by the former Atomic Energy Commission, later succeeded by the Department of Energy, to manufacture materials for use in nuclear weapons systems. Hanford contains 149 single
shell underground storage tanks; as of April, 1994, 67 of the tanks have been identified as assumed leakers. The single shell tanks range in capacity from 55,000 to 1,000,000 gallons, with a maximum drainable volume of 413,000 gallons in a single tank. C-Tank Farm was one of the first tank farms, constructed in 1943, and at the time of construction, functional design life for the tanks was 30 years. All of the single shell tanks are now well beyond the original design life and DOE has established a program to address this problem as quickly and safely as possible.

Characterization of contaminated sediments resulting from past tank leaks, continued safe operation of tanks, total confinement of leaking materials, secondary waste minimization, and final closure of the single shell tanks are five of the many facets of the storage tank issue at Hanford and elsewhere in the nation. Each of these issues is considered in the development of the CAB system, which is designed to function as a containment barrier to prevent contamination of the water table located approximately 200 feet below the base of the C-Tank Farm underground storage tanks. This task addressed the need to design a CAB system for cold testing in uncontaminated soils at Hanford in order to gain regulatory acceptance from the U.S. Environmental Protection Agency and the Washington State Department of Ecology.

The Circulating Air Barrier System is a desiccant-type barrier designed to prevent the migration of liquid contaminants toward the ground water by using an air circulation and processing system to lower the saturation in a targeted subsurface zone below the saturation level required for liquid flow through that zone. The barrier can be installed using either vertical (Figure 1) or horizontal wells (Figure 2), establishing a pattern of air movement from the injection wells through the targeted barrier zone to the production wells. The dry injected air circulates through the targeted zone vaporizing in-situ water and other volatile or entrained contaminants to the production wells. The production stream is then processed in a surface facility to remove the water, contaminants and particulates. In time, the circulating air reduces the water saturation level in the target zone, and continues to remove, by evaporation, liquids that move into the zone. In the event of a tank leak, the system serves as an early detection tool and provides a method to withdraw volatile contaminants for surface treatment.

The CAB system offers several important advantages, including the fact that it is a non-physical confinement technology; it has an active monitoring and leak detection capability; it is based on proven, commercially available equipment and oil and gas technologies; it has excellent potential for emergency response and rapid deployment; and offers high potential for integration with other remediation technologies. Demonstration- and full-scale CAB systems have been designed for the Hanford Site as part of this Task.

PROJECT DESCRIPTION

The technical approach to designing both the prototype and cold demonstration CAB systems includes the following elements:

- selection and use of a simulator to predict and optimize performance of the CAB;
- detailed geologic characterization of the sites;
- detailed chemical characterization of the potential contaminants which may leak from the single shell tanks and enter the CAB zone;
- selection of a drilling system for installation of the CAB wells;
$P = \text{Production Well}$

$I = \text{Injection Well}$

$T = \text{Single Shell Tank}$

Figure 1. CAB System Utilizing Vertical Wells

Figure 2. CAB System Utilizing Horizontal Wells
• finalizing subsurface configuration and design of the surface processing equipment;
• development of test program and schedule;
• investigation of applicable environmental, safety and health issues; and
• estimation of costs for program/application.

An overview of each of these elements, as applied to design of the CAB system for deployment at the DOE's Hanford Site, is provided.

RESULTS

The CAB design methodology included detailed analysis of candidate system configurations and issues of scale between the prototype and small-scale designs. The prototype CAB for a single-tank application utilizes three horizontal wells (1 injection, 2 production) to create the CAB zone 100' x 100' x 60', with the top of the 60' thick CAB zone located 60 feet below the surface.

The demonstration design is for a quarter-scale CAB system and utilizes four vertical wells (2 injection, 2 production) to create the 25' x 25' x 15' CAB zone; the top of 15' thick CAB zone is located 15 feet below the surface. The five-spot configuration upon which the design is based was evaluated using classical potential flow theory in addition to the detailed numerical modeling.

BVAP Model Selection

After establishing the objectives for barrier design, a simulator was selected, modified, and used to simulate the CAB process. The program, BVAP, is a modified version of BOAST3-PC, a validated, commercially available black oil reservoir simulator, selected to model the CAB process due to the following capabilities/attributes: three-dimensional, three-phase flow model; finite-difference, implicit pressure/explicit saturation solution; isothermal Darcy flow simulation; flexibility for application at other sites; PC capability; and vapor phase transport simulation (BVAP modification).

