

APPENDIX B

**RVO REPORT: HEX PIT REMEDIATION PROJECT: IN-SITU THERMAL DESORPTION (ISTD)
REMEDY FAILURE ASSESSMENT REPORT 2002**

**Hex Pit Remediation Project
In-Situ Thermal Desorption (ISTD) Remedy
Failure Assessment Report
2002**

This Failure Assessment Report was prepared by the Remediation Venture Office (RVO). This failure assessment summarizes information in documents in the Administrative Record, which present the hex pit history, technology selection, remedial design, treatability study, field implementation, and subsequent failure of the In-Situ Thermal Desorption (ISTD) remedy.

Record of Decision (ROD) Remedy Description

The ROD for Rocky Mountain Arsenal (RMA) identifies the remedy for the Hex Pit site as, “Treatment of approximately 1,000 bank cubic yards (bcy) of principal threat material using an innovative thermal technology. The remaining 2,300 bcy are excavated and disposed in the on-post hazardous waste landfill. Remediation activities are conducted using vapor- and odor-suppression measures as required. Treatability testing will be performed during remedial design to verify the effectiveness of the innovative thermal process and establish operating parameters for the design of the full-scale operation. The innovative thermal technology must meet the treatability study technology evaluation criteria described in the dispute resolution agreement (PMRMA 1996). Solidification/stabilization will become the selected remedy if all evaluation criteria for the innovative thermal technology are not met. Treatability testing for solidification will be performed to verify the effectiveness of the solidification process and determine appropriate solidification/stabilization agents. Treatability testing and technology evaluation will be conducted in accordance with EPA guidance (OSWER-EPA 1989a) and EPA’s “Guide for Conducting Treatability Studies under CERCLA” (1992).”

Technology Choice

The Innovative Thermal Technology Evaluation Report for the Hex Pit Site at RMA, prepared by the Colorado Department of Public Health and the Environment (CDPHE), Tri-County Health Department (TCHD), and the United States Environmental Protection Agency (EPA), was finalized on September 10, 1998. (HPWG 1998) This report documented the comparative analyses and evaluation process that lead to the final selection of ISTD as the most technically appropriate technology for this site. Of the 12 innovative thermal technologies investigated, ISTD was chosen to be the most technically appropriate using characteristics of effectiveness, implementability, and cost. At the time of selection of this technology, no full-scale ISTD operations had been conducted on sludge or buried drums. However, bench-scale tests indicated the operation was likely to be successful for both. (ENSR 2000)

Site History

The Hex Pit site covers approximately 205 square yards and is located in Section 1 of the RMA near the north boundary of the South Plants Central Processing Area (SPCPA). The Hex Pit was used between 1950 and 1952 to dispose of residual materials (tar-like, chlorinated organic, resinous material called Hex bottoms or Hex residue) resulting from the production of hexachlorocyclopentadiene (Hex, also known as HCCPD and CL6CP). The material was buried in drums and in bulk and the pit was covered with several feet of soil. During site investigation work, it was clearly demonstrated that the site contained not only contaminated soil but also lenses of pure waste. Concentrations of HCCPD obtained through sampling ranged up to 160,000 parts per million (ppm). The primary contaminant of concern at the site is HCCPD. However, other organic pesticide and dioxin contamination is present at the site as well. HCCPD characteristics include a relatively

high boiling point and the tendency to corrode iron and other metals. It is a semi-volatile organic compound with a strong tendency to adsorb onto organic matter. It has low water solubility and a high organic partitioning coefficient, which indicates a relatively immobile contaminant. Immobility of the waste pit material was demonstrated through synthetic precipitation leaching procedure (SPLP) testing performed July 2002, after system failure. (RVO 2002)

ISTD Technology Description

ISTD is an in-situ remediation process involving the application of heat and a vacuum simultaneously to subsurface contaminated soils. Heat and vacuum are applied to the subsurface through the use of heater and heater vacuum wells. As heat is applied and soil temperatures rise, the vaporized contaminated fluids are collected by the vacuum system and drawn into an off-gas treatment system. Destruction of contamination is most effective once heater wells have reached higher temperatures (>250 C). At the start of heating, higher amounts of water vapor, carbon dioxide, and hydrochloric acid (HCl) are present. As configured for the Hex Pit remediation, the vacuum system delivers the vapors to a mobile off gas treatment unit consisting of six major components: cyclone separator, flameless thermal oxidizer (FTO), heat exchanger, two acid gas scrubber beds, two carbon adsorber beds, and main process blower. The system also contained a knockout pot for collection of HCl. The knockout pot was located between the heat exchanger and the acid gas scrubber beds.

