

28 May 2013

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Subject: In-Situ Chemical Oxidation Bench Test Work Plan

Cabot Carbon/Koppers Superfund Site

Dear Scott:

This letter accompanies an In-Situ Chemical Oxidation (ISCO) Bench Test Work Plan for evaluating ISCO for source treatment in the Upper Hawthorne Group (UHG) Formation at the Cabot Carbon/Koppers Superfund Site. The work plan was prepared by Geosyntec on behalf of Cabot Corporation (Cabot).

A draft of the attached work plan was prepared prior to completion of the recent UHG investigation activities and provided to Neil Thomson (consultant for the Gainesville Regional Utilities (GRU)) on 3 April 2013 for preliminary review. Geosyntec received comments on the draft work plan from Neil Thomson on 22 April 2013.

Since the receipt of those comments, Cabot and its consultants have completed the UHG investigation. The attached work plan has since been refined based on 1) field observations and analytical results from the recent investigation and 2) input from Neil Thomson. The work plan follows a phased approach to evaluating the use of ISCO for treating site contaminants of potential concern in the UHG. Based on the results of each phase of testing, modifications may be made to the procedures for subsequent phases to keep our efforts focused on achieving the objectives of the test.

Sincerely,



Chapman Ross, P.E.
Senior Engineer

Scott Miller
28 May 2013
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Attachment:

In-Situ Chemical Oxidation Bench Test Work Plan – Cabot Carbon/Koppers Superfund Site

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In-Situ Chemical Oxidation Bench Test Work Plan

Cabot Carbon/Koppers Superfund Site

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ATTACHMENTS

1. INTRODUCTION

This document describes the objectives and procedures associated with a laboratory-scale treatability testing program (bench test) proposed to evaluate the potential for *in-situ* chemical oxidation (ISCO) to treat residual Site-related compounds of potential concern (COPCs) present in the suspected source area associated with the former Cabot lagoons at the Cabot Carbon/Koppers Superfund Site (the Site). The proposed bench test program will be performed using Site soil and groundwater collected during recent source characterization activities. The characterization program has advanced our understanding of the nature and extent of COPCs within the source area, while the bench test will support the selection and design of a remedy to treat impacted zones within the source area.

1.1 Program Purpose and Objectives

The purpose of the bench test proposed in this work plan is to assess the efficacy of treating COPCs, principally benzene, toluene, ethylbenzene, xylenes (BTEX), phenols, and ketones, in the Upper Hawthorn Group (UHG) formation using ISCO. The bench test has been designed to achieve the following objectives:

- Determine if ISCO is a viable treatment alternative for Site-related COPCs in the suspected source area;
- Evaluate the range of oxidant consumption rates and demands in the presence of Site soil and groundwater;
- Evaluate the potential for ISCO to influence metals mobility in the source area;
- Assess the potential effectiveness of aerobic bioremediation following the application of ISCO; and
- Select the most favorable oxidation technology for further evaluation at field-scale.

1.2 Site and Technology Background

The primary COPCs have been established based on Site history and investigation activities conducted to date. The COPCs are listed in Table 1 and consist primarily of volatile and semi-volatile organic compounds (VOCs and SVOCs) related to the historical production of pine tar. In particular, the groundwater plume associated with the former Cabot lagoons contains BTEX, phenols, ketones, and terpenes and terpenoids. The purpose of ISCO, if effective, would be to remediate the source area. The use of ISCO would be necessary to address mobile COPCs, such as BTEX compounds, phenols and ketones, in the groundwater plume. Terpenes and terpenoids, although useful indicator compounds for pine tar contamination, have limited mobility in the subsurface and are not likely to migrate far beyond the source area – a conclusion that is corroborated by the available groundwater quality data for the Site (Gradient & Weston, 2012). Thus, this group of compounds has been assigned a lower priority, as compared to the more mobile COPCs, in the design of the ISCO bench test.

**Table 1: Contaminants of Potential Concern
Cabot/Carbon Koppers Superfund Site, Gainesville, FL**

Volatile Organic Compounds (VOCs)	Semi-Volatile Organic Compounds (SVOCs)
BTEX	Phenol
Acetone	Methyl phenols
2-Hexanone (Butyl Methyl Ketone)	Terpenes
2-Butanone (Methyl Ethyl Ketone)	Terpenoids

ISCO applications involve the injection of an oxidant into the subsurface to promote chemical reactions that convert COPCs to innocuous degradation products, such as carbon dioxide and water. The relative effectiveness of an oxidant for treating a given compound depends on a number of factors, including the standard reduction potential (E°) of the oxidant, the reactivity of the oxidant with a particular contaminant, and the reactivity of the oxidant with non-target species. Oxidants to be included in the bench test program are: ozone, ozone with hydrogen peroxide, catalyzed hydrogen peroxide (CHP) and peroxide-activated persulfate (PAP). The reduction potentials of these oxidants are listed in Table 2.

Table 2: Standard Reduction Potential for Oxidants Selected for Bench Testing

Oxidant Type	Standard Reduction Potential, E° (Volts)
Catalyzed Hydrogen Peroxide	2.8
Ozone with Hydrogen Peroxide	2.8
Peroxide Activated Persulfate	2.6
Ozone	2.1

The selected oxidants all have high reduction potential and are among the most powerful oxidants used for ISCO. The reduction potentials listed in Table 2 are associated with the direct reduction of the oxidant relative to a hydrogen electrode. However, several of the oxidants listed may decompose into free radicals with higher reduction potential than the oxidants themselves.

Literature related to ISCO of pine tar constituents is somewhat limited. However, pine tar is natural material that is readily oxidized under normal environmental conditions (e.g., decaying of pine trees, bark and needles), so it is expected that ISCO can be used to effectively degrade this material at the Site. The oxidants listed in Table 2 have been selected based on professional judgment and a literature review to assess each oxidant's effectiveness for degradation of Site COPCs. Each of the selected oxidants has demonstrated effectiveness at degrading a wide variety of organic compounds, including VOCs and SVOCs. Degradation of fuel hydrocarbons (e.g., benzene), phenolic compounds and polycyclic aromatic hydrocarbons (PAHs; e.g., naphthalene) using these oxidants is generally well understood (Siegrist, et al. 2011). Permanganate compounds are not included for testing because their reduction potential is insufficient to oxidize some of the Site COPCs. In particular, permanganates are not effective at degrading benzene or many PAHs (Siegrist et al. 2011).