The simulator was used to predict CAB performance for each of the three modes of operation:

• initial drying: the CAB system operates at up to full capacity to create the CAB zone of reduced water saturation;
• leak response: the CAB system operates at up to full capacity in order to contain and produce a leak; and
• monitoring and barrier maintenance: the CAB system operates at reduced capacity to provide continuous or intermittent monitoring and maintain the target level of water saturation in the zone.

The key simulator output is the length of time and volumetric air flow rate required to dry and maintain the CAB zone, and the air flow rates and pressures required to confine any simulated leak. These volumetric air flow rates become the critical parameters for design of the subsurface configuration and injection and production stream processing facilities.

Geologic Characterization

A detailed analysis was then performed of aspects of the depositional history, stratigraphy, and sediment properties which may affect CAB operation
at the Hanford Site. For prediction of CAB performance at Hanford, the complex geology had to be characterized and converted to 22-layer BVAP grid format. In the C tank farm, studies of four RCRA wells drilled since 1989 indicate 10 easily-grouped soil units of relatively constant grain size and appearance. These beds are grouped into three stratigraphic units; the upper, middle, and lower Hanford Formation, based on correlation with wells drilled for the ERA-VOC project in the 200 West area, which were cored and extensively sampled and studied. The range of variability of the geologic characteristics are summarized below:

- materials range from fine sand and clay to gravel;
- thickness of the various subsurface layers ranges from 2 to 85 feet;
- porosity ranges from 20 to 55%;
- vertical and horizontal permeabilities range from 24 to 9785 millidarcies; and
- initial water saturation ranges from 6 to 10% of pore volume.

Potential geologic complications were identified, including regions of extremes in permeability such as systems of sedimentary dikes. Effective CAB design, most importantly well orientation (horizontal v. vertical)/placement and pressure differentials, will ensure improved performance in these types of soils.

Sensitivity Analysis and Performance Optimization

This geologic characterization data was used to predict CAB performance using the BVAP model. A preliminary sensitivity study was performed using a 25' x 10' x 20' simulated CAB cross-section; these results were then used to target specific areas of focus for the detailed, three-dimensional sensitivity analysis.

The detailed sensitivity study was then performed to evaluate the effect on CAB operation of site-and process-specific parameters, based on a five-spot vertical well pattern for a single-tank application. Evaluated parameters included, but were not limited to: volumetric air flow rate; horizontal and vertical permeabilities; leak fluid viscosity; leak volume; minimum water saturation required for fluid flow; soil porosity; high and low permeability zones; initial water saturation; completion interval; depth to CAB zone; well orientation; CAB thickness; and leak rate and volume.

The sensitivity analysis was used to optimize practical operating ranges for volumetric flow rates, operating pressures, and water production levels:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Baseline</th>
<th>Maximum</th>
<th>Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow Rate (mcf/d)</td>
<td>2,000</td>
<td>3,600</td>
<td>400</td>
</tr>
<tr>
<td>Water Production Level (Gal/day)</td>
<td>56.0</td>
<td>94.9</td>
<td>10.4</td>
</tr>
<tr>
<td>Injection Pressure (psia)</td>
<td>17.8</td>
<td>20.5</td>
<td>15.4</td>
</tr>
<tr>
<td>Production Pressure (psia)</td>
<td>11.3</td>
<td>14.2</td>
<td>6.0</td>
</tr>
</tbody>
</table>

Following the sensitivity analysis, the input data files were then modified from a homogenous region approximating C Tank Farm soils to the actual permeability and porosity distributions detailed in the geologic characterization. Optimized parameters, including horizontal well configuration, were used to predict performance of both the prototype CAB system and the quarter-scale demonstration.
Chemical Characterization and Processing Design

The site chemical characterization effort details the chemical evaluation of a possible leak from the C Tank Farm storage tanks in order to design the air production stream processing equipment. Sources of characterization data for the C Tank Farm contents included waste characterization sample data for tanks 103, 104, 105, and 106, TRAC model predictions, and a PNL comparison of waste stream feed characteristics for single-shell tank waste treatment. Potential rates of removal for radon gas, radioactive and non-radioactive particulates, volatile organics, and tritiated water vapor were estimated. While the production processing system is designed to filter each of these potential contaminants, estimated quantities were minimal.

