100% DESIGN
ENHANCED AEROBIC BIOREMEDIATION
at
FORMER CHLOROBENZENE PROCESS AREA

W.G. KRUMMRICH FACILITY
SAUGET, ILLINOIS

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Executive Summary

XDD, LLC (XDD) has prepared this 100% design document for Full-Scale Enhanced Aerobic Bioremediation (*EABR 100% Design*) for the remediation of saturated zone impacts at the Solutia Inc. (Solutia) W.G. Krummrich Facility in Sauget, Illinois (site). This *EABR 100% Design* contains the design basis for implementation, and schedule for full-scale Enhanced Aerobic Bioremediation (EABR) treatment in the Former Chlorobenzene Process Area (CPA) of the site. A separate 100% design document has been prepared for the Full-Scale Thermally Enhanced Soil Vapor Extraction (T-SVE) treatment of the unsaturated zone impacts in the CPA. These remedies are being implemented per the United States Environmental Protection Agency (USEPA) issued *Explanation of Significant Difference (ILD 000 802 702)* dated April 26, 2011.

Treatment Areas: The area targeted for EABR treatment is an approximately 3.5 acre area within the CPA. The target treatment area is shown on **Figure ES-1**. The contaminants of concern (COCs) are volatile organic compounds (VOCs), primarily monochlorobenzene (MCB), 1,2-dichlorobenzene (1,2-DCB), 1,3-DCB, and 1,4-DCB, 1,2,4-trichlorobenzene (1,2,4-TCB), and benzene. The total COC mass in the unsaturated zone treatment interval is estimated at 386,000 pounds (lbs).

Geology and Hydrogeology: The target depth interval for the EABR treatment is the within the saturated portion of the Shallow Hydrogeologic Unit (SHU), between approximately 15 and 30 feet below ground surface (feet bgs). The SHU generally consists of silty sands, which transition to fine/medium sands with depth. According to the CPA boring logs, there are indications of clay and silty clay layers (ranging from 2 to 7 feet thick) within the SHU. The top of these clay and silty clay layers are encountered at depths generally ranging between 18 to 26 feet bgs.

Historically, groundwater levels in the treatment area have ranged from 10 feet bgs to greater than 15 feet bgs. Water levels are directly influenced by the level of the Mississippi River (located approximately one mile west of the site).

Overview of EABR Design: EABR will be implemented by injection of pure oxygen (i.e., gaseous O_2) into the saturated zone to increase dissolved oxygen (DO) levels. This will stimulate the native aerobic bacteria to degrade the target COCs. This injection technology is also referred to as "biosparging". Treatability studies have been conducted for this site and results indicate that the target COCs are degradable.

EABR Well Network: EABR will be implemented using a dual-level injection well network (i.e., shallow and deep well screens). Due to the presence of a low permeability silty clay layer in portions of the CPA, a single depth injection well may not effectively distribute oxygen throughout the entire target interval. Based on field testing results, where clay layers are observed, the deep EABR wells are designed to target the fine/medium sands between approximately 22 and 30 feet bgs, and the shallow EABR wells are designed to target the depth interval between approximately 15 and 22 feet bgs within the silty sand to fine/medium sands. However, in the areas where no clay layers are present, the deep EABR wells are designed to target the entire treatment interval of 15 to 30 feet bgs.

The silty clay layers will not be directly targeted by the EABR system because the low permeability prevents direct injection of O_2 into these units. However oxygen will potentially diffuse into the low permeability silty clay layers, and COCs will diffuse out of these low permeability layers into the aerobic saturated zone, to potentially achieve additional COC mass reduction.

EABR System Equipment Overview: The EABR system will include an oxygen supply (i.e., bulk liquid oxygen tank with vaporizers), and an oxygen pulse distribution system with a Programmable Logic Controller (PLC) to control flow rates and distribute the oxygen to the individual injection wells. The distribution system will be equipped with electromechanical solenoid valves and mass flow control meters to control flow rates and distribute the oxygen to individual injection wells.

EABR Operation Strategy: Biosparging is typically conducted using a pulse-injection mode. Pulse injection is conducted by injecting into a number of individual wells using an "on/off" cycling approach (i.e., one set of wells will be "on" at a time while the others are "off"). The volume of oxygen delivered during the injection "on" time needs to be sufficient to maintain the oxygen levels to support aerobic degradation, but should also not exceed the aquifer's capacity to solubilize the gas (oxygen solubility is typically in the 50 milligram per liter [mg/L] range).

The wells are divided into 30 groups containing between 4 and 8 wells each, and within a group, oxygen will be delivered to one well at a time. Approximately 10 wells (one each from 10 groups) will be "on" at a time, while the others are "off." Wells and groups will be sequentially turned "on" and "off" (pulsed) to deliver oxygen into the subsurface. The pulsing rate will be optimized during field operations to maintain dissolved oxygen (DO) levels.

A summary of the EABR well counts and overall design parameters is presented in **Table ES-1** (see next page).