In addition to reduction potential and oxidant reactivity with COPCs, other conditions in the subsurface at the Site will influence the treatment efficiency of a given oxidant. These conditions include pH, naturally occurring metals, and organic carbon. The pH observed in the UHG formation in the vicinity of the former Cabot lagoons is typically less than 5. Low pH has the potential to improve the performance of CHP processes. As a result of the low pH, iron and manganese are predominately present in solution in groundwater in this portion of the UHG; ISCO processes are likely to create metal oxides with dissolved iron and manganese, thus reducing the mobility of these metals. Based on groundwater analytical results from this portion of the UHG, the presence of non-target oxidant demand has the potential to reduce the efficiency of ISCO processes at the Site. The background non-target oxidant demand testing described in Section 3.2 is intended to investigate the relative importance of this issue for each oxidant selected for testing with Site soil and groundwater.

1.3 Program Design

The bench test program will be used to assess oxidant reactivity with COPCs and to evaluate the effects of non-target oxidant demand and Site geochemistry on treatment efficiency.

During the source investigation described in the *Hawthorn Group Investigation WorkPlan*, non-aqueous phase liquid (NAPL) was observed in surficial aquifer soils within the footprint of the former lagoons (October 2012). Based on the conceptual model for the Site, locations where residual NAPL is most likely to exist in the UHG are located below areas of the surficial aquifer where NAPL is present. In these areas, UHG soils were not accessible without potentially introducing NAPL from the surficial aquifer into the UHG formation during drilling. While NAPL-impacted soils from the UHG formation were not observed during the investigation, high concentrations of COPCs – approaching ten percent of aqueous solubility for some compounds – in groundwater sampling results from recent characterization activities suggest that residual NAPL may be present in the UHG formation below the former lagoons. Based on these findings, soil sample selection and oxidant dosing for the bench tests will reflect the potential need to treat NAPL-impacted soils in the UHG formation.

The bench test program will consist of the following two phases:

- Comparative Screening Studies; and
- Detailed Studies.

The objectives and analytical procedures associated with each phase are described in Sections 3 and 4 below. Samples of Site materials to be used in the bench test program were collected during the Hawthorn Group Investigation. Section 2 below describes the procedures for selecting soil and groundwater samples to be used in bench testing, and the sample preparation and baseline analyses to be conducted prior to the start of the bench test program. In order to test the treatability of NAPL-impacted soil in the UHG, NAPL-impacted soil recovered from the surficial aquifer will be combined with UHG soil prior to testing using the sample preparation procedure described in Section 2 below. Note that the scope of the detailed studies (*i.e.*, the choice of the oxidants and the required analytical testing) will be finalized based on the results of the comparative screening studies.

2. SAMPLE COLLECTION AND PREPARATION

The bench test will use soil and groundwater collected from the Site during the Hawthorn Group Investigation performed during the spring of 2013. The sections below describe the approach that will be used to create samples for laboratory testing.

2.1 Soil Sampling

Soil samples were collected from the surficial aquifer and UHG at the locations and using the methods described in the *Hawthorn Group Investigation WorkPlan* (October 2012). After soil cores were field-screened and sampled for laboratory analysis, residual soil from each boring location was placed into sealable polyethylene bags. The bags were then sealed, labeled and refrigerated. Laboratory results for these soils were used to select a subset of the sampling locations (e.g., four to six) with the highest COPC concentrations, and these samples will be sent to the laboratory for compositing and use in the bench testing.

Compositing will be performed by the laboratory by taking an equal mass of soil from each container of residual soil and combining it to create a composite sample. This procedure is intended to yield a 12-kg composite soil sample that is generally representative of available UHG soil samples with higher concentrations of COPCs (typically within the upper quartile of COPC concentrations measured in UHG soils during the recent source area investigation). Separately, a sample of NAPL-impacted soil collected from the surficial aquifer will be homogenized to create a soil composite containing residual NAPL. The homogenized UHG formation soil and homogenized surficial aquifer soil (containing residual NAPL) will then be added to individual reactors in a 4:1 ratio by mass and mixed with groundwater composited from samples collected from the UHG (see Section 2.2 below) to create the slurry mixture for testing. The NAPL-impacted surficial soil added to each reactor will be used to simulate the presence of residual NAPL in UHG soils. As described later in this work plan, the ISCO test program includes time zero sampling to determine the initial concentrations and total mass of COPCs in reactors used for comparative screening and detailed testing. Time zero results will be used as baseline concentrations to evaluate COPC destruction.

2.2 Groundwater Samples

Groundwater for bench testing will be created by compositing groundwater collected from the UHG formation. These samples will be refrigerated, and following receipt of analytical data, a subset of the retained samples will be composited by the laboratory performing the bench testing to create a 30-liter sample of groundwater for bench testing. Groundwater samples collected during the recent UHG investigation will be combined with samples collected from monitoring wells HG-28S, HG-29D, and/or HG-30S; water from the selected samples will be mixed to create the composite groundwater sample for bench testing. The composited groundwater will be combined with the soil samples (described in Section 2.1) to create the slurry phase mixture used in reactors for comparative screening and detailed testing.

2.3 Background Soil and Groundwater Samples

The non-target oxidant demand of Hawthorn Group soils will be assessed using soil and groundwater collected from a location that is uncontaminated or minimally contaminated (i.e.,

background samples). Two kilograms of soil and five liters of groundwater will be collected from the Hawthorn Group at plume delineation location 13, 20, 23 or 24 and sent to the laboratory performing the bench testing. These background samples will be used in the background non-target oxidant demand tests and the metals attenuation tests described in Sections 3.2 and 4.2.3 below.

3. COMPARATIVE SCREENING STUDIES

The comparative screening studies are designed to evaluate the viability and relative performance of several oxidation technologies for treatment of COPCs in both Site groundwater and Site soil/groundwater. The results of the comparative screening studies will be used to select two oxidants for further bench testing (i.e., detailed studies as described in Section 4 below).

3.1 Objectives

The objectives of the comparative screening studies are to determine if ISCO is a viable technology for treatment of pine tar constituents and other COPCs at the Site, and to identify the most effective oxidant(s) for inclusion in detailed studies. Groundwater only (e.g. aqueous phase) tests are designed to evaluate COPC treatment with limited competing oxidant demand. Slurry-phase tests, consisting of Site soil and groundwater, are designed to evaluate treatment of high concentrations of COPCs in NAPL-impacted soils in the presence of competing non-target oxidant demand. Results from the comparative screening studies will be used to evaluate each oxidant based on the following criteria: effectiveness of COPC destruction¹ and the amount of oxidant consumed. The oxidant(s) exhibiting the best overall performance based on these criteria will be included in detailed studies to be conducted in the next phase of the bench testing program.