Treatability Study Report (TSR), Feb 2000

A Treatability Study (TS) was performed in late 1999 with its report completed February 2000. (ENSR 2000) Some of the conclusions reached by the TS were:

- HCl vapor and sulfur dioxide (SO₂) gas were produced from the thermal oxidation and/or pyrolysis of the site contaminants of concern (COCs), and may require treatment during full-scale remediation.
- PCDD/F congeners (dioxins) were detected in the Master and Waste Composite samples and in the post-treatment samples
- Analytical PCDD/F results for the Waste Composite test sample could not be quantitated due to their high concentration
- Steam distillation and volatilization were not significant removal mechanisms of the site COCs

System Failure

Construction of the ISTD system started in October 2001, and field implementation of the process began in March 2002. As the soil and waste became heated, the contaminants were being destroyed as planned, releasing the chlorine present in the waste. When mixed with heated water from the surrounding soil, HCl vapor was formed.

The sequence of events leading to system shutdown are:

- On the morning of Thursday 3/14/02, one of the 1.5-inch by 6-inch long flanged nipples that were welded to the 4 inch manifold piping on the western most vacuum pipe spool appeared to be leaning over. The manifold tap was connected to well HVGG18. Inspection determined the welded joint between the 1.5 inch flanged tap and the 4 inch manifold pipe had failed. The reason for the failure (faulty weld or corrosion) could not be readily determined with the insulation in place. During the overnight shift on Thursday 3/14/02 PM - Friday 3/15/02 AM, a second flanged nipple, this one connected to well HVKK18, was observed to be leaning over, and, upon inspection, appeared to be in a similar condition.
- During the overnight shift on Thursday 3/14/02 PM - Friday 3/15/02 AM, the RTV caulk between the well and the steel plate was apparently pulled apart while the ISTD operator was walking in the vicinity of well HVGG18. As a result, steam began escaping from the torn RTV seal. It should be noted that due to the thermal expansion the ISTD thermal wells undergo upon

heating, the RTV seals would need to be regularly checked and re-applied as necessary throughout the project. The appearance of vapor was disconcerting and an indication of low vacuum in the well field.

- On the afternoon of Friday, 3/15/02, it was discovered there was no amperage to heater circuit CB7 and that CB7 in DP2 was in the tripped position. Since there appeared to be a problem with the heaters in one of the heater-vacuum well circuits, TerraTherm decided to shut down all of the currently operating well heaters.
- The electricians determined the location of the failed heater element in the heater vacuum well. The NEMA housing was removed revealing that acidic material had collected in the housing. Several unsuccessful attempts (in Level B) were made to remove the heater element and/or the heater can (3 inch Stainless Steel pipe) housing the heater element. Apparently, when the heater element shorted, it arced sufficiently to weld the heater can to the Stainless Steel vacuum well casing that surrounds it. The determined cause for failure of the heater element was extensive acid corrosion.
- TerraTherm donned Level B personal protective equipment (PPE) and went into the well field Saturday, 03/16/02. The flanged nipples were easily removed as only the RTV caulk was holding them in place. It was clear failure occurred because of acidic corrosion from the HCl produced by the system. Approximately 2 inches of the pipe was completely corroded and the rest was very thin or perforated. The apparent cause was rapid cooling and condensation of the hot HCl vapors emerging from the heater vacuum wells after hitting the exposed metal flange and nipple. Liquid HCl is many times more corrosive than the hot vapor phase gas.
- The in-line insertion heater in the same manifold pipe as the two failed nipples, shorted against the thermocouple wire. The pipe housing the insertion heater was pressure tested and held meaning it had not also been compromised to the point of failure yet by the acid in the manifold. The failure of this heater and thermocouple precipitated the first of the two FTO shutdowns. The FTO shut down twice over the weekend.
- The knockout pot sight glass was discovered to be slowly leaking. Upon investigation, approximately 200 gallons of nearly 0 pH HCl were discovered in the tank.
- In the process of removing the HCl from the knockout pot and rinsing the tank, excessive water was drawn by vacuum into the first acid gas scrubber bed. The acid gas scrubber bed was flooded, effectively making it impermeable. When this occurred, there was such vacuum loss through the tank that the flow out of the well field dramatically dropped and caused the second FTO shutdown. As much weakly acidic liquid as possible was pumped from the acid gas scrubber bed. The ambient airflow through the heat exchanger was dropped to raise the exhaust temperature in hopes of drying the acid gas scrubber bed. In the meantime most of the airflow was diverted through the carbon absorber beds. This resulted in a fire in the first carbon adsorber bed. The entire system had to be shut down.
- Upon further inspection of various wellfield components it was determined that most of the system had some degree of damage due to corrosive HCl.
- As part of the ISTD subcontractor assessment, 23 samples of liquid and solid residues were collected from various locations throughout the wellfield and off-gas treatment system. The pH of all samples was acidic and Hex was the most commonly detected and most concentrated organochlorine pesticides in the solid samples. The maximum concentration detected was 148,000 ug/g (comparable to maximum level identified in previous studies). Chloride was the most common anion detected with a maximum value of 237,000 ug/g in solids and a maximum of 284,000 mg/L in liquid samples.

