Raytheon Company

Phase IV Remedy Implementation Plan Addendum

Former Raytheon Facility 430 Boston Post Road Wayland, Massachusetts

Tier IB Permit No. 133939

28 April 2004

13606.02

Environmental Resources Management
399 Boylston Street, 6th Floor
Boston, Massachusetts 02116

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John C. Drobinski, P.G., LSP
Principal-in-Charge

R. Joseph Fiacco, P.G.
Project Manager

Environmental Resources Management
399 Boylston Street, 6th Floor
Boston, Massachusetts 02116

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1.0 *INTRODUCTION*

1.1 *BACKGROUND*

On behalf of Raytheon Company (Raytheon), Environmental Resources Management (ERM) has prepared this Remedy Implementation Plan (RIP) Addendum for portions of an approximately 83-acre property located at 430 Boston Post Road in Wayland, Massachusetts (Figures 1 and 2). For purposes of this document, the Site is defined as the portion of the Former Raytheon Property covered under Release Tracking Number (RTN) 3-13302 and Tier IB Permit Number 133939.

The Phase IV is the fourth part of a five-phase process required under the Massachusetts Contingency Plan (MCP, 310 CMR 40.0000) for assessment and remediation of a release(s) of oil and/or hazardous materials (OHM) to the environment. ERM submitted a Phase IV RIP to the Department of Environmental Protection (Department) on 30 December 2002 presenting conceptual remedial designs for abatement of OHM impacts to Site wetland soil/sediment and groundwater that pose a potential risk to human health and the environment, as identified in the Phase II–Comprehensive Site Assessment (Phase II; ERM, 2001a). The technologies utilized as part of Phase IV are those selected in the Phase III–Remedial Action Plan (Phase III; ERM, 2001b).

Subsequent to submission of the Phase IV RIP (ERM, 2002), ERM developed a Revised Application for Risk-Based Disposal Approval document, dated 31 July 2003, that was submitted to the United States Environmental Protection Agency (EPA). This document provided additional information regarding cleanup of wetland soil/sediment at the Site. Wetland soil/sediment restoration activities are currently ongoing and will not be discussed in this document.

This Phase IV RIP Addendum is intended to provide additional information regarding proposed groundwater remediation activities at the Site. Pursuant to 310 CMR 40.0874, this document presents the engineering concepts and design criteria that will be used to design and construct the Comprehensive Remedial Action for Site groundwater. Following construction and implementation of the remedy, an As-Built Construction Report, Final Inspection Report and Phase IV Completion Statement will be prepared to fulfill remaining Phase IV requirements, as appropriate.

Department transmittal form BWSC-108 and public notification documentation are included in Appendix A.

1.2 *PURPOSE & SCOPE*

The purpose of this Phase IV RIP Addendum is to provide updated Site data and groundwater remedial design information to support implementation of the Comprehensive Remedial Action. This document is intended to supplement information provided in the Phase IV RIP (ERM, 2002) and therefore, is not intended to satisfy all requirements for a Phase IV RIP.

1.3 *REPORT ORGANIZATION*

The report is organized to satisfy the requirements of the MCP (310 CMR 40.0874). The report contains the following sections:

Section 1.0 *Introduction*- describes the background, purpose and scope of the RIP Addendum.

Section 2.0 *Site Information*- includes a summary of new information obtained since submission of the Phase IV RIP, and an updated list of relevant Site contacts.

Section 3.0 *Design Basis*- includes the identification of target cleanup levels and areas of OHM impacted groundwater that requires abatement to achieve remedial goals.

Section 4.0 *Remedial Design* – includes the engineering design, and construction plans and specifications for groundwater remediation.

Section 5.0 *Implementation Schedule*- includes a proposed schedule to implement the Comprehensive Remedial Action.

Section 6.0 *References*

2.0 *NEW SITE INFORMATION*

2.1 *BACKGROUND*

Since completion of the Phase IV RIP (ERM, 2002), additional pre-remedial Site characterization and monitoring activities have been conducted, including:

- in-situ chemical oxidation (ISCO) pilot studies conducted as a Release Abatement Measure (RAM);
- three quarterly groundwater gauging rounds;
- two semi-annual groundwater monitoring rounds; and
- vertical profiling using the Modified Waterloo Profiler and monitoring well installation.