3.2 Background Non-Target Oxidant Demand Tests

The background samples of soil and groundwater collected during the Hawthorn Group investigation (see Section 2.3 above) will be used to construct slurry phase reactors for each oxidant dose and oxidant/activator combination (see Attachment B). For liquid oxidants, reactors will be constructed by first adding 75 g of homogenized UHG soil collected from background locations to sterile 250 mL (nominal volume) screw cap Boston round clear glass bottles (Systems Plus, New Hamburg, ON). Liquid oxidants (persulfate or hydrogen peroxide) will be added to the reactors using concentrated stocks. The reactors will then be filled with approximately 200 mL of homogenized Site groundwater from background locations. Activators (concentrated stocks) will be added to reactors leaving zero headspace. Continuous reactors will be capped with Mininert[™] closures, or equivalent, to allow repetitive sampling of the reactors with minimal VOC loss throughout the reaction period, and reactors for sacrificial sampling will be capped with Teflon-lined septa closures.

¹ COPC destruction will be evaluated by comparing final COPC concentrations to initial (time zero) values. The rate of COPC destruction will also be considered, and the relative reduction in COPC concentration at each time step will be weighed against the amount of oxidant consumed in assessing the effectiveness of each oxidant.

For ozone tests, the reactors will be constructed in a similar manner with a total of 50-100 g of homogenized UHG formation soil from background locations and enough background UHG groundwater to leave a nominal headspace in a 250-500 mL vessel. Reactors will be continuously sparged with approximately 95% oxygen containing 3% ozone and 2% nitrogen through a sintered ceramic diffuser placed at the bottom of the vessel at a flow rate of 25-75 mL/min.

The tests will be run for 10 days, and aqueous samples will be used to monitor pH, ORP and liquid oxidant concentrations at the 2, 5 and 10-day durations. Ozone concentrations will be measured twice daily in reactor effluent. Changes in groundwater chemistry and oxidant concentration throughout the course of each test will be used to evaluate the potential effects of non-target oxidant demand on the oxidant consumption rate for each oxidant tested and to fine-tune oxidant dosing for COPC treatment testing described below.

3.3 Test Setup – Aqueous Phase COPC Treatment Tests

For liquid oxidants, batch reactors will be prepared using approximately 250 mL of Site groundwater. Reactors will be 250 mL bottles (nominal volume) and will be constructed with zero headspace. Prior to testing, a sample of Site materials will be dosed with each oxidant to evaluate production of off-gases (e.g., COPC volatilization and/or generation of reaction by-products). Off-gas production will be evaluated prior to testing and managed as necessary during testing.²

Liquid oxidants and associated activators will be added to each reactor, and bottles will be inverted periodically to ensure adequate mixing and allowed to react for five days. CHP and PAP concentrations are anticipated to be approximately 25-100 g/L and 25-50 g/L, respectively as detailed in Attachment A. The final oxidant doses will be determined based on the results of the non-target oxidant demand testing described in Section 3.2 above. Tests will be performed in duplicate, and control reactors containing no added oxidant will be monitored in parallel with the active reactors. Vessels will be inverted periodically to ensure adequate mixing.

For ozone tests, the reactors will be constructed with enough UHG groundwater to leave a nominal headspace in a 250-500 mL vessel. Reactors will be continuously sparged with approximately 95% oxygen containing 3% ozone and 2% nitrogen through a sintered ceramic diffuser placed at the bottom of the vessel at a flow rate of 25-75 mL/min. Volatilization will be assessed prior to initiating the comparative screening study by sparging two reactors with nitrogen and destructively sampling these reactors after 5 days to measure the proportion of COPC degradation attributable to volatilization. If COPC loss due to volatilization is found to be significant, steps will be taken to manage COPC losses due to volatilization in the comparative

² For those reactors for which significant gas production is anticipated, a check valve will be used to allow off-gases to vent into a tedlar bag when sufficient pressure develops inside the reactor. The tedlar bag will be used to track the total volume of gas produced during the test. Depending on the volume of gas produced, selected tedlar bags will be submitted for analysis of VOCs by EPA Method TO-15. At a minimum, gases from the first 24 hours of testing will be analyzed using this method.

screening study. The reactors used to assess volatilization will also serve as control reactors (with nitrogen as the sparge gas) for the ozone tests.

Reactor volumes and the number of reactors for each oxidant are summarized in Attachment B.

3.4 Test Setup – Soil and Groundwater Slurry COPC Treatment Tests

Batch reactors will be prepared for each test using materials collected during source area characterization activities. Site soil and groundwater will be placed in a fume hood with the materials required to construct the various treatment and control reactors. Sufficient additional replicate reactors will be prepared as required to provide sufficient sample volumes for external laboratory analyses (see Attachment B).

For liquid oxidants, reactors will be constructed by first adding 60 g (measured gravimetrically) of homogenized UHG soil and 15 g of homogenized NAPL-impacted surficial soil to sterile 250 mL (nominal volume) screw cap Boston round clear glass bottles (Systems Plus, New Hamburg, ON). Liquid oxidants³ (persulfate or hydrogen peroxide) will be added to the reactors using concentrated stocks. The reactors will be filled with approximately 200 mL of Site groundwater. Activators (concentrated stocks) will be added to reactors leaving a zero headspace. Vessels will be capped with MininertTM closures to allow repetitive sampling of the reactors with minimal VOC loss throughout the reaction period, and replicate reactors for sacrificial sampling will be capped with Teflon lined septa closures. Off-gas production will be evaluated prior to testing and managed as necessary during testing using a similar procedure as described in Section 3.3 above. Vessels will be inverted periodically to ensure adequate mixing.

For ozone tests, the reactors will be constructed with a total of 50-100 g (maintaining a 4:1 ratio of UHG formation soil to NAPL-impacted surficial aquifer soil) and enough UHG groundwater to leave a nominal headspace in a 250-500 mL vessel. Reactors will be continuously sparged with approximately 95% oxygen containing 3% ozone and 2% nitrogen through a sintered ceramic diffuser placed at the bottom of the vessel at a flow rate of 25-75 mL/min. For ozone and peroxide tests, a target concentration of 0.1-0.5% peroxide will be initially applied to the vessel, and additional peroxide will be added as needed based on daily peroxide measurements. Nitrogen tests will again be conducted to quantify COPC loss due to volatilization. The reactors used to assess volatilization will also serve as control reactors (with nitrogen as the sparge gas) for the ozone tests.

3.5 Monitored Parameters – Aqueous Phase and Slurry COPC Treatment Tests

For each oxidant dose, a continuous reactor will be allowed to run for the full duration of the 5-day test and sampled periodically to measure pH, ORP, and oxidant concentrations. In addition, reactors for each oxidant dose will be destructively sampled and analyzed for COPCs as specified in Table 3 below. All analytical samples will be quenched with ascorbic acid to stop

³ Final oxidant doses for the comparative screening studies will be determined based on COPC concentrations observed during source characterization activities and results from non-target oxidant demand testing. Preliminary estimates of oxidant doses are included in Attachment A.

oxidant driven reactions and preserved as required by the analytical laboratory for the requested analyses.