The corrosion resulted in failure of some of the ISTD process equipment and forced a shutdown of the entire system. The ISTD design anticipated that the HCl formed would be largely neutralized by the higher pH of the surrounding soil; however, this did not occur. Assessment of the system

indicated that the corrosion rate of the HCl for the system materials was greater than anticipated resulting in the failure. Large volumes of highly concentrated HCl vapor were drawn into the vacuum wells, piping, and process equipment. This vapor, as it condensed, began to corrode the piping, wells and other process equipment. The first corrosion failures detected were in uninsulated areas of the well field.

The ISTD subcontractor identified extremely cold weather as a contributing factor to failure due to greater than anticipated heat losses in uninsulated piping. These conditions should have been foreseen, and the uninsulated piping design probably was a contributing factor to failure, since during the design of the project, the remediation system was always scheduled to occur during the winter months to avoid high groundwater and high summer electrical demand.

There was speculation if the majority of clogging in the vapor tees and hoses occurred prior to or after the heaters were shut down. There were several documented occurrences when vacuum loss occurred prior to heater shutdown. The increasingly difficult to achieve vacuum on the well field prior to shutdown indicates that clogging was occurring during heating. Clogging may have been exacerbated once heaters were shut down due to continued condensation caused by cooling.

There was also speculation if corrosion occurred primarily before or after shutdown of the heaters. It would seem obvious that corrosion occurred before shutdown due to the fact that the heaters were shut off after corrosion had already caused two different pieces of aboveground wellfield equipment to fail. At that point, with further investigation, the corrosion was discovered to be widespread. No definitive conclusion can be made as to whether most of the corrosion occurred pre- or post-shutdown.

Another concern was if there were any potential impacts from horizontal well installation to the heater well field. During well installation, drilling mud frac out (loss of drilling muds or fluids) occurred twice within the Hex Pit boundary. The ISTD subcontractor suggested there was potential that the frac out events may have caused hex to be forced into the heater wells, changing the underground conditions. This seems unlikely given the volume of drilling mud calculated to have been lost during the frac out events was minimal (800 gallons or less). The total estimated quantity of soil moisture in the Hex Pit is greater than 170,000 gallons, so suggesting that the addition of up to 800 gallons of frac-out liquid could move Hex contamination around or could increase the rate or quantity of HCl formed during heating seems unlikely. It is also unlikely that the very low pressure (8 psi) used to install the horizontal wells would have been sufficient to move a much higher density and viscous (tar-like) material such as hex. It was noted during the follow-up remediation that upon completion of the excavation to elevation 5250.0 (approximately 8 feet above the horizontal wells) there was no evidence of drilling mud frac out on the excavation surface.

The ISTD technology has changed hands throughout the process of technology selection, design, and implementation. Although the company names have changed over this period of time, the same initially identified experts have remained. Concerns as to HCl generation during the treatment process were expressed to the ISTD experts as early as the Draft sampling and analysis plan for the technology selection in 1999. Per the experts' advice, samples were analyzed for chlorine, chlorinated COCs, and total chlorine in the airstream from the technology selection. This information was to be used by the ISTD subcontractor to design the system to account for HCl generation during treatment. The 100% design (Section 5.3, 5.4, Appendix A) included requirements for robustness of materials to withstand extreme temperatures and a corrosive atmosphere of HCl. Of potential impact to robustness was the decision by the ISTD designer to replace the previously used wells with Gen 2 Heater well designs. The original well design called for the use of expensive materials. The designer

never metallurgically tested materials in order to select correct materials for the system in this environment.

Again, Section 6.1.2 of the design states that highly chlorinated vapors will be present in the subsurface during heating. (TerraTherm 2001) The design concluded that the corrosive environment necessitated the use of heater cans to protect the heater elements. In the field, the heater cans proved ineffective against the environment and in protecting the heater elements. Throughout the design, a highly corrosive atmosphere is acknowledged by the ISTD designer, yet the material specified for the equipment is consistently stainless steel (304L). This type of stainless steel is generally the least expensive and the least acid corrosion resistant stainless steel available.

In RVO's evaluation, the primary causes of failure of this system were due to an underestimation of volume of HCl generation during remediation, an inappropriate equipment material choice for the site conditions, and an overestimation of buffering capacity of surrounding soils. There were also contributing factors to the failure such as uninsulated piping where cold temperatures caused condensation of HCl vapor, and shutdown of the off gas treatment system exacerbating condensation.

REFERENCES

ENSR (ENSR Corporation)

2000 (Feb.) *Hex Pit Treatability Study Report (TSR), Part A – Treatability Test Results, Part B – Conceptual Design and Cost Estimate.*

HPWG (The Hex Pit Working Group)

1998 (Sept.) *Innovative Technology Evaluation Report for the Hex Pit Site at Rocky Mountain Arsenal.*

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