The ISCO pilot study activities conducted since submission of the Phase IV RIP (ERM, 2002) were documented in the following reports previously submitted to the Department:

- Release Abatement Measure Six-Month Status Report, dated 31 January 2003;
- Release Abatement Measure Six-Month Status Report, dated 31 July 2003; and
- Release Abatement Measure Completion Report, dated 17 December 2003.

In addition, two documents were submitted to the Department for ongoing response actions associated with RTN 3-22408, which pertain to separate release conditions on the Former Raytheon Property:

- Final Scope of Work, dated 13 June 2003; and
- Phase I Initial Site Assessment, dated 17 December 2003.

2.2 *ADDITIONAL SITE ASSESSMENT ACTIVITIES*

2.2.1 *Groundwater Gauging*

The purpose of this task was to collect the data necessary to evaluate the direction of groundwater flow and determine horizontal and vertical hydraulic gradients. ERM conducted groundwater gauging at accessible

Site wells on the following dates: 21 April, 28 July, and 29 September 2003. Table 1 details the results of the groundwater gauging. Table 2 presents the vertical gradients for well clusters at the Site. Figures 3, 4 and 5 are groundwater elevation contour maps for the April, July and September 2003 gauging rounds, respectively. Groundwater elevation data from the entire Former Raytheon Facility property were used to prepare the contour maps.

2.2.2 *Groundwater Quality Sampling*

The purpose of this task was to collect the data necessary to evaluate groundwater quality. Groundwater samples were collected using either low-flow or passive diffusion bag (PDB) sampling techniques. Geochemical field parameters, including temperature, conductivity, pH, dissolved-oxygen, and oxidation-reduction potential (ORP) were measured at the time of sample collection for wells sampled using low-flow techniques. Field parameters were not measured for wells sampled using PDBs. ERM conducted groundwater sampling at the Site on the following dates: 22 April to 1 May and 29 September to 3 October 2003.

Groundwater samples were collected and analyzed for volatile organic compounds (VOCs) using EPA Method 8260B or EPA Method 8021B. Tables 3 and 4 present groundwater field parameter and VOC data, respectively, from the April-May and September-October 2003 sampling events. Laboratory analytical reports are presented in Appendix B.

2.2.3 *Waterloo Profiling*

The purpose of this task was to further characterize the vertical distribution of VOCs within unconsolidated deposits in areas of the Site targeted for remediation and the previously inaccessible area beneath the main building on Site. A modified Waterloo Profiler was used to simultaneously collect continuous hydrogeologic data and depth-discrete groundwater samples in a single push. The groundwater samples were analyzed in using either a mobile field laboratory (i.e., by gas chromatography/mass spectrophotometry (GC/MS)) or a fixed laboratory to provide compound-specific VOC screening data.

The modified Waterloo Profiler was used to collect continuous relative hydraulic conductivity data, referred to as the index of hydraulic conductivity (I_k). The I_k data were generated during tool advancement by continuously injecting a small volume of deionized water into the formation through the sampling ports and monitoring variations in injection pressures. The I_k data were evaluated in real time to select groundwater sampling intervals. In general, groundwater samples were collected from higher conductivity zones and analyzed for Site-specific VOCs:

- tetrachloroethene (PCE),
- trichloroethene (TCE),
- cis-1,2-dichloroethene (cDCE),
- trans-1,2-dichloroethene (tDCE),
- vinyl chloride (VC),
- 1,1,1-trichloroethane (TCA),
- 1,1-dichloroethene (DCE),
- 1,1-dichloroethane (DCA) and
- methyl tert butyl ether (MTBE).

The following physico-chemical properties were also measured for each sample:

- pH,
- temperature,
- specific conductance,
- dissolved oxygen and
- ORP.

From 10 February to 9 April 2004, ERM collected a total of 151 groundwater samples for VOC analysis at 18 locations (Figure 2). VOC field screening data are presented in Table 5. Waterloo Profiler I_k data, field parameter data and field laboratory sheets are presented in Appendix C.

2.2.4 *Monitoring Well Installation*

The purpose of this task was to install monitoring wells at locations inside or adjacent to the main building to monitor groundwater concentrations. Boreholes were advanced using a direct-push drill rig as part of the vertical profiling program. Four monitoring wells were installed (Figure 2). Monitoring well construction logs are presented in Appendix C.

