ACCELERATED CLOSURE OF THE CHEMICAL WASTE LANDFILL THROUGH VOLUNTARY CORRECTIVE MEASURES

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ABSTRACT

The Chemical Waste Landfill (CWL) is a 1.9 acre site operated from 1962 until 1985 to dispose of chemicals and waste generated by Sandia National Laboratories/New Mexico (SNL/NM) research and development activities. Waste disposal operations at the CWL were discontinued completely in 1989. Because the CWL was operational when the Resource Conservation and Recovery Act regulations were promulgated, the CWL qualified for interim status. To implement the closure provisions contained in 40 Code of Federal Regulations 265 Subpart G; SNL/NM and the New Mexico Environment Department (NMED) began negotiating a Closure Plan in May 1988, which was approved conditionally in 1993.

In 1996, an expedited approach to closure of the CWL was proposed to accelerate risk reduction through source removal; mitigate groundwater impacts; and reduce the complexity, schedule, and cost of final closure. The expedited strategy at the CWL included two interrelated Voluntary Corrective Measures (VCMs): a Vapor Extraction (VE) VCM and a Landfill Excavation (LE) VCM. The two VCMs were successfully performed in series from 1997 through 2002 at a cost of approximately $25 million. The benefits of the expedited VCM approach are now being realized in terms of achieving final site closure. This paper summarizes the VCM results, the critical elements of implementing the VCM approach, and the benefits of this approach.

INTRODUCTION

The CWL is a 1.9-acre disposal site located in the southeastern corner of Technical Area-3 (TA-3) at SNL/NM (Figure 1 and Figure 2). From 1962 until 1981, the CWL was used for the disposal of chemical, radioactive, and solid waste generated by SNL/NM research activities. The CWL was used as a hazardous waste drum-storage facility from 1981 to 1989. From 1981 through 1985 only solid waste was disposed at the CWL; after 1985 all waste disposal was ended, and after 1989 the CWL was no longer used as a hazardous waste drum-storage facility.

Site History

Disposal of waste into unlined pits and trenches at the CWL began in 1962. Reportedly, separate pits were used for the disposal of acids, oxidizers, reducers, organics, reactives, bulk materials, metal, neutral compounds, and salts. Waste was to be separated by type and placed in the appropriate pits. However, based upon evidence including direct

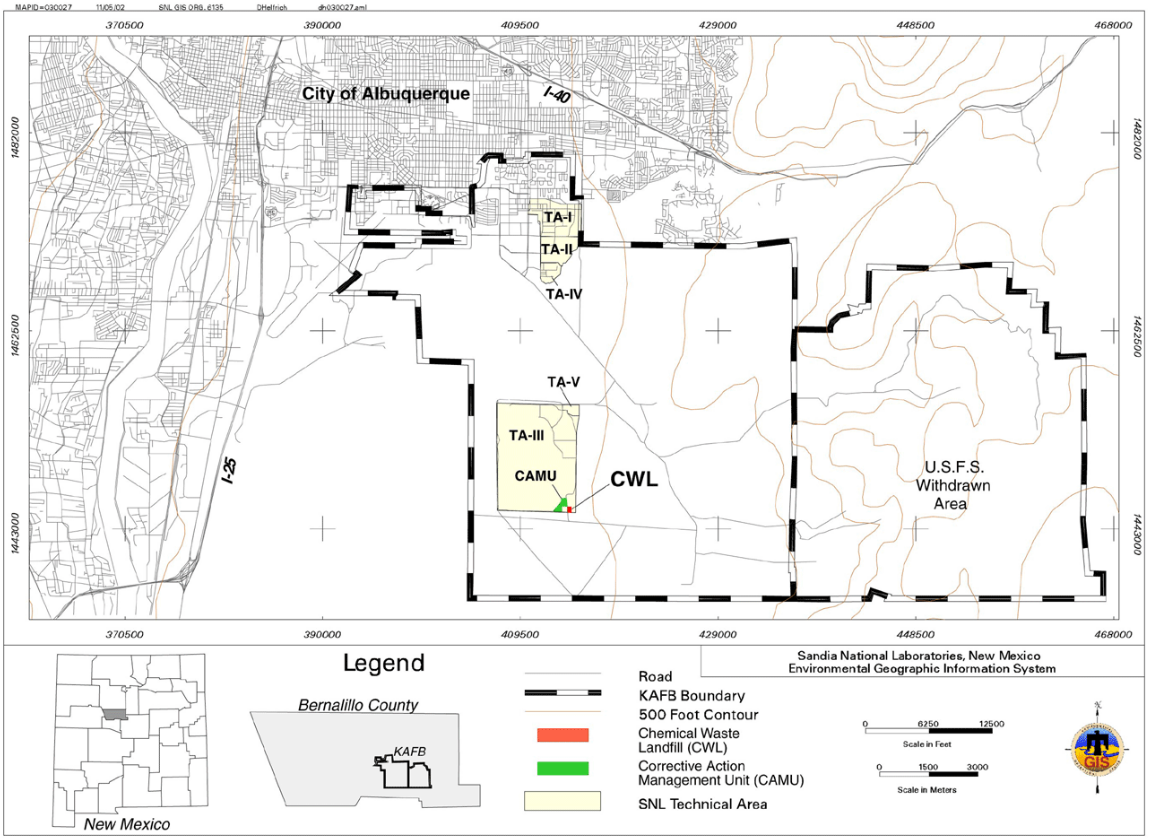

Fig. 1. Location of the Chemical Waste Landfill (CWL) with respect to Kirtland Air Force Base (KAFB) and the City of Albuquerque.