Table ES-1: EABR System Design Summary

Parameter	Value	Notes
Total Number of EABR Wells	191	71 shallow, 120 deep injection locations.
Total Number of Piezometers	23	11 shallow, 12 deep locations.
EABR Well Screens	Shallow = 21-23.5 feet bgs Deep = 29-31.5 feet bgs	Actual well screen placement will be adjusted based on actual geological conditions encountered.
Piezometer Well Screens	Shallow = 17-22 feet bgs Deep = 25-30 feet bgs	
EABR Well Spacing	40 feet between rows 30 feet center-to-center within rows	Rows are placed 40 feet apart in direction of groundwater flow (generally westerly). Wells have 30-foot center to center spacing within each row.
Oxygen Injection Rates	3 to 5 scfm per well (average). Maximum well head pulse rates up to 10 scfm can be applied, if needed to increase oxygen distribution.	Total system flow will be 30 scfm on average, with maximum total pulse capacity of 50 scfm.
Well Groups	30 groups containing 4 to 8 well each; only 1 well "on" from a group at a time; approximately 10 wells (1 each from 10 group) "on", while others are "off".	System manifolding will allow injecting and controlling flow into individual wells. At any given time, approximately 10 wells (one each from a group) will operate simultaneously.
Oxygen Injection Mode	Pulsing of between 10 and 30 minutes "on" and 2 to 8 hours "off" (Startup: 15 minutes "on" 6 hours "off")	Oxygen injection will be conducted using a pulsing "on/off" cycle approach which involves injecting into 10 wells at a time.
Injection Pressure	Shallow 3 to 17 psig Deep 6 to 24 psig	Wellhead injection pressures will be limited to below the upper end of the pressure range to prevent the potential of subsurface fracturing.

Notes:

scfm = Standard cubic feet per minute
CF = cubic feet
feet bgs = feet below ground surface
psig = pounds per square inch gauge pressure

Remediation Objectives: The overall remediation objective is to reduce COC mass within the saturated zone of the CPA. Attainment of objectives will be based upon the following observations and evaluations:

- Oxygen utilization rates have declined (i.e., suggesting that bacteria are no longer utilizing as much oxygen because COC mass has been depleted and/or has reached mass-transfer limiting conditions).
- Groundwater monitoring parameters suggest that conditions for biological treatment have been created and remain favorable to support the biological degradation processes.
- Annual assessment of soil COC mass reductions.

EABR Shutdown and Potential Transition to Monitored Natural Attenuation: As outlined in the EABR shutdown protocol, when the EABR system has reached a condition where oxygen utilization has declined and/or COC mass reduction has reached a mass-transfer limited condition, there may be little additional benefit of continuing EABR operations. The EABR shutdown protocol was approved (with conditions) by USEPA in a letter dated March 28, 2011. After a minimum of two years of EABR operation, and on an annual basis thereafter, an evaluation of potential impacts to groundwater and/or potential human health risks associated with the residual COC concentrations will be conducted. Based on the results of these risk evaluations, there are two potential options:

- If the risk evaluations indicate that there is an acceptable level of risk and/or residual risks can be addressed by institutional controls, then a recommendation would be made to shut down the EABR system.

- If the risk evaluations indicate the need for further action, an evaluation to determine if EABR operation should continue, or if Monitored Natural Attenuation (MNA) will address the residual soil concentrations in the saturated zone, will be conducted.

A report will be prepared for USEPA making the appropriate recommendation to either shut down the EABR system or transition into an MNA program. Upon USEPA's approval of either recommendation, the appropriate action would be taken.

Operations and Monitoring: Process and performance monitoring will be conducted during EABR system operations to evaluate overall oxygen distribution and bioremediation performance. Soil/groundwater sampling will be conducted annually to assess the overall COC mass reduction. Additional data collection will include measurements of dissolved oxygen levels and various groundwater parameters to confirm that conditions favorable for aerobic biodegradation are maintained. The performance monitoring data will be used to optimize the EABR system.

The system optimization strategies will include:

- Adjustment of oxygen injection rates to maintain aerobic conditions within the target areas. Areas that achieve clean-up faster than others may be taken offline as appropriate.
- Conducting oxygen utilization assessments by temporarily turning off portions of the system to assess oxygen utilization rates.