2.3 *RELEVANT CONTACTS*

The following table provides updated contact information for Site owners and those persons who will operate and/or maintain the selected remedial action alternative(s) during and following construction.

Name	Role	Contact Information
John Drobinkski	LSP of Record	ERM 399 Boylston St., 6th Floor Boston, MA 02116
Edwin Madera	Raytheon Representative Restoration Project Manager	Raytheon Company 528 Boston Post Road Mail Stop 1880 Sudbury, MA 01776

3.0 DESIGN BASIS

3.1 IMPACTED AREAS

Three chlorinated VOCs (PCE, TCE, and DCE) were detected in Site groundwater during 2003 at concentrations above applicable Method 1 GW-1 Cleanup Standards. MTBE was also detected at concentrations exceeding the applicable cleanup standard during 2003. However, MTBE is covered under a separate Release Tracking Number (RTN 3-22408). As shown in the following table, TCE is the primary contaminant-of-concern in groundwater at the Site. TCE concentrations for the April 2003 sampling event and Winter-Spring 2004 Waterloo Profiler program are shown in plan view on Figure 6.

VOCs Detected at Concentrations Exceeding Method 1 GW-1 Cleanup Standards During 2003

VOC	MCP Method 1 GW-1 Cleanup Standards	Number of Detections Above Method 1 GW-1 Standard*	Minimum Detected Concentration (ug/L)	Maximum Detected Concentration (ug/L)
PCE	5	8	0.50	17
TCE	5	93	0.53	790
DCE	7	2	0.57	8.4

Note:
* Total of 175 groundwater samples (including duplicates) were collected from existing monitoring wells and analyzed for VOCs during 2003. These data do not include Waterloo Profiler samples collected during 2004.

Since the Site is located within a DEP-approved Zone II Aquifer Protection Zone, VOCs in groundwater at concentrations above the Method 1 GW-1 Cleanup Standard pose a condition of "significant risk" to human health.

3.2 REMEDIAL GOALS

Since the Site is located within a current drinking water source area, Method 1 GW-1 Cleanup Standards (i.e., drinking water standards) are applicable. A reduction in VOC concentrations to Method 1 GW-1 standards would achieve a condition of "no significant" risk to human health under future conditions (i.e., groundwater is not currently used as a source of drinking water within the defined or projected extent of the plume).

The level and extent of TCE, PCE and DCE in groundwater is not anticipated to adversely impact down-gradient surface water quality or potential environmental receptors.

To achieve a Permanent Solution, Response Action Performance Standards (RAPS, 310 CMR 40.0191) also require consideration of abatement to background levels, if feasible. Department guidance indicates that "achievement" of background is considered "generically infeasible" for chlorinated hydrocarbons in groundwater, but indicates that a reduction in contaminant concentrations should "approach" background levels (i.e., one half the applicable cleanup standard), if feasible. Therefore, as a secondary target cleanup goal, abatement of TCE, PCE and DCE in groundwater will attempt to "approach" background levels, if feasible. The feasibility of abatement of VOCs in groundwater to these levels will be based on the success of remedial measures at reducing VOC concentrations in groundwater to Method 1 GW-1 standards.

4.0 *REMEDIAL DESIGN*

4.1 *OVERVIEW*

ISCO is a remedial technology that, through a series of chemical reactions, mineralizes contaminant mass into neutral by-products such as manganese dioxide (i.e., solid precipitate), water, chloride and carbon dioxide. A variety of chemical oxidants exist, including hydrogen peroxide, permanganate, persulfate and ozone, each of which can be used to destroy TCE and other contaminants-of-concern at the Site. These oxidants are strong and somewhat non-selective, which means that, in addition to chlorinated hydrocarbons, they can oxidize reduced soil and groundwater constituents. These other constituents referred to as the soil oxidant demand (SOD) potentially include natural organic carbon, such as humic and fulvic acids, and reduced minerals. As part of the pilot study conducted at the Site (ERM, 2003), the SOD was determined to range from 0.033 to 0.068 grams per kilogram (g/kg) of wet soil, which translates to a required range of 0.09 to 0.18 pounds of permanganate per cubic yard (yd^3) of soil (assuming a soil density of 100 pounds per cubic foot (ft^3) and 30% porosity). This SOD value is relatively low.