Fig. 2. Chemical Waste Landfill in 1992 (View to the Southeast).

observation during excavation of the CWL, it is apparent that this procedure was not always followed. In addition to pits and trenches, an unlined surface impoundment, approximately 23 by 6 feet in area by 7 feet deep, was used for disposal of chromic-acid waste from the early 1970s to 1978. Between 1979 and 1982, a lined surface impoundment, approximately 15 by 15 feet in area by 5 feet deep, was used to dispose liquid chromic-acid waste and ferric chloride.

During disposal operations, the original waste pits and trenches were excavated using a backhoe, forming pits from 8 to 12 feet deep by at least 2 feet wide. After a pit had been filled with waste, a new one was excavated and was given the same number as the original pit. The number assigned to each waste pit corresponded to a specific chemical type. Historically, markers were used for identifying pit locations. These markers were subsequently destroyed or buried during grading activities.

The rate at which the waste pits were filled varied depending on the type(s) of waste. Waste pits designated for organic contaminants were filled most quickly. When the pits had been filled to capacity, they were covered with fill material and allowed to settle over time. As the material settled, new fill material was added. Heavy-equipment traffic on the CWL surface, in addition to natural settling processes, resulted in compaction of the material.

In 1981 all liquid-waste disposal into unlined pits ceased, and in 1982 liquid waste disposal was discontinued in the lined chromic acid pit. Solid waste disposal ended in 1985. From 1981 to 1989, the CWL operated under RCRA interim status as a hazardous waste drum-storage facility with a 300-drum capacity. Waste operations at the CWL were discontinued completely in 1989, and all pits were covered with fill material.

History of the VCM Approach

In 1985, groundwater monitoring began at the CWL as required in 40 CFR Part 265 Subpart F. To implement the closure provisions contained in 40 CFR 265 Subpart G, the DOE, SNL/NM, and the NMED began negotiating a Closure Plan in May 1988. In 1990, TCE was identified in groundwater at a concentration exceeding the maximum contaminant level (MCL) of 5 parts per billion (ppb). This finding led to the development and incorporation of a corrective action program into the Closure Plan in October 1991, which also addressed the closure performance standards of Subpart G. In February 1993, the Closure Plan [1] was conditionally approved by the NMED. The Closure Plan is the regulatory document that details the approved closure process for the CWL.

In 1996, an expedited approach to the CWL Corrective Action program was proposed to accelerate risk reduction through source removal; mitigate groundwater impacts; and reduce the complexity, schedule, and cost of final closure. The following key factors that led to development of the expedited approach are summarized below.

- TCE concentrations in groundwater continued to exceed the MCL.
- Additional site characterization completed in 1995 confirmed the source for TCE groundwater contamination was a VOC vapor plume.
- New cleanup initiatives were developed by the EPA (Area of Contamination policy [2] and Corrective Action Management Unit (CAMU) regulations [3]), making it feasible to manage and treat excavated hazardous wastes on site, significantly reducing the cost to excavate source terms at sites like the CWL.
- The DOE and SNL/NM Environmental Restoration (ER) Project were developing a programmatic strategy to more efficiently complete the ER Project, including reducing the closure schedule and the associated cost of the ER Project.

The expedited strategy for the CWL included two interrelated VCMs: VE and LE. The two VCMs were incorporated as Appendix S to the Closure Plan in May 1996 through a Class 1 Permit Modification request. The Class 1 Permit Modification was approved with conditions on March 1997.

Based upon the site characterization work performed between 1992 and 1995, a volatile organic compound (VOC) vapor plume migrating downward through the vadose zone was determined to be the source of the elevated levels of TCE in the groundwater [4]. The original waste in the landfill was the source for the VOC vapor plume. Therefore, the two VCMs were developed with the following objectives:

- Remove/control the VOC vapor plume to mitigate groundwater impacts such that TCE does not exceed the MCL,
- Waste/source removal to eliminate future groundwater impacts and reduce the risk posed by the site; and
- Reduce the complexity, schedule, and long-term cost of final site closure.

The VCM approach was selected over the more typical "RCRA characterization-Corrective Measures Study-Corrective Measure Implementation" approach for several reasons. Uncertainties associated with the waste inventory made traditional characterization techniques, such as drilling and soil sampling, potentially unsafe and inconclusive relative to adequately defining the nature and extent of contamination. Initial characterization studies were sufficient to determine the VOC vapor plume had already migrated from the shallow subsurface disposal area to groundwater approximately 500 feet below ground surface. However, it did not appear that characterization information alone would be sufficient to achieve an agreement with NMED regarding final site closure within the desired timeframe. To achieve this goal it was determined that a more aggressive corrective action strategy was necessary.

SUMMARY OF VE VCM RESULTS

The VCM strategy for the CWL, as described in Appendix S of the Closure Plan and summarized in the previous section, involved an initial active soil VE VCM. A passive soil VE phase was conducted concurrently with the LE VCM. Details on VE system pilot testing, design, and operation; VOC mass calculations and assumptions; and significant deviations from the original VE system construction and/or operational specifications are presented in the VE VCM Final Report [5].

Baseline soil gas samples collected prior to the start of the VE VCM identified 29 compounds, including: chlorinated hydrocarbons, aromatics, chlorinated aromatics, ketones, and Freon® compounds. Compounds detected most frequently and at the highest concentrations were TCA (14 parts per million vapor [ppmv]), Freon®-113 (28 ppmv), 1,1-dichloroethylene (11 ppmv), PCE (11 ppmv), toluene (21 ppmv), and TCE (130 ppmv). As indicated by Henry's Law and site groundwater monitoring results, gas phase TCE concentrations at this level can cause concentrations in the groundwater that exceed the MCL.

The VE VCM was designed to prevent further degradation of the groundwater and reverse groundwater contamination, if possible, through extraction of contaminated soil vapor from several specific depth intervals over the nominally 500-foot-thick vadose zone. Minimization of long-term, low-level exposure to VOCs entering the atmosphere was a secondary objective. The most important factor for success was the simultaneous treatment of defined depth horizons of the vadose zone and treatment over the area of the plume exhibiting the highest soil gas VOC concentrations. Injection of clean air into the deepest zone, over the water table, accelerated the cleanup process.