Table 3: Monitored Parameters for Comparative Screening Studies

Analyte	Frequency	Laboratory Method
VOCs - GW	Days 0* and 5	EPA Method 8260B
SVOCs - GW	Days 0* and 5	EPA Method 8270
VOCs – Soil	Days 0* and 5	EPA Method 8260B
SVOCs - Soil	Days 0* and 5	EPA Method 8270
Liquid Oxidant/Activator	Days 0* and 5 for liquid oxidant tests	Titration or Test Kit
Activator (peroxide) – GW	Daily for entire ozone + peroxide tests	Test Kit
Ozone @ influent	Twice daily for entire ozone test	UV-based detector
Ozone @ effluent	Twice daily for entire ozone test	UV-based detector
ORP	Days 0* and 5	Probe
pH	Days 0* and 5	Probe

GW = groundwater

*Day 0 samples for COPCs will be collected from the Unamended Control reactors only (see Attachment B)

3.6 Oxidant Selection

Results from the comparative screening studies will be used to evaluate each oxidant based on the following criteria: effectiveness of COPC destruction and oxidant consumption. The oxidant(s) exhibiting the best overall performance based on these criteria will be included in detailed studies to be conducted in the next phase of the bench testing program (i.e., detailed studies described in Section 4). A maximum of two oxidant systems will be retained for further testing.

4. DETAILED STUDIES

The detailed studies are designed to further evaluate COPC treatment, determine the optimal oxidant dose for treating Site COPCs, and evaluate compatibility with Site geochemistry for the two oxidant systems selected based on the results of the comparative screening studies. In addition to testing these selected oxidation technologies, the detailed treatability study will also include tests to evaluate the effectiveness of post-ISCO aerobic bioremediation and attenuation of metals following ISCO.

4.1 Objectives

There are three objectives of the detailed studies:

- to provide the data required to select oxidant doses for field-scale application;
- to assess the effectiveness of the selected oxidant technologies for treating Site COPCs; and
- to evaluate metals attenuation and the effectiveness of aerobic biological treatment following ISCO.

4.2 ISCO Test Methodology

The test setup for the detailed studies will depend on the oxidant(s) selected for evaluation based on the results of the comparative screening tests. Testing procedures for liquid oxidants and ozone are outlined below.

4.2.1 Liquid Oxidant

If liquid oxidants are selected for detailed testing, the detailed test setup will include several steps to evaluate oxidant consumption and treatment of COPCs. In addition to the reactors described below, each test will also include duplicate control reactors containing no oxidant (see Attachment B).

- Oxidant Consumption Test: Multiple reactors will be used to evaluate the oxidant concentration over the experimental period for a given oxidant dose/initial concentration and oxidant-activator combination. Oxidant concentrations/dosages for this test will be determined based on the results of the comparative screening studies described in Section 3. Reactors will be prepared in a similar manner to the comparative screening studies using 75 g of homogenized Site soil with residual NAPL and approximately 200 mL of groundwater (see Section 3.4). Vessels will be inverted periodically to ensure adequate mixing and allowed to react for 15 days. Reactors will be constructed in duplicate, and aqueous samples from each reactor will be collected and analyzed as outlined in Table 4 below.

Table 4: Monitored Parameters – Oxidant Consumption Tests

Analyte	Frequency	Laboratory Method
Oxidant/Activator	Days 2, 5, 10 and 15	Titration or Test Kit
ORP	Days 2, 5, 10 and 15	Probe
pH	Days 2, 5, 10 and 15	Probe

Results from the oxidant consumption test will be used to select the optimal oxidant dose and activator concentration to be used in the COPC treatment test described below.

- **COPC Treatment:** This test will consist of a set of reactors prepared with an oxidant dose selected based on the results of the oxidant consumption test. Reactors will be prepared in a similar manner to the comparative screening studies using 75 g of homogenized Site soil with residual NAPL and approximately 200 mL of groundwater (see Section 3.4). Vessels will be inverted periodically to ensure adequate mixing and allowed to react for 15 days. Reactors will be constructed in duplicate, and samples of soil and groundwater from each reactor will be collected and analyzed as outlined in Table 5 below.

Table 5: Monitored Parameters – Liquid Oxidant COPC Treatment Tests

Analyte	Frequency	Laboratory Method
VOCs - GW	Days 0*, 2, 5, 10 and 15	EPA Method 8260B
SVOCs - GW	Days 0*, 2, 5, 10 and 15	EPA Method 8270
Terpenes*** – GW	Days 0* and 15	EPA Method 8270C
Dissolved Metals* – GW	Days 0*, 2, 5, 10 and 15	EPA Method 6010
VOCs - Soil	Days 0*, 2, 5, 10 and 15	EPA Method 8260
SVOCs - Soil	Days 0*, 2, 5, 10 and 15	EPA Method 8270
Terpenes – Soil	Days 0* and 15	EPA Method 8270C
Metals – Soil	Days 0*, 2, 5, 10 and 15	EPA Method 1312
Oxidant/Activator	Days 0, 2, 5, 10 and 15	Titration or Test Kit
ORP	Days 0, 2, 5, 10 and 15	Probe
pH	Days 0, 2, 5, 10 and 15	Probe

GW = groundwater

*Day 0 samples for COPCs and metals will be collected from the Unamended Control reactors only (see Attachment B)

**Metals analysis will include arsenic, iron, manganese, lead, molybdenum, nickel, selenium and vanadium

*** Analysis of terpenes concentrations in groundwater will be conducted with a detection limit of 50 µg/L. This elevated detection limit reduces the required sample volume from 1 L to 40 mL and allows for the use of smaller reactors in the bench testing program. Concentrations of the most frequently detected terpenes have exceeded 50 µg/L in samples collected during Site investigation activities conducted to date.