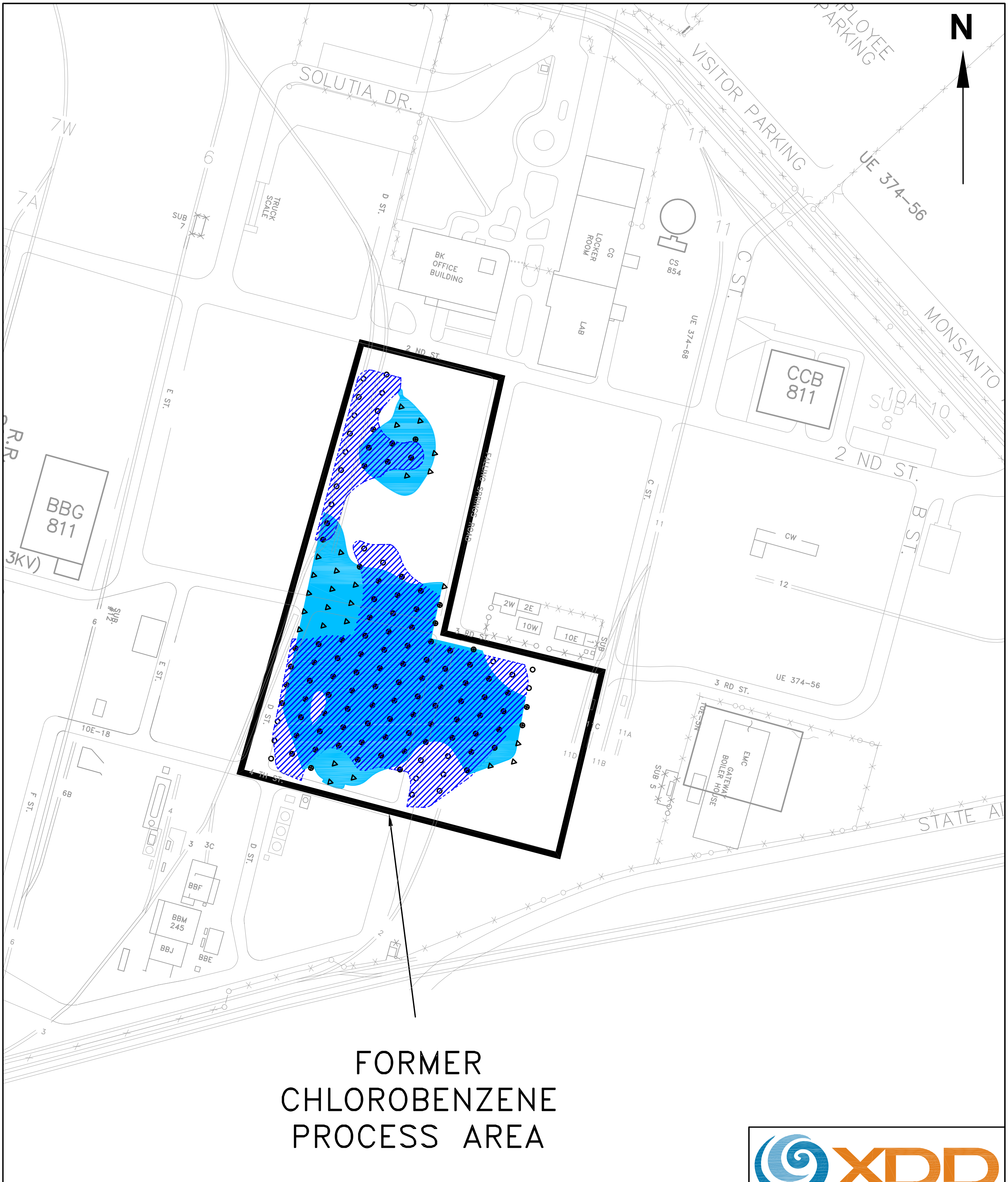
Schedule: The EABR system is anticipated to begin operation by the beginning of 2012 and operate for up to four years. The project schedule is summarized in **Table ES-2**.

Table ES-2: Summary of Project Schedule

Task Description	Dates
EABR Implementation	
• Design	April-September 2011
• Permitting	April-October 2011
• Construction	September 2011-February 2012
• Construction Completion Report	Submittal March 2012
• Operation	March 2012-July 2016
• Soil Sampling	March 2013-March 2016
• EABR Shutdown Evaluation/Recommendation Report	Submittal May 2016
Demobilization/Decommissioning[1]	**December 2020-February 2021**

Notes:

[1] = The T-SVE/Bioventing (BV) system operation may still be ongoing after shutdown of the EABR system. Therefore, for cost effectiveness, the final demobilization and decommissioning of the EABR system may be postponed until completion of the T-SVE/BV operations when the entire system can be decommissioned at the same time (refer to the T-SVE 100% Design).



🟦 15-22 FOOT INTERVAL COC EXCEEDANCE AREA

▨ 22-30 FOOT INTERVAL COC EXCEEDANCE AREA

△ EABR SHALLOW WELL LOCATION

○ EABR SHALLOW WELL LOCATION

⊕ EABR COMBINATION SHALLOW AND DEEP WELL LOCATION

SCALE: AS SHOWN	TITLE: SITE PLAN W.G. KRUMMRICH FACILITY SAUGET, IL
DATE: NOVEMBER 2011	
PROJECT NO.: 11003	
CLIENT: SOLUTIA INC.	
DRAWN BY: ELS	DRAWING NO.: FIGURE ES-1 — REV: 2
CHECKED BY: DK	
PROJ. MGMT. APPROVAL: SC	

1.0 INTRODUCTION

This design document (*100% Design*) provides drawings and specifications for the Enhanced Aerobic Bioremediation (EABR) System for treatment of the former Chlorobenzene Process Area (CPA) at Solutia Inc. (Solutia) W.G. Krummrich Facility in Sauget, IL (site, see **Figure 1**).

EABR will be applied to the saturated zone soil in the CPA. A separate technology, Thermally Enhanced Soil Vapor Extraction (T-SVE), will be used to treat the unsaturated zone portion of the CPA. A separate design document has been prepared for the T-SVE system. These remedies are being implemented per the United States Environmental Protection Agency (USEPA) issued *Explanation of Significant Difference (ILD 000 802 702)* dated April 26, 2011.