The VE VCM was guided by a series of five numerical performance objectives that were driven by the understanding that the relative level of risk posed by VOCs in soil vapor was directly proportional to how close any specific mass of VOC was to the groundwater surface or the ground surface. In the portion of the vadose zone immediately above the groundwater surface, the objective was to reduce detected soil gas VOC concentrations to low levels (i.e., less than 2 ppmv). Near the center of the vadose zone, at relatively large distances from the groundwater and atmosphere, the performance objective was higher (i.e., less than 100 ppmv). Detailed conceptual models of the unsaturated zone, the subdivided stratigraphic zones, and vacuum extraction well design were developed as part of the VE VCM Design Report [6].

On May 5, 1997, the first vacuum extraction wells were activated. The VE VCM operated in two stages: an active VE mode for a 13-month period (May 1997 to July 1998) followed by a passive VE phase (December 1998 to current). The active phase was designed to reduce the magnitude and extent of the VOC vapor plume in the vadose zone beneath the CWL and the surrounding vicinity. The active VE system design incorporated eleven extraction wells and two injection wells. System monitoring and performance assessment integrated real-time, semi-qualitative field screening using a calibrated organic vapor analyzer with periodic quantitative sampling using SUMMA® canisters and off-site analyses by EPA Method TO-14 [7]. Operation of the active VE system was ended due to the successful remediation of the VOC vapor plume, and to allow the startup of the LE VCM.

The passive VE phase was conducted concurrently with the LE VCM by initially converting ten of the thirteen active VE wells to passive venting wells by installing BaroBalls in December 1998. The BaroBalls act as low-pressure relief valves (1 millibar), allowing soil vapor containing VOCs to vent to the atmosphere during periods of low barometric pressure. The ten wells initially converted to passive VE wells. The current passive VE well network includes six wells.

During the VE VCM design phase, approximately 7,700 pounds (lbs) of VOCs were estimated to have been distributed in soil pore space or on pore water and soil surfaces prior to the startup of the VE VCM [8]. Additionally, a partitioning interwell tracer test (PITT) performed in December 1995 indicated approximately 2,200 lbs of VOCs were present as NAPL in the southwest corner of the CWL, where relatively high concentrations of VOCs were observed in both soil and vapor samples to a depth of approximately 30 feet bgs. Thus, 9,900 lbs of VOCs were estimated to have been distributed on soil gas, pore water, and soil surfaces, or as NAPL prior to the VE VCM pilot testing and full-scale operation period.

During the active phase of the VE VCM, approximately 400,000,000 cubic feet (cf) of soil vapor were extracted and 44,000,000 cf of atmospheric air were injected. The hydraulic performance of the VE and air injection systems translated into the removal of approximately 6,500 lbs of VOCs from the subsurface. Additionally, approximately 500 lbs of VOCs were removed during prior VE pilot testing conducted in 1995 and 1996. Of the approximately 30 VOCs measured in the extracted vapors, TCE, acetone, toluene, Freon®-113, and methylene chloride constituted the bulk of the extracted VOCs.

An estimate of the VOC mass remaining in the unsaturated zone at the end of the VE VCM was calculated to be approximately 2,900 lbs [5].

Based upon a more detailed analysis of VE data and results from the southwest corner of the CWL where the PITT was conducted, it appears that all NAPL VOC mass was removed [5]. This was later confirmed during the LE VCM. The VOC vapor plume extent in the vadose zone and the impact of the VE VCM is shown schematically in the vertical profiles included in Figure 3. This representation graphically shows the reduction in the concentrations and overall subsurface extent of the VOC plume before, during, and after the completion of the VE VCM.

VE VCM Conclusions

The results of the VE VCM demonstrate that the objectives of removal and control of the VOC vapor plume were accomplished. Within six months after the start of the VE VCM, groundwater TCE concentrations, as measured through quarterly groundwater sampling, decreased below the MCL of 5 ppb. No TCE concentrations exceeding the MCL have been detected during routine groundwater monitoring since that time (5 years of semi-annual monitoring data), except in one monitor well with documented integrity issues. Testing is ongoing to determine if the results from this particular monitor well are indicative of actual groundwater contamination, or if they are a result of construction problems with this well. TCE has not been detected in most groundwater samples.