4.2.2 Ozone

If ozone is selected for detailed testing, oxidant consumption and COPC treatment will be evaluated with a set of reactors prepared in a similar manner to the comparative screening studies (see Section 3.4). The reactors will be constructed with a total of 50-100 g (maintaining a 4:1

ratio of UHG formation composited soil to NAPL-impacted surficial aquifer soil) and enough UHG groundwater to leave a nominal headspace in a 250-500 mL vessel. Reactors will be continuously sparged with approximately 95% oxygen containing 3% ozone and 2% nitrogen through a sintered ceramic diffuser placed at the bottom of the vessel at a flow rate of 25-75 mL/min. For ozone and peroxide tests, a target concentration of 0.1-0.5% peroxide will be initially applied to the vessel, and additional peroxide will be added as needed based on daily peroxide measurements. Nitrogen tests will again be conducted to quantify COPC loss due to volatilization. The reactors used to assess volatilization will also serve as control reactors (with nitrogen as the sparge gas) for the ozone tests. Reactors will be constructed in duplicate, and samples of soil and groundwater from each reactor will be collected and analyzed as outlined in Table 6 below. The ozone concentration and air flow rate will be determined based on the results of the comparative screening study described in Section 3 above. Vessels will be sparged continuously for 15 days. In addition to the ozone sparged reactors, two sets of duplicate control reactors will also be included: one with nitrogen as the sparge gas and one with no treatment applied.

Table 6: Monitored Parameters – Detailed Study Using Ozone

Analyte	Frequency	Laboratory Method
VOCs – GW	Days 0*, 2, 5, 10 and 15	EPA Method 8260B
SVOCs - GW	Days 0*, 2, 5, 10 and 15	EPA Method 8270
Terpenes*** – GW	Days 0* and 15	EPA Method 8270C
Dissolved Metals* – GW	Days 0*, 2, 5, 10 and 15	EPA Method 6010
Activator (peroxide) – GW	Daily for entire test	Test Kit
VOCs – Soil	Days 0*, 2, 5, 10, and 15	EPA Method 8260
SVOCs – Soil	Days 0*, 2, 5, 10, and 15	EPA Method 8270
Terpenes – Soil	Days 0* and 15	EPA Method 8270C
Metals** – Soil	Days 0*, 2, 5, 10, and 15	EPA Method 1312
VOC – Gas***	Days 2 and 5 only	EPA Method 8260
Ozone @ influent	Twice daily for entire test	UV-based detector
Ozone @ effluent	Twice daily for entire test	UV-based detector

*Day 0 samples for COPCs and metals will be collected from the Unamended Control reactors only (see Attachment B)

**Metals analysis will include arsenic, iron, manganese, lead, molybdenum, nickel, selenium and vanadium

***Gas samples will be collected from the column effluent for one to two hours immediately before the collection of the Day 2 and Day 5 samples and submitted for analysis of COPCs.

4.2.3 Metals Attenuation Tests

A metals attenuation test will be performed to evaluate metals concentrations in groundwater after oxidant depletion. The primary metals of concern for the Site will be determined based on a review of the dissolved metals concentrations measured in the day 15 sample⁴ from the COPC treatment test. If elevated oxidant concentrations are observed in day 15 samples from liquid oxidant tests, then groundwater collected from the COPC treatment reactor on day 15 will be quenched with ascorbic acid to simulate oxidant depletion and added to a new 250 mL reactor containing 75 g of background Site soil collected during the Hawthorn Group investigation (see Section 2.3 above). Due to the short half-life of ozone, groundwater from ozone COPC treatment reactors is not expected to require quenching. This sequential batch procedure is designed to simulate transport of dissolved metals by groundwater flow away from the primary treatment area following the application of ISCO.

After seven days of contact time, the groundwater will be sampled and analyzed by EPA Method 6010 to determine the dissolved concentrations of the primary metals of concern. The dissolved metals concentrations remaining after seven days of contact time will be compared to the concentrations measured in the day 15 sample from the COPC treatment test to assess the rate of metals attenuation.

The remaining groundwater will then be placed in a new 250 mL reactor with a new sample of background Site soil. The groundwater will be re-sampled after a specified contact time⁵ and submitted for analysis of dissolved metals (EPA Method 6010). This process will be repeated up to four times or until the dissolved concentrations of the metals of concern have reached a baseline level determined from historical data collected at the Site. As groundwater is removed from the system for metals analysis, the amount of soil used in each subsequent phase of testing will be adjusted to maintain a constant soil to groundwater ratio.

The monitoring frequency used during the metals attenuation test and the observed attenuation rates of the primary metals of concern will provide a basis for development of a monitoring program for the field scale pilot study.

4.3 Test Setup – Aerobic Bioremediation Tests

Detailed testing will also include tests to evaluate the potential effectiveness of aerobic bioremediation at the Site before and after the application of ISCO to Site soil and groundwater. Baseline aerobic microcosms will be used to assess COPC degradation rates under ambient aerobic conditions and to prepare a culture of native biomass for bioaugmentation of post-ISCO bioremediation tests.

⁴ If significant variability in ORP or dissolved metals concentration is observed over the duration of the COPC treatment tests, dissolved metals data from the 2-, 5- and 10-day samples may also be used to identify metals of concern.

⁵ The amount of attenuation observed after the first sampling event will be used to inform decision-making about contact time for subsequent sampling.

4.3.1 Baseline Aerobic Microcosm Tests and Biomass Generation

A 15-day aerobic microcosm test will be conducted concurrent with the COPC treatment test. For this test, a sample of homogenized Site soil and groundwater containing moderate levels of COPCs will be exposed to ambient aerobic conditions (i.e., 21% oxygen) to stimulate microbial activity. Reactors will be constructed by filling 250 mL (nominal volume) glass bottles with approximately 200 mL of Site groundwater and 75 g of homogenized UHG soil, leaving a nominal headspace for gas exchange. The reactors will be amended with a redox indicator (resazurin), and neat oxygen gas will be re-amended throughout the study as required based on resazurin color to ensure aerobic conditions are maintained. Aqueous samples from the 15-day aerobic microcosm will be collected and analyzed as outlined in Table 7 below.

Table 7: Monitored Parameters – Baseline Aerobic Microcosm

Analyte	Frequency	Laboratory Method
VOCs - GW	Days 0, 7 and 15	EPA Method 8260B
SVOCs - GW	Days 0, 7 and 15	EPA Method 8270
Anions	Days 0, 7 and 15	EPA Method 300.0
ORP	Days 0, 7 and 15	Probe
pH	Days 0, 7 and 15	Probe

GW = groundwater

Results from these analyses will be used to establish baseline degradation rates for COPCs due to aerobic biological processes at the Site. Soil from these reactors will be dried and used to inoculate the reactors for the post-ISCO aerobic microcosm test described in Section 4.3.2 below.⁶

4.3.2 Post-ISCO Aerobic Microcosm Tests

For each oxidant dose selected for inclusion in the detailed studies, additional reactors will be included in the COPC treatment test for use in the post-ISCO aerobic microcosm (see Attachment B). These reactors will be constructed with the same soil and groundwater quantities used in the detailed oxidant and comparative screening studies (see Section 3.4), dosed with the oxidant(s) selected for detailed testing and incubated for the full 15-day test duration to allow for chemical oxidation.