The facility design includes subsurface configuration and surface processing facility for both the full-scale prototype and the quarter scale demonstration CAB systems. The single-tank prototype system, designed for C tank farm application, consists of a three-horizontal well (one injection, two production) subsurface CAB approximately 100 ft², 60 feet thick with the top of the CAB zone 60' deep. The surface processing injection components include (two-train redundancy) a blower/aftercooler, a desiccant dryer and associated filtration. The production-side components include (dual train) an initial heat exchanger, roughing and HEPA filter units, vacuum blower/aftercoolers, and a desiccant dryer/filter. The carbon filter/HEPA unit is not necessary for demonstration of the CAB concept at a clean site.

Drilling Technology Review

An assessment was performed in parallel with other design activities to provide an update of the analysis of alternative drilling technologies which was completed during the previous study. Of particular importance was an assessment of the various types of drilling equipment that might be used to install horizontal wells in the difficult Hanford geologic media while providing safe working conditions for the drill rig employees. Because of the severe problems associated with effluent control for drill cuttings and air returns for air drilling operations, a review of the state-of-the-art in compaction boring equipment and operations was completed.

Other important components of the drilling systems review were:

- modified oil field drilling equipment bits: roller cone, drag, and hammer;
- directional drilling systems: air rotary, sonic, coiled tubing, compaction boring, river crossing; and
- directional control (measurement-while-drilling) systems: hard-wired, mudpulse-telemetry, electromagnetic.

The study team recommended the sonic drill rig for installation of the cold test vertical wells, and additional testing on compaction boring units for installation of prototype horizontal wells.

Test Program Development and Costs

The proposed test program for demonstrating the CAB design concept in an
uncontaminated area (Washington Public Power Supply System (WPPSS) site) includes the following objectives:

- demonstrate the CAB system concept and operability;
- validate and update the BVAP model by comparing field performance with model-predicted performance of the demonstration design;
- provide data for scale-up to hot-test and detailed cost estimates;
- demonstrate CAB system capability to comply with applicable environmental health and safety regulations; and
- demonstrate CAB system potential as a monitoring system for potential use in conjunction with other barrier and/or remediation technologies.

The Cold Test as proposed consists of drilling a system of four process wells (2 injection and 2 production) and seven monitoring wells that demonstrate the air circulating and drying process, including demonstration of the equipment required to remove all particulates and liquids that will be removed from the subsurface environment.

The demonstration as planned would verify the ability to contain any material leaked from a tank by vapor phase transport of the liquid component of that material to the surface, where it will be contained and stored in suitable containers until testing of the material can be accomplished and it can be disposed of in accordance with the proper regulations.

The test program duration is two years, including permitting; drilling and soil analysis; model modification and process design verification; detail engineering and procurement specification; procurement; subsurface equipment installation; system commissioning and check-out; cold test operation; and site restoration.

Costs were estimated for installation and operation of the demonstration CAB and capital costs for the prototype. The total cost of the demonstration test program is $3,304,000, with the largest cost components being system equipment installation ($989,000), contingency ($762,000), and cold test operation ($744,000).

Capital cost for the full-scale prototype is $13,772,000. The largest cost components are system equipment installation ($5,862,000), contingency ($3,178,000), and drilling and soil analysis ($1,474,000).

A preliminary overview of the regulatory environment for demonstration testing of the CAB system was performed. A general overview of applicable federal regulations includes DOE Order 5400.0, "General Environmental Protection Program"; the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA); the Emergency Planning and Community Right to Know Act; the Resource Conservation and Recovery Act (RCRA); the Clean Air Act; the Clean Water Act; and the National Environmental Policy Act (NEPA). An overview of the Hanford Site-specific regulatory issues were developed from the WHC-CM-7-5, the Hanford Site Environmental Compliance Manual, and it addresses the following as related to the CAB system:

- Environmental Compliance
- Requirements for New Facility
- Regulatory Permitting Requirements

FUTURE WORK

Activities recommended to complement the CAB demonstration at Hanford include laboratory-scale studies of soil characteristics and CAB performance, which will also serve to validate the model; a survey/characterization of other candidate sites for CAB deployment; continued
testing and demonstration of horizontal drilling technologies; and a study of instrumentation and monitoring options for the CAB system.

ACKNOWLEDGEMENTS

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