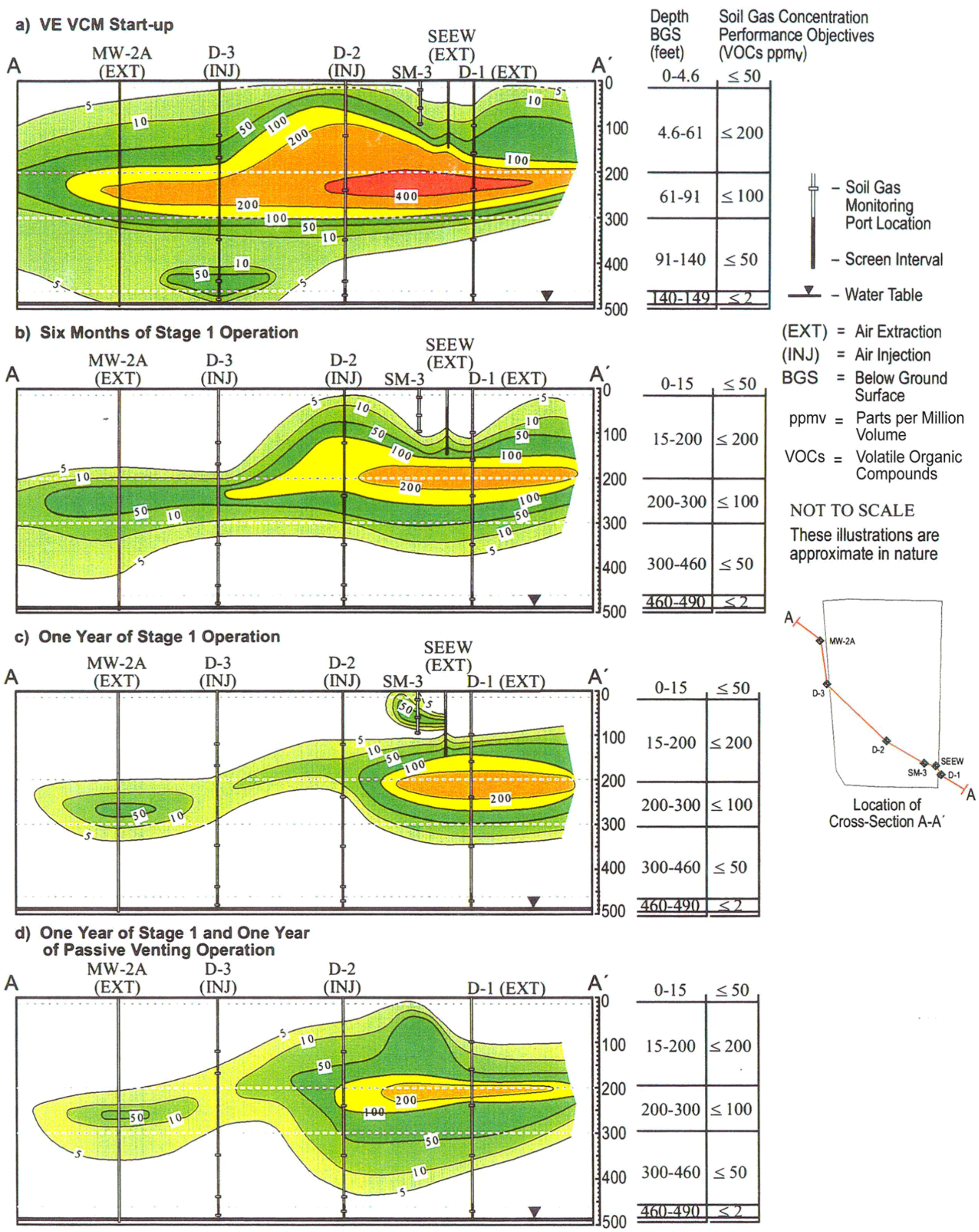

Fig. 3. Vertical profiles of total VOC concentration distribution along Alignment A-A', Chemical Waste Landfill, Sandia National Laboratories/New Mexico.

On August 13 and 14, 2001, soil vapor sampling was conducted at all passive system soil gas sampling ports. The results of the sampling showed that VOC concentrations did not appear to have changed significantly since completion of the VE VCM in July 1998; and between the monitoring performed in June 1999 and August 2001. There is no evidence of a significant increase in VOC vapor concentrations based upon these results.

Based upon vapor and groundwater monitoring data collected since the end of the VE VCM in July 1998, it appears that the VOC vapor plume has been largely removed and controlled. This conclusion is also supported by limited transport modeling that did not include lateral dispersion or natural degradation of the VOC vapor plume [8].

SUMMARY OF LE VCM RESULTS

Following completion of the active VE VCM, excavation of the CWL was initiated under the LE VCM. Details of the LE VCM are presented in the LE VCM Final Report [9]. The primary objective of the LE VCM was to eliminate contaminant source areas associated with the waste contents of the CWL. To meet this objective, designated disposal areas, defined primarily based upon trenching and geophysical surveys, were excavated to a minimum of 12 feet bgs to remove all debris and highly contaminated soil. The delineation of disposal areas (North, East-Central, Southeast, and Southwest Areas) and areas where disposal did not occur (Non-Designated Area) within the CWL boundary are shown superimposed over the geophysical survey results in Figure 4. Additional excavation was performed to remove debris buried deeper than 12 feet bgs and to remove soil contaminated at levels that exceeded the CWL risk-based criteria [8] as approved by the NMED in October 2000. Trenching and sampling were performed in areas within the landfill that were not excavated to 12 feet bgs to confirm geophysical survey data that indicated no debris was buried in these areas.

The CWL was excavated from September 1998 through February 2002. Over 52,000 cy of contaminated soil and debris (including chemical containers) were removed, segregated, and managed for final disposal. Approximately 89 percent of the excavated soil was taken to the adjacent CAMU for final treatment and/or disposition. Approximately 11 percent of the excavated soil has been returned to the excavation as backfill material. Less than 1 percent of the total volume of excavated material, including debris, will be disposed at permitted off-site disposal facilities. Tables I and II provide summary information on the excavated soil and debris, respectively.

During the LE VCM, a risk-based approach was developed in consultation with the NMED that defined risk-based cleanup standards or criteria (SNL/NM August 2000). The risk-based approach was the most critical project change relative to achieving the