The following information is included in this 100% design document:

- Site background information, including a summary of geology, hydrogeology, and distribution of the contaminants of concern (COCs) within the former CPA.
- Overview of the remediation approach, including the design basis, remedial goals, and shutdown protocols.
- Detailed design drawings for the following components:
    - Subsurface well layouts, well construction details, and system manifolding.
    - Process equipment design details including oxygen supply, and oxygen distribution equipment.
    - General infrastructure (equipment building, area barricading, insulating cap, etc.).
- General Operations, Maintenance, and Monitoring (OM&M) protocols.
- Anticipated project schedule.

The drawings contained in this design are schematics and layouts and as such do not show all potential construction conditions. Minor modifications to the specifications provided in this 100% design document can occur during the remedy installation/construction, including but not limited to the modifications due to physical interferences and obstructions.

1.1 SUMMARY OF REMEDIATION APPROACH

EABR will be applied by injection of pure oxygen (i.e., gaseous O_2) into the saturated zone to increase dissolved oxygen (DO) levels. This will stimulate the native aerobic bacteria to degrade the target COCs. This injection technology is also referred to as “biosparging”.

A treatability study[1] performed by Solutia in 2006 demonstrated that the major constituents (MCB and DCB isomers) are biodegradable by aerobic processes (i.e., there were no toxicity effects, naturally occurring bacteria were present, etc.). A screening evaluation was also conducted by Groundwater Services, Inc. (GSI)[2] which indicated that EABR could be an effective treatment technology for the saturated portion of the Shallow Hydrogeologic Unit (SHU). GSI reviewed EABR technology, considering site-specific conditions, and used the United States Environmental Protection Agency (USEPA) screening tool[3], which indicated that EABR via pure oxygen injection (POI) is “likely to be effective” at the site.

EABR will be implemented within the upper saturated portion of the SHU with a target treatment interval of 15 to 30 feet bgs. Due to the presence of low permeability silty clay layers in portions of the treatment interval, a single depth injection well may not effectively distribute

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[1] Groundwater Services, Inc. (GSI). *Mass Removal Treatability Tests, Enhanced Aerobic Bioremediation, Saturated Shallow Hydrogeologic Unit, Solutia Inc., W.G. Krummrich Facility, Sauget, Illinois*. May 2006.

[2] GSI. *Suitability of Enhanced Aerobic Bioremediation (EABR) via Pure Oxygen Injection (POI) for SHU Treatment at the Former Chlorobenzene Process Area.* February 4, 2011.

[3] USEPA. *How to Evaluate Alternative Cleanup Technologies for Underground Storage Tank Sites, A Guide for Corrective Action Plan Reviewers*. EPA 510-R-04-002, May 2004.

oxygen throughout the entire target interval (refer to **Section 2.3** for geology). An oxygen injection field test was conducted in the treatment area in June 2011[4]. The field testing results indicated that dual-level wells (a shallow and a deep well) are necessary in the areas where lower permeability (e.g., clay) layers are observed within the treatment interval. However, in the areas where no clay layers are present, a deep injection well can influence the entire treatment zone of 15 to 30 feet bgs. Therefore, the EABR well design includes deep wells to target either the entire treatment interval where no clay layers are present, or the fine/medium sands below the clay layer, generally between 22 and 30 feet bgs, and shallow wells to target the silty sand to fine/medium sands shallower than the clay layer, generally between 15 and 22 feet bgs.

Low Permeability Silty Clay Layers: The silty clay layers that have been identified in portions of the saturated zone (ranging in depth between 18 and 26 feet bgs, and ranging in thickness from 2 to 7 feet thick) will not be directly targeted by the EABR system. Direct injection of O_2 into these units is not feasible due to the low permeability. However, oxygen will potentially diffuse into the low permeability silty clay layers, and COCs will diffuse out of these low permeability layers into the aerobic saturated zone to potentially achieve additional COC mass reduction.

1.2 REMEDIATION OBJECTIVES

The overall remediation objective is to reduce COC mass within the saturated zone within the CPA. A *Proposed Protocol for Completing Enhanced Aerobic Bioremediation Operations* memorandum dated February 24, 2011 (**Section 14.6**) outlined the basis for making the recommendation to shut down EABR operations, and was approved with conditions by the USEPA in a letter dated March 28, 2011. Attainment of objectives will be based upon consideration of the following lines of evidence:

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[4] XDD, *Summary of EABR Field Testing Results*, June 24, 2011

1. Oxygen Utilization Rates: As COC mass is depleted over time and becomes mass-transfer limited, the oxygen utilization rate would be expected to decline. A reduction in oxygen utilization rates can be considered the primary line of evidence for anticipating the completion of EABR operations.
2. Groundwater Monitoring: Groundwater COC monitoring will be conducted prior to start-up (baseline) and on an annual basis thereafter. Groundwater data will also be assessed as an additional line of evidence that conditions for biological treatment have been created, and remain favorable to support the biological degradation processes.
3. Assessment of COC Mass: Annual soil sampling will be conducted in the target interval and the reduction of COC mass in the soils will be estimated.

Following the second annual soil sampling event (i.e., after Year 2 of EABR operation), and annually thereafter, an evaluation of potential impacts to groundwater and/or potential human health risks associated with the residual COC concentrations remaining in the saturated zone soils will be conducted. Based on the results of the risk evaluation, there are two potential options:

- If the risk evaluations indicate that there is an acceptable level of risk and/or residual risks can be addressed by institutional controls, then a recommendation would be made to shut down the EABR system.
- If the risk evaluations indicate the need for further action, an evaluation to determine if EABR operation should continue, or if Monitored Natural Attenuation (MNA) will address the residual soil concentrations in the saturated zone.