Assuming detectable concentrations of COPCs are present after 15 days of oxidative treatment, microcosm tests will be conducted on the oxidized Site materials to assess the feasibility of

⁶ Additional continuous reactors will be included in the baseline aerobic microcosm to ensure sufficient soil mass for inoculation of all post-ISCO microcosms.

aerobic bioremediation as a secondary treatment step. At the conclusion of the COPC treatment test, the contents of the reactors will be quenched (if needed based on 15 day oxidant measurements) with ascorbic acid to simulate oxidant depletion, and approximately 15 g of soil from the baseline aerobic microcosm (Section 4.3.1) will be added to each reactor (bringing the total soil mass to approximately 90 g) to inoculate the oxidized material with Site-specific microorganisms following the completion of ISCO treatment.

Controls and treatments will be constructed as detailed in Table 8 below and in Attachment B.

Table 8: Treatments and Controls for Post-ISCO Biotreatability Study

Treatment/Control		Description
1	ISCO Control	ISCO pretreatment, no amendments
2	Aerobic Treatment	ISCO pretreatment and amended with oxygen
3	Aerobic Treatment Amended with Nutrients	ISCO pretreatment and amended with oxygen, nitrogen and phosphorous

Microcosms will be sealed with Mininert™ valves to allow repetitive sampling of each microcosm, and to allow addition of amendments to sustain metabolic/biodegradation activities. All aerobic controls and treatments will be amended with resazurin. Neat oxygen gas will be re-amended throughout the study as required based on resazurin color to ensure aerobic conditions are maintained. One set of the aerobic treatment microcosms will be used to measure intrinsic biodegradation activity and will not receive amendments except for oxygen to maintain aerobic conditions. The second set of aerobic treatment microcosms will be amended with oxygen and standard nutrients (nitrogen and phosphorus) at approximately a 100:10:1 carbon: nitrogen: phosphorus ratio (concentrations to be determined based on Site COPCs remaining after oxidant treatment). These post-ISCO microcosms will be incubated for a period of approximately 45 days.

Monitored Parameters

Aqueous samples will be collected and analyzed as specified in Table 9 below. The ISCO control microcosms will be sampled on Day 0 and at the end of the incubation period. Analytical results from the ISCO controls will be used to represent the time zero concentrations in the aerobic treatment microcosms. Sampling intervals for individual treatments may be modified (either shorter or longer intervals) during the study based on observed microbial activity, degradation rates, and depletion of electron donors/acceptors.

Table 9: Scope of Microcosm Sampling and Analyses

Analyte	Frequency	Laboratory Method
VOC - GW	Days 0*, 15, 30, and 45	EPA Method 8260B
SVOC - GW	Days 0*, 15, 30, and 45	EPA Method 8270
Anions	Days 0*, 15, 30, and 45	Ion Chromatography
TKN and P**	Days 0*, 15, 30, and 45	Laboratory Specific Method
pH	Days 0*, 15, 30, and 45	Probe

*Controls will also be sampled at time zero and end of the study. Treatment microcosms will be sampled at two mid-point events and end of the study

**Nutrient amended microcosms only

5. SUMMARY

The testing procedures described in this work plan are designed to determine if ISCO is a viable treatment alternative for Site-related COPCs in the suspected source area and to identify the most favorable oxidation technology for further evaluation at field-scale. Attachment C provides a summary of the contributions of each study phase to the overall program objectives. The comparative screening studies (Section 3) will be used to evaluate effectiveness of COPC destruction, oxidant consumption, and reaction rate for several oxidation technologies. The detailed studies (Section 4) will be used to further evaluate the two most favorable oxidants to determine the optimal oxidant dose for treating Site COPCs. The detailed studies will also assess the potential for ISCO to influence metals mobility in the source area and the effectiveness of aerobic bioremediation following the application of ISCO. Knowledge gained from this testing program will be used to design a field-scale pilot test, remedy and monitoring program for *in-situ* treatment of Site COPCs.

ATTACHMENTS

Attachment A
ISCO Bench Test Work Plan
Cabot Carbon/Koppers Superfund Site

Table A.1: Preliminary Estimates of Oxidant Doses for Comparative Screening Tests – Groundwater Only

Oxidant	Ozone	Nitrogen Controls	Catalyzed Hydrogen Peroxide	Persulfate	None (Unamended Control)
Activator	N/A	N/A	Chelated Fe	Hydrogen Peroxide	N/A
Oxidant Dose*	3% O ₃ in O ₂	N/A	25-100 g/L H ₂ O ₂	25-50 g/L S ₂ O ₈ ²⁻	N/A
Activator Concentration(s)	N/A	N/A	2.5-10% Chelated Iron***	1-2% H ₂ O ₂	N/A
Air Flow Rate for Ozone Sparging	25-75 mL/min	N/A	N/A	N/A	N/A

Table A.2: Preliminary Estimates of Oxidant Doses for Comparative Screening Tests – Soil and Groundwater Slurry

Oxidant	Ozone	Ozone	Catalyzed Hydrogen Peroxide	Persulfate	Amended Controls**	None (Unamended Control)
Activator	N/A	Hydrogen Peroxide	Chelated Fe	Hydrogen Peroxide	N/A	N/A
Oxidant Dose*	3% O ₃ in O ₂	3% O ₃ in O ₂	25-100 g/L H ₂ O ₂	25, 50 g/L S ₂ O ₈ ²⁻	N/A	N/A
Activator Concentration(s)	N/A	0.1 to 0.5 % H ₂ O ₂	2.5-10% Chelated Iron***	1%, 2% H ₂ O ₂	N/A	N/A
Air Flow Rate for Ozone Sparging	25-75 mL/min	25-75 mL/min	N/A	N/A	N/A	N/A

Notes:

* - Screening level tests are intended to be high dose tests to evaluate the treatment of target COPCs with each oxidant. Non-target oxidant demand tests will be conducted as a preliminary step to inform the selection of oxidant concentrations/dosages for screening level tests.

** – Amended controls for slurry-phase tests will consist of the following:

- Matrix activated controls for PAP
- Nitrogen controls for ozone tests

*** – Chelated iron concentration range is approximate, proprietary activator for CHP to be provided by In-Situ Oxidative Technologies, Inc.