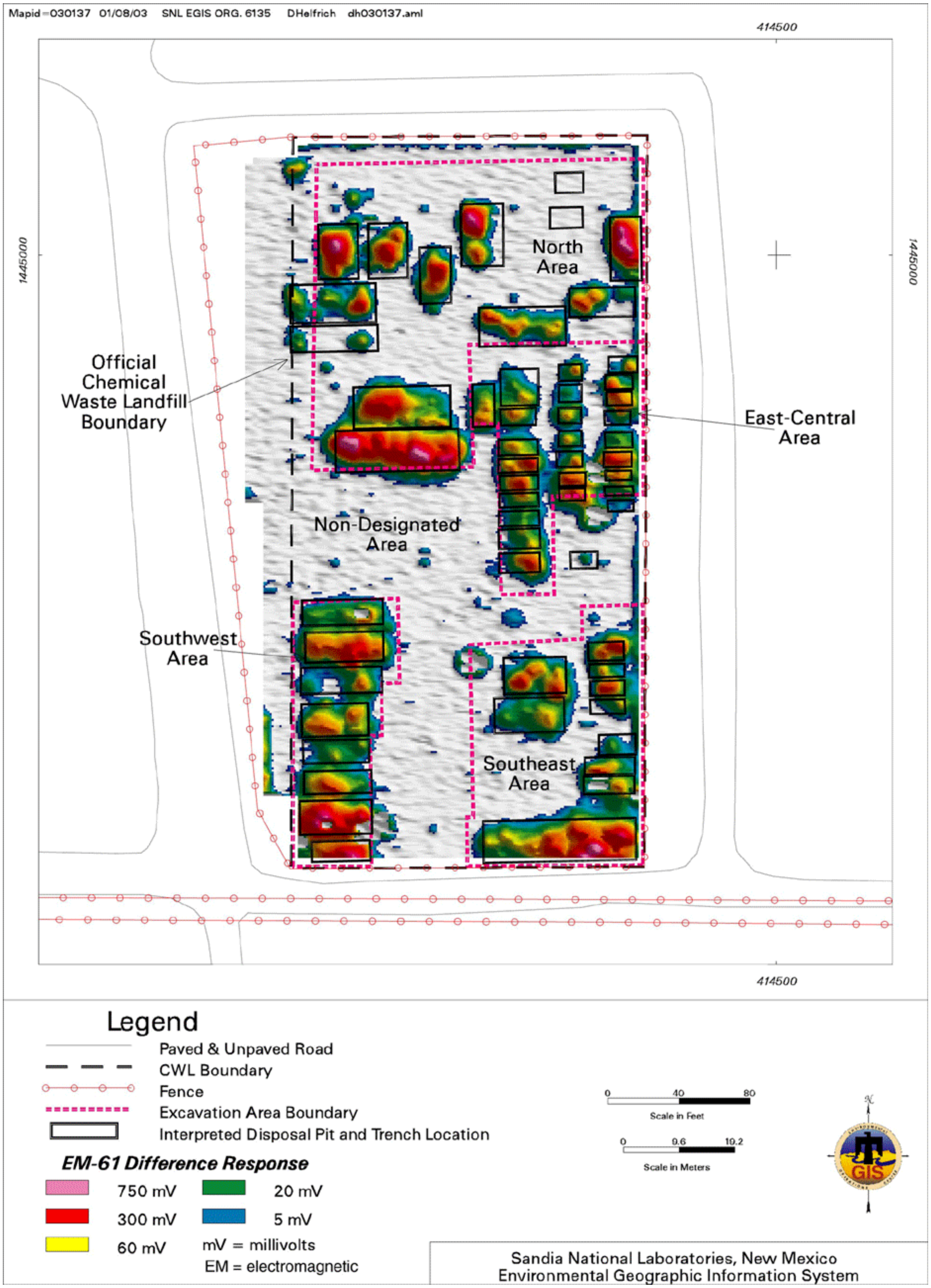

Fig. 4. Interpreted disposal locations based on 1998 geophysical survey, Chemical Waste Landfill.

Table I Summary of LE VCM Excavated Soil

<table>
<tr><td colspan="4">Excavated Soil Volumes by Area</td></tr>
<tr><td colspan="2" rowspan="8"></td><td>Volume (cy)</td><td>Excavation Area</td></tr>
<tr><td>6,655</td><td>East-Central Area</td></tr>
<tr><td>10,300</td><td>Southeast Area</td></tr>
<tr><td>10,265</td><td>Southwest Area</td></tr>
<tr><td>18,930</td><td>North Area</td></tr>
<tr><td>5,085</td><td>Non-Designated Area</td></tr>
<tr><td>865</td><td>Soil from Screening the Rock Pile (865 cy)</td></tr>
<tr><td>52,100</td><td>Grand Total – Excavated Soil</td></tr>
<tr><td></td><td>Final Disposition</td><td>Volume (cy)</td><td>Material Description</td></tr>
<tr><td rowspan="5">Soil Sent to the CAMU</td><td>CAMU[a]</td><td>2,780</td><td>Organic constituents at/above CAMU Treatment Levels</td></tr>
<tr><td>CAMU[a]</td><td>15,522</td><td>Metals at/above CAMU Treatment Levels</td></tr>
<tr><td>CAMU[a]</td><td>6,170</td><td>Metals and organic constituents at/above CAMU Treatment Levels</td></tr>
<tr><td>CAMU[a]</td><td>5,315</td><td>TSCA-regulated PCB soil (>50 mg/kg) with tritium levels below CAMU WAC</td></tr>
<tr><td>CAMU[a]</td><td>17,105</td><td>No-Treat Soil and Soil that Passed the Risk-Based Criteria</td></tr>
<tr><td colspan="2"></td><td>46,892</td><td>Total Volume of Soil Sent to CAMU</td></tr>
<tr><td rowspan="3">Soil Not Sent to the CAMU</td><td>Excavation</td><td>5,670</td><td>Passed Risk-Based Criteria as "Replaceable"</td></tr>
<tr><td>Off-site[b]</td><td>50</td><td>Does not meet the CAMU WAC, potential mixed waste</td></tr>
<tr><td>Off-site[b]</td><td>20</td><td>TSCA-regulated PCB soil with Tritium > CAMU WAC, potential mixed waste (also above CAMU Treatment Levels for metals)</td></tr>
<tr><td colspan="2"></td><td>5,740</td><td>Total Volume of Soil that did not go to the CAMU</td></tr>
<tr><td colspan="2"></td><td>52,632[c]</td><td>Grand Total – Excavated and Scraped Soil</td></tr>
</table>

[a]Analytical reports for all soil sent to the CAMU have been included in the CWL Quarterly Closure Reports.
[b]Final characterization and off-site disposal are ongoing. Off-site disposal will be documented in the Waste Management Addendum to this report.
[c]Estimate is biased slightly high due to rounding soil pile volumes for CAMU reporting. This total also includes 240 cy of scraped soil not included in the excavation area grand total. See Section 4.1.1 for a detailed explanation.