Permanganate was selected as the appropriate oxidant for the Site based upon the subsurface conditions, contaminants present (i.e., chlorinated ethenes), low SOD values, and pilot study results (ERM, 2003). In addition, there are fewer health and safety issues associated with the use of permanganate versus hydrogen peroxide or ozone, since vapors (VOCs or oxygen) are not generated using this oxidant.

Permanganate has an oxidation potential of 1.68 V, based on the following half reaction:

$$MnO_4^- + 4H^+ + 3e^- \rightarrow MnO_2 + 2H_2O$$

Unreacted permanganate imparts a purple or pink color to water, which makes it easy to detect in groundwater following application.

Successful implementation of ISCO is ultimately dependent on the effectiveness of delivering oxidant to the impacted groundwater. As part of the pilot study conducted at the Site (ERM, 2003), pressure injection was determined to be more effective than gravity feed injection in that it achieved a significantly greater radius of influence. Pressure injection resulted in an apparent radius of influence of approximately 20 feet.

Gravity feed injection resulted in an apparent radius of influence of approximately five to ten feet.

Based on results of the pilot study conducted at the Site (ERM, 2003), lower volume, higher concentration sodium permanganate injections were more effective than higher volume, lower concentration potassium permanganate injections. This approach minimized the potential for displacement of impacted groundwater from the treatment zone. Pilot study results indicated that TCE concentrations were reduced by approximately 90 percent (ERM, 2003).

4.2 *ISCO DESIGN AND IMPLEMENTATION*

Based on the distribution of TCE in groundwater at the Site (Figure 6), ERM has defined five ISCO treatment areas as shown on Figure 7. These treatment areas are focused areas where dissolved-phase TCE concentrations are highest. It is anticipated that the proposed remediation will reduce TCE concentrations in groundwater within and immediately downgradient of the treatment zones. Over time, this treated groundwater will migrate downgradient, resulting in abatement of a significantly larger area than that proposed for active treatment.

A groundwater-monitoring program will be implemented to evaluate the efficacy of the ISCO remediation program over time. Monitoring data will be reviewed and the need to conduct additional oxidant applications will be evaluated. If necessary, additional permanganate applications may be conducted. The following sections present details of the proposed ISCO remediation program.

4.2.1 *Establish Baseline Groundwater Data*

The purpose of this task is to establish baseline groundwater flow and groundwater quality within the treatment areas prior to permanganate injection. A groundwater gauging and monitoring round will be conducted prior to oxidant injection. The baseline monitoring program will consist of the following field measurements and laboratory analyses:

Baseline Monitoring Program

Analysis	*Method of Analysis*	*Rationale*
Groundwater Elevation	Field Probe	Evaluate groundwater table elevation
pH	Field Flow-Through Cell	Evaluate aquifer geochemistry
Electrical Conductivity	Field Flow-Through Cell	Evaluate aquifer geochemistry
Temperature	Field Flow-Through Cell	Evaluate aquifer geochemistry
ORP	Field Flow-Through Cell	Evaluate aquifer geochemistry
Dissolved Oxygen	Field Flow-Through Cell	Evaluate aquifer geochemistry
Color	Field Visual Assessment	Indicator of permanganate
Permanganate	Lab – Colorimetry	Permanganate concentration
VOCs	Lab – EPA Method 8021B	Contaminant concentrations
Chloride	Lab – EPA Method 300.0	Degradation by-product
Sodium	Lab – EPA Method 200.7	Degradation product of $NaMnO_4$
Dissolved Manganese	Lab – EPA Method 200.7	Degradation product of MnO_4
Dissolved Chromium	Lab – EPA Method 200.7	Oxidation can convert Cr^3 to Cr^6
Dissolved Hexavalent Chromium	Lab – SM 3500Cr-D/EPA 7196A	Oxidation can convert Cr^3 to Cr^6

ERM will conduct gauging and groundwater sampling activities in general accordance with accepted practices outlined in the DEP's Standard References for Monitoring Wells, WSC-310-91, dated April 1991 and updated July 1994. ERM will collect the necessary quality assurance/quality control (QA/QC) samples to satisfy the requirements and specifications outlined in the Compendium of Analytical Methods (CAM) to achieve Presumptive Certainty status for data usability, pursuant to 310 CMR 40.0017 and 310 CMR 40.0191(2)(c).