Attachment B
ISCO Bench Test Work Plan
Cabot Carbon/Koppers Superfund Site

	Reactor Constituents		Duration (Days)	Sampling Events	# of Continuous Reactors	# of Sacrificial Reactors	Total # of Reactors	Sample Matrix	Total Organic Carbon (TOC) ⁴	Parameters Sampled from Continuous Reactors				Parameters Sampled from Sacrificial Reactors (Destructive Sampling)				
	Site Groundwater (mL)	Homogenized Site Soils ⁷ (g)								Number of Samples				Number of Samples				
										Anions	pH / ORP	Oxidant ⁶	Activator (peroxide)	Nutrients (P+ TKN)	Metals	VOCs 8260 and SVOCs 8270	Terpenes 8270C	
Required Sample Volumes										10 g	0 mL	5 mL	5 mL	5 mL	10 mL	50 mL	80 mL	40 mL
Baseline Analyses	N/A	N/A	N/A															
Totals - Baseline Analyses	N/A	N/A	N/A															
Baseline Non-Target Oxidant Demand Test (Background Samples)	200	75	10															
Treatments																		
Persulfate																		
Matrix Activated Persulfate - dose 1				2, 5, 10 days	1	0	1	GW	0	3	3	0	0	0	0	0	0	0
Peroxide Activated Persulfate - dose 1				2, 5, 10 days	1	0	1	GW	0	3	3	3	0	0	0	0	0	0
Peroxide Activated Persulfate - dose 2				2, 5, 10 days	1	0	1	GW	0	3	3	3	0	0	0	0	0	0
CHP																		
Catalyzed Hydrogen Peroxide (CHP) - dose 1				2, 5, 10 days	1	0	1	GW	0	3	3	0	0	0	0	0	0	0
Catalyzed Hydrogen Peroxide (CHP) - dose 2				2, 5, 10 days	1	0	1	GW	0	3	3	0	0	0	0	0	0	0
Ozone																		
Ozone				2, 5, 10 days	1	0	1	GW	0	3	20	0	0	0	0	0	0	0
Ozone with Hydrogen Peroxide - dose 1				2, 5, 10 days	1	0	1	GW	0	3	20	10	0	0	0	0	0	0
Ozone with Hydrogen Peroxide - dose 2				2, 5, 10 days	1	0	1	GW	0	3	20	10	0	0	0	0	0	0
Totals - Baseline Test (Background Samples)	1600	600	10		8	0	8	GW Soil	0 2	24 0	75 0	26 0	0 0	0 0	0 0	0 0	0 0	0 0
Comparative Screening Test - Aqueous Phase	250	0	5															
Controls																		
Unamended Control				0, 5 days	1	4	5	GW	0	4	0	0	0	0	0	4	0	0
Nitrogen Control for Ozone Test				0, 5 days	1	4	5	GW	0	4	0	0	0	0	0	4	0	0
Treatments																		
Persulfate																		
Peroxide Activated Persulfate - dose 1				5 days	1	2	3	GW	0	2	2	2	0	0	2	0	0	0
CHP																		
Catalyzed Hydrogen Peroxide (CHP) - dose 1				5 days	1	2	3	GW	0	2	2	0	0	0	2	0	0	0
Ozone																		
Ozone				5 days	1	2	3	GW	0	2	20	0	0	0	2	0	0	0
Totals - Aqueous Phase Screening Test	4750	0	0		5	14	19	GW Soil	0 0	14 0	24 0	2 0	0 0	0 0	0 0	14 0	0 0	0 0
Comparative Screening Test - Slurry Phase	200	75	5															
Controls																		
Unamended Control				0, 5 days	1	4	5	GW Soil	0 0	4 0	0 0	0 0	0 0	0 0	4 4	0 0	0 0	0 0
Nitrogen Control for Ozone Tests				0, 5 days	1	4	5	GW Soil	0 0	4 0	0 0	0 0	0 0	0 0	4 4	0 0	0 0	0 0
Treatments																		
Persulfate																		
Matrix Activated Persulfate - dose 1				5 days	1	2	3	GW Soil	0 0	2 0	2 0	0 0	0 0	0 0	2 2	0 0	0 0	0 0
Peroxide Activated Persulfate - dose 1				5 days	1	2	3	GW Soil	0 0	2 0	2 0	2 0	0 0	0 0	2 2	0 0	0 0	0 0
Peroxide Activated Persulfate - dose 2				5 days	1	2	3	GW Soil	0 0	2 0	2 0	2 0	0 0	0 0	2 2	0 0	0 0	0 0
CHP																		
Catalyzed Hydrogen Peroxide (CHP) - dose 1				5 days	1	2	3	GW Soil	0 0	2 0	2 0	0 0	0 0	0 0	2 2	0 0	0 0	0 0
Catalyzed Hydrogen Peroxide (CHP) - dose 2				5 days	1	2	3	GW Soil	0 0	2 0	2 0	0 0	0 0	0 0	2 2	0 0	0 0	0 0
Ozone																		
Ozone				5 days	1	2	3	GW Soil	0 0	2 0	20 0	0 0	0 0	0 0	2 2	0 0	0 0	0 0
Ozone with Hydrogen Peroxide - dose 1				5 days	1	2	3	GW Soil	0 0	2 0	20 0	10 0	0 0	0 0	2 2	0 0	0 0	0 0
Totals - Slurry Phase Screening Test	6200	2325	5		9	22	31	GW Soil	0 0	22 0	50 0	14 0	0 0	0 0	22 22	0 0	0 0	0 0
Detailed Oxidant Study - Oxidant Consumption Test	200	75	15															
Oxidant A (to be selected)³																		
Oxidant Consumption - dose 1				2, 5, 10, 15 days	2	0	2	GW	0	8	8	8*	0	0	0	0	0	0
Oxidant Consumption - dose 2				2, 5, 10, 15 days	2	0	2	GW	0	8	8	8*	0	0	0	0	0	0
Oxidant B (to be selected)³																		
Oxidant Consumption - dose 1				2, 5, 10, 15 days	2	0	2	GW	0	8	8	0	0	0	0	0	0	0
Oxidant Consumption - dose 2				2, 5, 10, 15 days	2	0	2	GW	0	8	8	0	0	0	0	0	0	0
Totals - Oxidant Consumption Test	1600	600	15		8	0	8	GW Soil	0 0	32 0	32 0	16 0	0 0	0 0	0 0	0 0	0 0	0 0
Detailed Oxidant Study - COPC Treatment Test¹	200	75	15															
Controls²																		
Unamended Control				0, 10, 15 days	2	6	8	GW Soil	0 0	6 0	0 0	0 0	0 0	6 6	6 6	4* 4*		
Treatments																		
Oxidant A (to be selected)																		
COPC Treatment				2, 5, 10, 15 days	2	8	10	GW Soil	0 0	8 0	8 0	0 0	0 0	8 8	8 8	2* 2*		
Oxidant B (to be selected)																		
COPC Treatment				2, 5, 10, 15 days	2	8	10	GW Soil	0 0	8 0	8 0	0 0	0 0	8 8	8 8	2* 2*		
Totals - COPC Treatment Test	5600	2100	15		6	22	28	GW Soil	0 0	22 0	16 0	0 0	0 0	22 22	22 22	8 8		