CAMU = Corrective Action Management Unit.
CWL = Chemical Waste Landfill.
cy = Cubic yard(s).
LE = Landfill Excavation.
mg/kg = Milligram(s) per kilogram.
PCB = Polychlorinated biphenyl.
TSCA = Toxic Substances Control Act.
VCM = Voluntary Corrective Measure.
WAC = Waste Acceptance Criteria.

Table II Summary of Excavated Debris
CWL LE VCM

Debris Type	Estimated Volume[a] (cy)	Comments
Soft Debris	120	Includes only excavated soft debris. Does not include project-generated soft debris (tarps, liners, PPE, etc.). All of this excavated debris has been shredded. Final characterization and off-site disposal are ongoing activities.
Metal	150	Includes 5 cy of nonferrous metal and 15 cy of ferrous metal with oily residue that is segregated from the other metal. Final characterization and off-site disposal are ongoing activities.
Wood	60	All excavated wood has been shredded except for 1 cy with oily residue. Final characterization and off-site disposal are ongoing activities.
Oversize Metal	40	Large items that may require sizing prior to disposal. Volume is approximate and will be revised after resizing debris. Final characterization and off-site disposal, as necessary, are ongoing activities.
Resins	60	50 cy were disposed of off site through the HWMF. Ten cy contain oily residue. Final characterization and off-site disposal are ongoing activities.
Rocks (> 2-inches)	1,250	All rocks have been placed on the floor of the excavation in the North, East-Central, and Southeast Areas prior to backfilling.
Concrete	35	All concrete was associated with well bollards and fence posts within or at the CWL boundary. All concrete has been placed in the Southeast Area of the excavation.
Specific Waste Forms (Not Included in Volume Estimate Totals)		
Intact chemical containers	~2,000 containers	Containers are 100 mL to partial 55-gallon drums. Final characterization and off-site disposal are ongoing activities.
Radioactive, Potential Mixed Waste, and NORM	300+ containers	Includes various containers (5 mL to 55 gallon) and debris types, including thorium slag, media contaminated with depleted uranium, potassium salts, etc. Final characterization and off-site disposal are ongoing activities.
Thermal batteries	1,050 items/batteries	Includes 360 breached batteries and parts plus 520 batteries already disposed of off site. One hundred seventy remain to be x-rayed as part of final characterization prior to off-site disposal.
Chemical batteries	2,740 pounds	Includes lead-acid, rechargeable nickel-cadmium, lithium, alkaline, mercury, and others. Batteries were recovered both in packs and separately, making an accurate item count very difficult. Final characterization and off-site disposal are ongoing activities.
Partially Expended Munitions Items	30	Includes items such as flash tubes and smoke grenades. All items disposed of by KAFB EOD.
Gas Cylinders	357	All gas cylinder contents have been treated on site and rendered inert. Empty cylinders are being treated as scrap metal.

[a]All volumes are estimates and numbers are rounded except for gas cylinders (see Section 4.1 for explanation).
CWL = Chemical Waste Landfill.
cy = Cubic yard(s).
EOD = Explosive Ordnance Disposal.
HWMF = Hazardous Waste Management Facility.
KAFB = Kirtland Air Force Base.
LE = Landfill Excavation.
mL = Milliliter(s).
NORM = Naturally occurring radioactive materials.
PPE = Personal protective equipment.
VCM = Voluntary Corrective Measure.

longer-term goal of CWL closure. The risk-based approach changed cleanup goals from background concentrations to risk-based criteria, consistent with the NMED-approved approach for other SNL/NM ER Project sites. Risk-based criteria were also developed to allow excavated soil to be returned to the excavation as fill (i.e., replaceable soil), based upon soil sample analytical results. The LE VCM "Risk-Based Approach for Excavation and Backfilling of the Chemical Waste Landfill" [8] presents the evaluation criteria for the excavation and fill material (including replaceable soil) analytical results, the verification soil sampling grid for the excavation (*in situ* excavation), and cleanup standards/criteria that were approved by the NMED for RCRA constituents [9], and by the EPA Region 6 for TSCA constituents [10]. A graded approach was used to develop cleanup standards for unexcavated *in situ* soils (excavation sidewalls and floor) and fill materials (replaceable soil and various local fill soil) based upon depth below grade. Risk criteria were defined separately for the 0- to 5-foot depths and for depths greater than 5 feet bgs. Transport modeling was performed for residual, adsorbed-to-soil phase contamination (*in situ* excavation and fill materials) and for the remaining VOC vapor plume in the deeper vadose zone to demonstrate that the resulting cleanup standards are protective of groundwater.

The risk-based approach established an approved 25-foot spaced verification sampling grid across the excavation floor, and judgmental sample locations in the excavation sidewalls. If residual contamination was suspected in an excavated area based upon excavation results, preverification samples were collected from the associated verification grid points for on-site laboratory/fast turnaround analysis. These preliminary results were screened against the risk-based criteria point by point to determine if additional excavation was required. As a result of this first screening step, several areas of the CWL were excavated more deeply (>12 feet bgs) and resampled to confirm removal of the constituents that exceeded risk levels. Final verification soil samples (off-site laboratory) were collected after this screening step, and these analytical results were later combined with replaceable soil and fill soil off-site analytical results in order to perform a cumulative site risk assessment for the CWL in the end-state condition (i.e. backfilled condition).