A report will be prepared for USEPA making the appropriate recommendation to either shut down the EABR system or transition into an MNA program. Upon USEPA's approval of either recommendation, the appropriate action will be taken.

Process and performance monitoring data will be used to assess EABR performance (see **Section 13.1**). Wellfield piezometers will be monitored and the EABR system will be regularly optimized to ensure efficient oxygen distribution (see **Section 13.2**). Soil data will also be collected on an annual basis (see **Section 13.4**) to assess overall remedial performance. The EABR shutdown protocol is included in **Section 13.7**[5]. Note that it may be appropriate to recommend shutdown of portions of the EABR system in a phased manner if sub-areas and/or specific depth intervals meet the remedial objectives sooner than other areas.

1.3 ALTERNATIVE TECHNOLOGY SELECTION

The United States Environmental Protection Agency (USEPA) originally issued a Final Decision (dated February 26, 2008) requiring Solutia to implement In Situ Thermal Desorption (ISTD) within the CPA. ISTD was proposed to treat both the unsaturated and saturated interval between surface grade and 30 feet bgs. However, based on the results of the ISTD pilot-scale implementation and the preliminary full-scale design efforts conducted between 2009 and 2010, ISTD treatment technology was determined to be cost-prohibitive.

Therefore, an alternative remedy of T-SVE for the unsaturated zone and EABR for the saturated zone was proposed by Solutia. These alternative technologies were approved by USEPA in a letter to Solutia dated March 11, 2011. An *Explanation of Significant Difference* (ESD) memorandum, dated April 26, 2011, was also completed by USEPA to document the decision to change the CPA remedy from ISTD to T-SVE/EABR.

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[5] The shutdown protocol is based upon the memorandum entitled "*Protocol for Completing Enhanced Aerobic Bioremediation Operations*", April 13, 2011, XDD, LLC.

2.0 SITE BACKGROUND

The W.G. Krummrich Facility is a 314-acre facility located at 500 Monsanto Avenue, Sauget, Illinois (**Figure 1**). The site is approximately one mile east, and in the floodplain, of the Mississippi River. The site is located in a heavily industrialized area, and has a history of approximately 100 years of industrial operations.

The former CPA is located in the south-central portion of the facility (refer to **Figure 1**). The CPA was previously used for manufacturing monochlorobenzene (MCB) and dichlorobenzene (DCB) from approximately 1926 through 2004. Numerous process tanks and overhead piping runs were present in this area until 2009 when Solutia initiated and subsequently completed dismantlement/demolition of the former CPA unit and associated surface features. The former railcar loading/unloading area located directly east of and adjacent to the CPA (i.e., located directly east of Falling Springs Road) is considered part of the CPA.

The area targeted for EABR treatment is approximately 3.5 acre areas. The target treatment area is shown on **Figure 2**. The primary contaminants of concern (COCs) that are targeted for treatment in the CPA include[6] MCB, 1,2-DCB, 1,3-DCB, and 1,4-DCB. Relatively lower levels of 1,2,4-trichlorobenzene (1,2,4-TCB) and benzene are also present in the CPA area. The total COC mass in the target treatment area is estimated at 386,000 pounds (lbs). Refer to **Section 2.2** for a more detailed description of the COC distribution.

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[6] URS Corporation, *Former Chlorobenzene Process Area Characterization Report*, February 2010.

2.1 TREATMENT AREA CHARACTERIZATION

Soil characterization was conducted by URS Corporation (URS) in 2009 and 2010 within the CPA. Soil cores were geologically characterized and field screened using a photo-ionization detector (PID) for total volatile organic compounds (VOCs). Selected samples were then analyzed for volatile organic compounds (VOCs) by USEPA Method 8260B. The results of the soil characterization are presented in the *Former Chlorobenzene Process Area Characterization Report,* by URS, submitted to USEPA in February 2010 (*Characterization Report*).

For the purposes of this design document, the areas for EABR treatment are based on the characterization provided in the Characterization Report. The extent of the EABR treatment area is presented in **Figure 2**, and was based upon the below characterization criteria. Note that the unsaturated zone characterization criteria are shown for informational purposes only (refer to **Figure 2** of the T-SVE 100% Design for the unsaturated zone soil characterization):

COC	**Characterization Criteria (mg/Kg)**	
	Unsaturated Zone (0-15 feet bgs)	**Saturated Zone (15-30 feet bgs)**
Chlorobenzene	307	342
1,2-Dichlorobenzene	225	237
1,3-Dichlorobenzene	180	190
1,4-Dichlorobenzene	640	640
Benzene	77	77
1,2,4-Trichlorobenzene	13	13

Notes: mg/Kg = milligrams per kilogram

The treatment areas shown on **Figure 2** were based upon the detailed soil characterization, but areas that are inaccessible to EABR technology due to the presence of buildings, roads, subsurface obstructions, etc., are not proposed for treatment.

According to the *Characterization Report*, approximately 135,000 cubic yards (CY) of soil is impacted above the characterization criteria (includes saturated and unsaturated zone soils between 0 and 30 feet bgs).