Attachment B
ISCO Bench Test Work Plan
Cabot Carbon/Koppers Superfund Site

	Reactor Constituents		Duration (Days)	Sampling Events	# of Continuous Reactors	# of Sacrificial Reactors	Total # of Reactors	Sample Matrix	Total Organic Carbon (TOC) ⁴	Parameters Sampled from Continuous Reactors				Parameters Sampled from Sacrificial Reactors (Destructive Sampling)			
	Site Groundwater (mL)	Homogenized Site Soils ⁷ (g)								Number of Samples				Number of Samples			
									Anions	pH / ORP	Oxidant ⁶	Activator (peroxide)	Nutrients (P+ TKN)	Metals	VOCs 8260 and SVOCs 8270	Terpenes 8270C	
Metals Attenuation Test	0	75	30														
<i>Oxidant A (to be selected)</i> Metals Attenuation				0, 7, ...	0	4	4	GW		0	4**	0	0	0	4	0	0
<i>Oxidant B (to be selected)</i> Metals Attenuation				0, 7, ...	0	4	4	GW		0	4**	0	0	0	4	0	0
Totals - Metals Attenuation Test	0	600	30		0	8	8	GW Soil	0 0	8 0	0 0	0 0	0 0	8 0	0 0	0 0	
Baseline Aerobic Bio	200	75	15														
No ISCO - Bio Only				0, 7, 15 days	4^^	2	6	GW		3	3	0	0	0	0	3	0
Totals - Baseline Aerobic Bio	1200	450	15		4	2	6	GW Soil	3 0	3 0	0 0	0 0	0 0	0 0	3 0	0 0	
Post-ISCO Aerobic Bio	200	75	45														
<i>Oxidant A (to be selected)</i> ISCO control				0, 45 days	1	1	2	GW		2	2	0	0	0	0	2	0
ISCO + oxygen				15, 30, 45 days	1	3	4	GW		3	3	0	0	0	0	3	0
ISCO + oxygen + nutrients				15, 30, 45 days	1	3	4	GW		3	3	0	0	3	0	3	0
<i>Oxidant B (to be selected)</i> ISCO control				0, 45 days	1	1	2	GW		2	2	0	0	0	0	2	0
ISCO + oxygen				15, 30, 45 days	1	3	4	GW		3	3	0	0	0	0	3	0
ISCO + oxygen + nutrients				15, 30, 45 days	1	3	4	GW		3	3	0	0	3	0	3	0
Totals - Post-ISCO Aerobic Bio	4000	1500	45		6	14	20	GW Soil	16 0	16 0	0 0	0 0	6 0	0 0	16 0	0 0	

	Groundwater (L)	Soil (kg)
Total Quantities of Site Materials³	27.4	9.20
Total Quantities of Background Site Material³	1.6	0.6

	Total Organic Carbon (TOC)	Anions	pH / ORP	Oxidant (peroxide/persulfate)	Activator (peroxide)	Nutrients (P+ TKN)	Metals	VOCs 8260 and SVOCs 8270	Terpenes 8270C
Total Number of Analyses - GW	0	19	141	197	58	6	30	79	8
Total Number of Analyses - Soil	2	0	0	0	0	0	22	46	8

Notes

GW - Groundwater

- In addition to the reactors listed, the reactors for the Post-ISCO Bioremediation tests (20 reactors per oxidant) will also be constructed during the COPC Treatment Test and allowed to run for the full 15-day duration.
- If ozone is selected as one of the oxidants for this phase of testing, a nitrogen control will also be included.
- Material quantities have been adjusted to address the possibility that ozone is selected for detailed study (see note 2 above).
- TOC will be included in baseline analysis for the composite soil sample. The groundwater composite will not be analyzed for TOC.
- Samples from the baseline non-target oxidant demand test will be collected from areas of the site with low concentrations of COPC, intended to represent background non-target oxidant demand from a typical (uncontaminated) UGH formation soils.
- Liquid oxidant samples will be collected in the aqueous phase, while samples of ozone will be collected from gas streams at influent and effluent points.
- Reactors will be constructed using homogenized UHG soil and homogenized soil with residual NAPL collected from the surficial aquifer combined in a 4:1 ratio by mass. The quantities indicated represent the total soil quantity in each reactor.

*Terpenes analysis will be conducted on Days 0 and 15 for the unamended control of the detailed study and on Day 15 only for reactors in the COPC Treatment test.

⁴Activator (peroxide) samples will be needed only if persulfate or ozone with peroxide is selected as one of the oxidants for detailed testing.

⁵pH samples from the metals attenuation test will be taken at the end of each contact period not from "continuous" reactors.

⁶Four continuous reactors will be included in the baseline aerobic microcosm to provide enough soil for inoculation of post-ISCO microcosms.

ATTACHMENT C - ISCO BENCH TEST PROCESS SUMMARY

Cabot Carbon/Koppers Superfund Site

Site Soil and
Groundwater
Samples

- **Source Characterization Activities**

- Assess concentrations of COPCs in Site soil and groundwater
- Collect samples for use in bench testing program

Two Most
Favorable
Oxidants

- **Comparative Screening Studies**

- Aqueous Phase Test
 - 5-day test with Site groundwater to evaluate COPC treatment with limited competing oxidant demand
 - Oxidants: Ozone, CHP, PAP
- Slurry Phase Test
 - 5-day test with Site soil and groundwater to evaluate treatment under *in-situ* conditions.
 - Oxidants: Ozone, Ozone plus Peroxide, CHP, PAP

Most Favorable
Oxidant for
Compatibility with
Site Geochemistry
and Aerobic
Bioremediation

- **Detailed Studies**

- ISCO Tests
 - *Oxidant Consumption Test* - 15-day test with Site soil and groundwater to evaluate oxidant consumption rates and determine optimal oxidant dose
 - *COPC Treatment Test* - 15-day test with Site soil and groundwater to evaluate COPC treatment with optimal oxidant dose
 - *Metals Attenuation Test* - 30-day post-ISCO test to evaluate attenuation of metals concentrations in Site groundwater
- Aerobic Bioremediation Tests
 - *Baseline Aerobic Microcosm* - 15-day test to evaluate COPC degradation under ambient aerobic conditions and to prepare a culture of native biomass
 - *Post-ISCO Aerobic Microcosm* - 45-day test to evaluate the effectiveness of bioremediation following the application of ISCO

- **Field-Scale Implementation and Monitoring Program**