Similarly, excavated soil was initially stockpiled in 100-cy piles and sampled for on-site laboratory analysis (preliminary screening data) to determine if was appropriate for use as fill material. The results for each 100-cy soil pile sample were screened against the risk-based criteria to make this determination. Any 100-cy soil pile that passed this preliminary screening process could then be combined with other soil piles that passed risk screening into a maximum volume pile of 1,000 cubic yards. These larger piles were then sampled for off-site laboratory analysis (final verification data), and these final verification analytical results were included in the cumulative risk assessment along with the *in situ* excavation and fill material results.

The results of the cumulative risk assessment presented in the LE VCM Final Report [9] are summarized in Table III (shaded rows, text in italics) along with the risk-based criteria (unshaded rows, text bolded) for direct comparison. As shown in Table III, the maximum detected concentrations for total PCBs and lead were below their respective threshold values for the two specified subsurface depth ranges. The hazard index (HI) and excess cancer risk were also below the most restrictive guidance values (for the 0- to

5-foot depth range) for all combined data, regardless of depth (HI = 0.25 versus 1, and excess cancer risk = 8E-6 versus 1E-5). The calculated ecological risk was low and acceptable for a "No Further Action" decision.

Table IV presents the screening threshold activities developed for radiological constituents and the maximum activities measured from final verification samples. The screening threshold values for cobalt-60 and tritium were exceeded by only one sample in each case. For cobalt-60, the sample was collected from the excavation floor (southeast area) and was the only detection of cobalt-60 in all final verification samples (*in situ* excavation and fill soils). In the case of tritium, the only sample exceeding the threshold value was from a 100 cubic yard replaceable soil pile. Per the risk-based approach, SNL/NM requested NMED approval of these individual results because the overall cumulative risk criteria for radiological constituents were achieved (i.e. are well below the risk criteria).

In summary, the final cumulative risk assessment assumed an industrial land use scenario; used a conservative, reasonable maximum exposure (RME) approach; and addressed the cumulative risk from the *in situ* excavation, replaceable soil, and local fill soil off-site laboratory analytical results (excluding duplicates, 236 sample results included). Risk-based cleanup criteria were achieved (see Table III) even with the conservative assumption that the industrial worker receptor is directly exposed to all remaining residual soil contamination regardless of depth [9]. In addition, this final risk assessment also demonstrates that the CWL meets all applicable requirements for unrestricted radiological release.

LE VCM Conclusions

The results of the excavation, final verification soil sampling, and the final risk assessment demonstrate that the LE VCM has achieved the objective of removing all buried waste material and highly contaminated soil from the former disposal areas at the 1.9 acre CWL. This removal eliminated remaining sources for VOC vapors.

The cumulative risk assessment demonstrates that the CWL meets the NMED- and EPA-approved cleanup criteria, which are protective of human health and the environment, and are based on the final verification analytical data set that is representative of the end-state condition of the CWL. Based upon the transport modeling performed as part of the development of the risk-based approach, the remaining residual soil contamination and the remaining, largely reduced VOC vapor plume will not adversely impact the groundwater.

Table III Screening Thresholds and Maximum Concentration/Risk Results for Nonradiological Constituents of Concern for the *In Situ* Excavation, Replaceable Soil and Fill Soil

	Requirements and Results for 0 to 5 ft bgs		Requirements and Results for >5 ft bgs	
	Fill Soil[a] 0 to 5 ft bgs	Unexcavated *in situ* material left in place 0 to 5 ft bgs	Fill Soil[b] 5 ft bgs to extent of excavation (30 ft bgs)	Unexcavated *in situ* material left in place >5 ft bgs
PCBs Threshold Screening Value	<1 mg/kg	<1 mg/kg	<100 mg/kg	<100 mg/kg
LE VCM Final Risk Results – Maximum PCBs Results	*0.0118 mg/kg*	*0.94 mg/kg*	*8.735 mg/kg [replaceable soil]*	*11.45 J*
Lead Threshold Screening Value	<1,500 mg/kg	<1,500 mg/kg	<2,000 mg/kg	<2,000 mg/kg
LE VCM Final Risk Results – Maximum Lead Results	*183 mg/kg*	*101 mg/kg*	*192 mg/kg [replaceable soil]*	*162 mg/kg*
Sum of All Nonradiological COCs (Industrial Human Health)	HI: < 1 Excess Cancer Risk: < 1E-05[5]	HI: < 1 Excess Cancer Risk: < 1E-05[5]	HI: < 2 Excess Cancer Risk: < 1E-05[6]	HI: < 2 Excess Cancer Risk: < 1E-05[6]
LE VCM Final Risk Results	*HI = 0.25 Excess Cancer Risk = 8E-6 Cumulative risk calculated using all data from all depths (backfill, replaceable soil, and excavation)*		*HI = 0.25 Excess Cancer Risk = 8E-6 Cumulative risk calculated using all data from all depths (backfill, replaceable soil, and excavation)*	
Ecological Risk	Passes SNL/NM ecological risk	Passes SNL/NM ecological risk	Insignificant pathway	Insignificant pathway
LE VCM Final Risk Results	*Based upon final risk analysis, ecological risks associated with the CWL are expected to be low and acceptable for a "No Further Action" recommendation*		*No ecological risk requirements for soil deeper than 5 ft bgs*	

Note: This table adapted from Table 1 of the "Risk-Based Approach for Excavation and Backfilling of the Chemical Waste Landfill" [8].

[a]Does not include replaceable soil. No replaceable soil will be placed at a depth less than 5 feet bgs.

[b]Does include replaceable soil. All replaceable soil will be placed at a depth greater than 5 feet bgs.

bgs = Below ground surface.
COC = Constituent of concern.
CWL = Chemical Waste Landfill.
ft = Foot (feet).
HI = Hazard Index.
J = Estimated concentration.
LE VCM = Landfill Excavation Voluntary Corrective Measure.
mg/kg = Milligram(s) per kilogram.
PCB = Polychlorinated biphenyl.
SNL/NM = Sandia National Laboratories/New Mexico.