2.2 CONTAMINANTS OF CONCERN

As previously discussed, the primary COCs are MCB, 1,2-DCB, 1,3-DCB, and 1,4-DCB, 1,2,4-TCB, and benzene. Chemical properties of these COCs are provided in **Appendix A**.

2.2.1 *MAXIMUM SOIL CONCENTRATIONS*

A summary of the soil COC concentrations within the CPA treatment area is presented in **Table 1** (refer to Appendix E of the *Characterization Report* for a complete set of soil data).

2.2.2 *MASS ESTIMATES*

The COC mass estimates are summarized in **Table 2**. The COC mass and the vertical distribution of the COC mass were estimated by URS using the soil characterization data and the Environmental Visualization System (EVS) software (EVS/MVS PRO Version 4.63). The saturated zone contaminant mass was estimated over two depth intervals (15 to 22 feet bgs and 22 to 30 feet bgs). The unsaturated zone contaminant mass for T-SVE treatment was estimated over the 0 to 15 feet bgs interval, and is shown for informational purposes only (refer to the T-SVE 100% Design for treatment of the unsaturated zone).

2.3 GEOLOGY AND HYDROGEOLOGY

The soil in the CPA area consists of a mixture of silt, sand, and gravel with occasional clay layers, and is generally divided into three hydrogeologic units:

- The SHU (Shallow Hydrogeologic Unit), between the water table (typically 15 to 17 feet bgs) and 35 to 40 feet bgs. The unsaturated zone soils (0-15 feet bgs) above the water table are generally considered part of the SHU.
- The Middle Hydrogeologic Unit (MHU), beginning at approximately 35 to 40 feet bgs and extending down to approximately 55 feet bgs.
- The Deep Hydrogeologic Unit (DHU), between approximately 55 feet bgs and the top of the limestone bedrock at approximately 110 feet bgs. The final five feet above the bedrock is characterized as gravel with cobbles.

The unsaturated portion of the SHU (0 to 15 feet bgs) consists of "sandy fill/upper silty sand layer", "intermediate silty clay layer" and "lower silty sand layer". The sandy fill/upper silty sand layer generally extends down from ground surface to between 4 and 10 feet bgs. The intermediate silty clay layer generally ranges in thickness between 4 and 12 feet, and the top of this layer is generally encountered at depths ranging from approximately 4 to 10 feet bgs. In at least one area, the intermediate silty clay layer is encountered at 2 or less feet bgs (e.g., in the vicinity of soil borings CPA-30/CPA-48). In some limited areas the intermediate silty clay layer is absent (e.g., near borings CPA-09 and CPA-55). The lower silty sand layer is encountered below the intermediate silty clay and is encountered at depths ranging between approximately 10 and 18 feet bgs.

The saturated portion of the SHU from 15 to 30 feet bgs generally consists of soils similar to the lower silty sand layer, which transitions to fine/medium sands with depth. According to the CPA boring logs, there are indications of clay and silty clay layers (ranging from 2 to 7 feet thick) within the SHU. The top of these clay and silty clay layers are encountered at depths generally ranging between 18 to 26 feet bgs.

The EABR system is designed to target the lower silty sand layer and fine/medium sand layer within 15 to 30 feet bgs. The clay and silty clay layers within the target interval will not be directly targeted with EABR technology. The T-SVE system is designed to target the 0 to 15 feet bgs interval (refer to the T-SVE 100% Design document).

2.3.1 *GEOLOGICAL CROSS-SECTIONS*

Geological cross-sections for the treatment area are presented in the following figures:

- **Figure 3A** – Cross Section A-A'
- **Figure 3B** – Cross Section B-B'
- **Figure 3C** – Cross Section C-C'

2.3.2 *GROUNDWATER LEVEL TRENDS*

Groundwater levels within the treatment areas are directly influenced by the Mississippi River, approximately one mile west of the site. Since 2008, groundwater levels have been relatively high compared to historical data, and portions of the lower silty sand layer have been submerged[7].

Groundwater flow direction is generally in a westerly direction with a groundwater velocity of approximately 10.4 feet per year (feet/year) reported in the SHU.

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[7] XDD, LLC. *Work Plan for Full-Scale Soil Vapor Extraction,* November 2010.

As shown in **Table 3**, several of the existing monitoring wells in or near the CPA area indicate that the water table elevation is between 6.2 and 13.8 feet bgs as of April 2011. The locations of the existing monitoring wells are shown on **Figure 2**.

Additional piezometers will be installed in the CPA area as part of the EABR remedy. The proposed locations for these piezometers are shown on **Figure 4**.

3.0 EABR DESIGN BASIS

A description of EABR technology and the design parameters used to develop the full-scale design are provided in this section.

3.1 DESCRIPTION OF EABR TECHNOLOGY

EABR technology, also referred to as “biosparging,” is typically applied by injection of atmospheric air or pure gaseous O_2 into the saturated zone to increase DO levels. Adding oxygen to the saturated zone will create an aerobic environment and stimulate the native aerobic bacteria to degrade the target COCs. The bacteria will degrade the COCs as long as a favorable aerobic environment is present (i.e., oxygen, nutrients, etc.) and/or until the COCs are depleted or reach a mass-transfer limited condition.