4.2.2 *Oxidant Injection*

As shown in Figure 7, oxidant applications will be conducted in five treatment areas, referred to as follows:

- MW-102 Area (west side of main building);
- MW-33 Area (southwest of main building)
- MW-43 Area (southernmost courtyard adjacent to main building);
- MW-40 Area (east of main building); and
- Main Building Area (accessible areas beneath main building).

Based on results of the pilot program, a combination of injection methods will be employed:

- Pressure injections (i.e., up to 60 pounds per square inch (psi) will be used in areas close to or beneath the building and in areas near topographic depressions to maximize the injection radii while minimizing the potential for adverse impacts to the main building structure or oxidant breakout at the surface.
- Hydraulic fracturing and liquid atomized injection (HFLAI) or similar injection technique will be used where appropriate to further maximize injection radii and enhance distribution of oxidant. The HFLAI technique uses pressure to fracture the formation and facilitate enhanced emplacement of oxidant along fracture planes.
- Pressure pulse injection, which is an innovative technology that uses fluctuating injection pressures to enhance injection radii and in situ mixing, may be implemented outside the building.

Figure 7 shows approximate oxidant application locations and projected radii of influence. The actual number and location of injection points may vary slightly, based on field observations and conditions during the application. Horizontal and vertical treatment intervals for each area were determined using a combination of April 2003 monitoring well and Winter-Spring 2004 Waterloo Profiler TCE concentration data. Vertical treatment intervals for each area are presented in the following table.

Summary of Vertical Permanganate Application Intervals

Treatment Area	Minimum Injection Depth (feet below grade)	Maximum Injection Depth (feet below grade)
MW-102 Area	Water Table	40
MW-33 Area	Water Table	45
MW-43 Area	Water Table	20
MW-40 Area	Water Table	35
Main Building Area	Water Table	45

A maximum 10 percent (by volume) or 12.5 percent (by weight) sodium permanganate solution will be applied in the treatment areas. The mass of permanganate required for each treatment area (i.e., total oxidant demand) was calculated using an SOD of 0.5 pounds per yd^3 and April 2003 TCE concentrations specific to each area. The total oxidant demand (i.e., SOD plus TCE demand) was calculated for each treatment area and a stoichiometric equivalent of permanganate was determined.

A maximum 10 percent (by volume) or 12.5 percent (by weight) sodium permanganate solution was selected to minimize the potential for displacement of TCE from the treatment areas by reducing the total volume of fluid injected. Application of lower permanganate concentrations may be employed around the periphery of the injection areas where lower TCE concentrations are present. The proposed injection volumes are estimated to generally displace less than a one percent of the pore volume (assumes 30 percent effective porosity) within the treatment areas. The injections will be conducted from the outside-in (i.e., injections will occur in the outermost points in each area prior to the interior points) to further reduce the potential for displacement of impacted groundwater outside the treatment area. The mass and volume of permanganate to be applied in each treatment area is presented below.

Summary of Permanganate Mass and Volumes for Treatment Areas

Treatment Area	Permanganate Ion Mass (pounds)	10% (by volume) Sodium Permanganate Solution (gallons)
MW-102 Area	15,000	13,000
MW-33 Area	3,300	3,000
MW-43 Area	1,500	1,400
MW-40 Area	1,500	1,400
Main Building Area	24,300	21,300

4.2.3 *Post-Injection Groundwater Monitoring*

The purpose of this task is to monitor the efficacy of the ISCO treatment program over time. ERM will implement a quarterly groundwater monitoring program following completion of the permanganate injections until such time as permanganate is no longer present in the monitoring wells on Site. The quarterly monitoring program will consist of the following field measurements and laboratory analyses:

Post-Injection Quarterly Monitoring Program

Analysis	*Method of Analysis*	*Rationale*
Groundwater Elevation	Field Probe	Evaluate groundwater table elevation
pH	Field Flow-Through Cell	Evaluate aquifer geochemistry
Electrical Conductivity	Field Flow-Through Cell	Evaluate aquifer geochemistry
Temperature	Field Flow-Through Cell	Evaluate aquifer geochemistry
ORP	Field Flow-Through Cell	Evaluate aquifer geochemistry
Dissolved Oxygen	Field Flow-Through Cell	Evaluate aquifer geochemistry
Color	Field Visual Assessment	Indicator of permanganate
Permanganate	Lab - Colorimetry	Permanganate concentration

The quarterly monitoring program will include the following wells:

- MW-102 Area (18 wells): MW-101, MW-102, MW-103, MW-213, MW-214, MW-47S, MW-47M, MW-47D, MW-201S, MW-201M, MW-201D, MW-203S, MW-203M, MW-203D, MW-204S, MW-204M, MW-204D and MW-403;
- MW-33 Area (11 wells): MW-33S, MW-33M, MW-107, MW-109, MW-111, MW-113, MW-115, MW-202S, MW-202M, MW-208S and MW-208M;
- MW-43 Area (11 wells): MW-43S, MW-104, MW-105, MW-105M, MW-106, MW-106M, MW-209, MW-210, MW-211, MW-212 and MW-212M;
- MW-40 Area (two wells): MW-40 and MW-40S; and
- Main Building Area (five wells): MW-117, MW-118, MW-404, MW-405S and MW-405D.

Groundwater samples will be collected semi-annually from those wells listed above for laboratory analyses of sodium, chloride and VOCs by EPA Method 8021B. The semi-annual sampling rounds will be conducted concurrently with quarterly monitoring rounds. ERM anticipates that the semi-annual groundwater sampling program will continue for approximately two years after the injection. However, the actual duration of the program will be determined based on results of each sampling round.

The final post injection sampling round will be conducted after permanganate is no longer visually observed in monitoring wells on Site and will include field measurements and laboratory analyses of the following parameters:

Final Post-Injection Monitoring Event

Analysis	*Method of Analysis*	*Rationale*
Groundwater Elevation	Field Probe	Evaluate groundwater table elevation
pH	Field Flow-Through Cell	Evaluate aquifer geochemistry
Electrical Conductivity	Field Flow-Through Cell	Evaluate aquifer geochemistry
Temperature	Field Flow-Through Cell	Evaluate aquifer geochemistry
ORP	Field Flow-Through Cell	Evaluate aquifer geochemistry
Dissolved Oxygen	Field Flow-Through Cell	Evaluate aquifer geochemistry
Color	Field Visual Assessment	Indicator of permanganate
VOCs	Lab – EPA Method 8021B	Contaminant concentrations
Chloride	Lab – EPA Method 300.0	Degradation by-product
Sodium	Lab – EPA Method 200.7	Degradation product of $NaMnO_4$
Dissolved Manganese	Lab – EPA Method 200.7	Degradation product of MnO_4
Dissolved Chromium	Lab – EPA Method 200.7	Oxidation can convert Cr^3 to Cr^6
Dissolved Hexavalent Chromium	Lab – SM 3500Cr-D/EPA 7196A	Oxidation can convert Cr^3 to Cr^6

The groundwater quality monitoring data will be used to determine compliance with the remedial target and evaluate the need for additional permanganate applications, as appropriate.

5.0 *IMPLEMENTATION SCHEDULE*

The anticipated schedule for remedial activities at the Site is presented below.

Proposed Implementation Schedule for Phase IV RIP

Date	*Event*
Spring – Summer 2004	Conduct Permanganate Injections
Summer 2004	Initiate Quarterly Groundwater Monitoring Program
Fall – Winter 2004	Initiate Semi-Annual Groundwater Sampling Program
Fall 2004	Final Inspection Report

6.0 *REFERENCES*

ERM, "Phase II - Comprehensive Site Assessment, Former Raytheon Facility, 430 Boston Post Road, Wayland, Massachusetts," 2001a.

ERM, "Phase III - Remedial Action Plan, Former Raytheon Facility, 430 Boston Post Road, Wayland, Massachusetts," 2001b.

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ERM, "Release Abatement Measure Completion Report, In Situ Chemical Oxidation Pilot Study, Former Raytheon Facility, 430 Boston Post Road, Wayland, Massachusetts," December 2003.