Table IV Screening Threshold Activities and Maximum Sample Activities for Radiological Constituents of Concern for the *In Situ* Excavation, Replaceable Soil, and Fill Soil

Radionuclide	Screening Threshold Activities Above Background	Resulting dose rate, Industrial Land-use	Maximum Activities from All Excavation and Fill Samples[a]
Cobalt-60	0.215 pCi/g	0.6 mrem/y	***0.46 pCi/g***
Cesium-137	0.973 pCi/g	0.6 mrem/y	*0.534 pCi/g*
Thorium-232	5.85 pCi/g	0.6 mrem/y	*2.3 pCi/g*
Uranium-235	4.19 pCi/g	0.6 mrem/y	*0.454 pCi/g*
Uranium-238	21.6 pCi/g	0.6 mrem/y	*3.26 pCi/g*
Tritium (H-3)	150,000 pCi/L or 7.5 pCi/g	1.4E-4 mrem/y	***198,000 pCi/L or 9.9 pCi/g***

Note: This table adapted from Table 2 of the "Risk-Based Approach for Excavation and Backfilling of the Chemical Waste Landfill" [8].
[a] Bolded values exceed their respective screening threshold and are explained in the text.
mrem/y = Millirem per year.
pCi/g = Picocurie(s) per gram.
pCi/L = Picocurie(s) per liter.

CONCLUSIONS

The benefits of the expedited approach based upon the results of the VCMs are now being realized in terms of achieving closure by the overall SNL/NM ER Project goal of 2006. The VCM approach implemented for the CWL had significant programmatic risks, with potential impacts of both time (closure schedule) and cost. The primary risk involved the fact that the VCMs were not approved as final corrective measures by the regulators prior to implementation, which translates into uncertainty regarding NMED requirements for closure after completion of the VCMs. The VCM approach made sense for the CWL because it was determined that corrective measures would be required, and the type of corrective measures were clear.

The main advantage of the VCM approach is the schedule and cost savings associated with not going through the much longer, formal CMS process to obtain approval of the two VCMs by the NMED prior to implementation. Several strategic elements that were key to the VCM success at the CWL are discussed below.

Teaming with Regulators

The primary risk involved with a VCM approach is that the corrective measure(s) are not formally approved through the standard regulatory process prior to implementation. However, by establishing a positive working relationship with the lead regulatory agency (the NMED) based upon the common goal of site closure, this risk was minimized and controlled to a reasonable extent. A critical element to establishing this successful working relationship at the project level was obtaining a commitment at the management level of both the SNL/NM ER Project and the NMED Hazardous Waste Bureau. Regular monthly meetings were held between SNL/NM CWL personnel and NMED regulators to address project challenges and their solutions as they were identified. An interim change notice (ICN) process was followed to document significant changes to the VCM project work plans as the changes were implemented, ensuring adequate documentation in the project administrative record. As an example, during the excavation phase of the LE VCM (late 1997 to early 2002), four ICNs were approved for the LE VCM Sampling and Analysis Plan, and two ICNs were approved for the Waste Management Plan documenting critical changes to the project that were necessary to address real site conditions and challenges as they were encountered. In addition, a risk-based approach to defining an end-point to excavation, along with criteria for allowing excavated soil to be used as backfill, was negotiated with and approved by the NMED in August 2000. Without this teaming mechanism for rapid decision-making and issue resolution, the LE VCM would not have been successful and long operational delays would have substantially increased the already high cost of the project.

Combined Submittal of Final Closure Plan Deliverables

In February 2003 after a significant NMED-SNL/NM team effort, a Closure Plan modification was submitted to the NMED that integrated the VCM results and significantly streamlined the final closure process. This was accomplished by working directly with NMED staff on the modification, which allowed the combined submittal of the Closure Plan-required Corrective Measure Study (CMS) Report, the Remedial Action Proposal (RAP), and the Post-Closure Care Plan and Permit Application (PCCP) as one Class 3 permit modification. On May 15, 2003 this modification was conditionally approved by the NMED, and on May 21, 2003 these three deliverables were submitted to the NMED, laying the groundwork for final closure and post-closure care.

Although the NMED will conduct their review of this submittal in series, starting with the CMS Report, the cost and schedule savings of the combined submittal is substantial. In time alone this will reduce the closure schedule by well over a year versus the standard approach of submitting each document in series after resolution of regulatory and public comments for the preceding deliverable. The impact of the VCMs on these key closure submittals is summarized in Table V.

Table V VCM Impact on Final Closure Plan-Required Deliverables for the CWL

Regulatory Deliverable	Impact of VCMs
CMS Report	The evaluation of potential final corrective measures was greatly simplified by the successful VCMs and associated risk-based approach. Only final cover designs were evaluated since the excavation meets previously negotiated NMED-approved risk-based cleanup standards.
RAP	This Closure Plan required deliverable presents a detailed conceptual final cover design based upon the CMS Report conclusions, including specific information requested by the NMED in a "pre-submittal" technical meeting.
PCCP	Post-closure care requirements presented in this document have been simplified for groundwater monitoring and cover maintenance (including surface water control features) based upon the successful results of the VCMs.

Current Status

The NMED is currently reviewing the CMS Report and comments are expected before the end of November 2003. Following resolution of these comments and the 30-day public comment period, the final cover design presented in the RAP will be reviewed by the NMED. Following resolution of the comments related to the RAP, SNL/NM will install the final CWL cover and the NMED will complete its review of the PCCP. After resolution of the PCCP comments and completion of the final cover construction, the CWL will enter the post-closure care period and site closure will be achieved.

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FOOTNOTE

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.