For this project, EABR will be applied to the saturated portion of the SHU (approximately 15 to 30 feet bgs) using pure oxygen injection. Use of pure oxygen can result in DO concentrations in groundwater up to 50 milligrams per liter (mg/L), as compared to injection of atmospheric air which can achieve DO levels in the 9 to 10 mg/L range. Also, in stratified formations (i.e., permeable sands interbedded with low permeability clay layers), use of pure oxygen will eliminate the potential for formation of nitrogen (N_2) gas pockets in the saturated zone, which can form when relatively insoluble N_2 from atmospheric air injection becomes trapped and cannot escape to the unsaturated zone.

3.2 TREATABILITY STUDY RESULT SUMMARY

A treatability study[8] performed by Solutia in 2006 demonstrated that the major constituents (MCB and DCB isomers) are biodegradable by aerobic processes (i.e., there were no toxicity effects, naturally occurring bacteria were present, etc.). A screening evaluation was also conducted by GSI[9] which indicated that EABR could be an effective treatment technology for the saturated portion of the SHU. GSI reviewed EABR technology, considering site-specific conditions, and used the USEPA screening tool[10], which indicated that EABR via pure oxygen injection (POI) is "likely to be effective" at the site.

3.3 FIELD TESTING RESULT SUMMARY

A field pilot test was conducted in May and June 2011 to assess several design parameters (refer to **Appendix B** for *Summary of EABR Field Testing Results* dated June 24, 2011). Four one-inch diameter injection wells and 19 one-inch diameter monitoring wells were installed in two test areas. During the field testing, pulses of oxygen were injected at varying flow rates, and monitoring was performed to assess oxygen distribution and related parameters. The following bullet points summarize the results of the field testing.

- The direct push technology (DPT) can be a successful drilling method for the EABR wells. All wells that were tested for oxygen injection performed as intended indicating that this drilling method is appropriate for the EABR well installation.
- Dual-level wells (a shallow and a deep well) are necessary in the areas where lower permeability (e.g., clay) layers are observed within the treatment interval. However, in

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[8] Groundwater Services, Inc. (GSI). *Mass Removal Treatability Tests, Enhanced Aerobic Bioremediation, Saturated Shallow Hydrogeologic Unit, Solutia Inc., W.G. Krummrich Facility, Sauget, Illinois*. May 2006.

[9] GSI. *Suitability of Enhanced Aerobic Bioremediation (EABR) via Pure Oxygen Injection (POI) for SHU Treatment at the Former Chlorobenzene Process Area*. February 4, 2011.

[10] USEPA. *How to Evaluate Alternative Cleanup Technologies for Underground Storage Tank Sites, A Guide for Corrective Action Plan Reviewers*. EPA 510-R-04-002, May 2004.

the areas where no clay layers are present, a deep injection well can influence the entire treatment zone of 15 to 30 feet bgs.

- EABR well spacing of 30 feet between wells within rows and 40 feet between rows is appropriate.
- Oxygen distribution may not be homogeneous due to subsurface heterogeneity; however, the overall design of well spacing is appropriate given the flexibility in injection flow rates available from the system design.
- An injection rate of approximately 5 standard cubic feet per minute (scfm) is appropriate for the full-scale EABR. Flow rates greater than 15 scfm were achievable without exceeding the maximum injection pressures specified in the design, however, groundwater mounding was observed at several monitoring locations at these higher flow rates. XDD recommends using an initially lower injection rate (e.g., 1 scfm per well) at the startup, and increase up to 5 scfm based on field observations and actual oxygen distribution. Additional adjustments in the flow rates will be made as a part of system operation optimization.

3.4 OXYGEN UTILIZATION RATE ESTIMATES

The rate of oxygen delivery should ideally equal the rate of oxygen utilization, so that oxygen is used efficiently over the course of the treatment. Oxygen injection rates should also be controlled to avoid significant off-gassing of excess oxygen into the vadose zone. Off-gassing can occur if oxygen delivery rates exceed the ability of the oxygen to dissolve into groundwater (oxygen solubility is typically in the 50 mg/L range), or if the oxygen utilization rates are slower than anticipated. Off-gassing can also occur if high injection pressures/flowrates cause direct channeling of oxygen gas to the unsaturated zone. Some off-gassing is expected and is acceptable; however, significant off-gassing will need to be avoided to maximize efficiency and to prevent potential interactions with the T-SVE system (refer to **Section 3.6**).

In practice, the oxygen delivery rate will be adjusted during system optimization as needed to supply oxygen to increase DO concentration in the 40 mg/L range (to be monitored using the proposed piezometer network). Oxygen demand may change as bacteria populations become established, as COCs are depleted, and as groundwater flux rates change due to seasonal groundwater fluctuations, etc. Therefore, the oxygen injection rates will likely be a dynamic parameter that will change over the course of system operation.

For design purposes, calculations were performed to confirm that the amount of oxygen that can be injected at reasonable injection flowrates (e.g., between 3 to 5 scfm, per well, based on industry standard practice) can provide the required amount of oxygen to:

- Supply oxygen to increase DO concentrations in the range of 40 mg/L, accounting for anticipated bacteria oxygen utilization rates and other losses (off-gassing to the vadose zone, groundwater flux out of the target area/depth intervals, etc.).
- Provide the mass of oxygen required to support the aerobic bacteria and degrade the mass of COCs within the target interval (i.e., 386,000 lbs of COCs).

Between 11,000,000 and 62,000,000 cubic feet (CF) of oxygen gas was estimated to be required over a four year operation period. The high end estimate was used to provide a conservative design basis. This volume of oxygen gas can be realistically delivered at a relatively low injection rate per well. The methods and parameters that were used to develop these oxygen utilization estimates are discussed in **Appendix C**.

3.5 EABR DESIGN BASIS

The overall EABR design is based upon the below parameters and assumptions.

- Total Oxygen Injection Volume: The total volume of oxygen to maintain DO concentrations up to 40 mg/L, and provide enough oxygen to degrade the COC mass in the saturated target interval ranges between 11,000,000 and 62,000,000 CF over the life of the project (refer to **Appendix C**). The higher (conservative) value of 62,000,000 is used for the system design.

- Oxygen Injection Rates: Oxygen injection rates of between 3 and 5 scfm per well (average) will be used to emplace the required oxygen quantity and achieve subsurface distribution (refer to the field testing results summary in **Section 3.3**). This flow rate is adequate to emplace the total oxygen volume required to aerobically degrade the COCs over the project duration. Note that oxygen flow rates can be higher during the initial phases of operation to enhance oxygen distribution. At the system startup, the injection rate will be 1 scfm per well that will be gradually increased to 5 scfm based on field observations and monitoring.

- Oxygen Pulsing Design: Biosparging is typically conducted using a pulse-injection mode. Pulse injection is conducted by injecting into a number of individual wells using an “on/off” cycling approach (i.e., one set of wells will be “on” at a time while the others are “off”). The pulse “on” time may range between 10 and 30 minutes, and is based on the time required to emplace the required volume of oxygen in the vicinity of each well, at the design injection rate. The duration of the pulse “off” time for each well is based on the rate of oxygen utilization occurring during the “off” cycle, and was estimated to range from 2 to 8 hours. The volume of oxygen delivered during the injection “on” time needs to be sufficient to maintain the oxygen levels to support aerobic degradation during the injection “off” time, but should also not exceed the aquifer’s capacity to solubilize the gas. The pulsing rate will be optimized during field operations. Refer to **Appendix C** for a discussion of how the pulsing “on/off” cycle was estimated. At the system startup, the pulse “on” time will be 15 minutes, and the pulse “off” time will be 6 hours that will be optimized based on field observations and monitoring.

- Total Oxygen System Injection Rate: The total average flow of the oxygen system will be 30 scfm on average, with a capacity of providing 50 scfm for operational flexibility.

This will provide enough capacity to inject into approximately 10 individual wells at a time, during the pulsing cycle. The wells are divided into 30 groups containing between 4 and 8 wells each, and within a group, oxygen will be delivered to one well at a time. Approximately 10 wells (one each from 10 groups) will be "on" at a time, while the others are "off." Wells and groups will be sequentially turned "on" and "off" (pulsed) to deliver oxygen into subsurface. The well groups can be modified as necessary during system operation optimization.

- Target Depth Intervals: The EABR design dual-level well screens, as necessary, to target the silty and sandy geology within the 15 to 30 foot bgs interval. The silty clay layers will not be directly targeted by the EABR system because the low permeability prevents direct injection into these units. The shallow EABR wells will target the silty sand to fine/medium sands shallower than the clay layer, generally between 15 and 22 feet bgs. The deep EABR wells will target either the entire treatment interval where no clay layers are present, or the fine/medium sands below the clay layer, generally between 22 and 30 feet bgs. Based upon the available CPA boring logs, the actual screen depth intervals for individual shallow and deep zone EABR wells have been customized based on the observed variations in geology. The individual well screen depth intervals will be further refined as needed based upon confirmation soil borings that will be conducted in the CPA during well installation.

- Well Spacing Basis: In general, the EABR wells are positioned on 30-foot centers within rows that are oriented perpendicular to the direction of groundwater flow (groundwater generally flows east to west across the site). These well rows are then spaced 40 feet apart in the direction of groundwater flow. The EABR field testing results indicated that this spacing was appropriate for oxygen distribution. Also, this layout accommodates the installation of the co-located EABR and T-SVE piping systems.

- Piezometers: Piezometer locations for groundwater monitoring were selected based on the distribution of COCs within the 15 to 22 and 22 to 30 feet bgs depth intervals[11]. Piezometers are generally installed in dual-level pairs, except in areas were impacts were absent in either the shallow or deep zones. Piezometers are positioned to provide coverage of the treatment areas, and locations are optimized to focus on the areas of highest impacts, as necessary.

- System Flexibility for Optimization: Average oxygen injection rate is designed to be 3 to 5 scfm per injection well with a total injection capacity of 50 scfm. The system operation will be optimized based on the oxygen distribution in the target area, oxygen utilization rates, and the level of treatment observed in different subareas. The optimization will include changes in injection rates, pulse "on" and "off" time intervals, grouping and sequencing of wells injecting at a time, etc. Therefore, the system design will have the flexibility to accommodate the changes in injection rates (e.g., up to 10 scfm per well), pulse "on" and "off" times, and well grouping and sequencing.

3.6 LIMITING OXYGEN OFF-GASSING

Because of the anticipated oxygen utilization rate by the aerobic bacteria (once the population is established) and controlled rate of oxygen injection, it is anticipated that limited amounts of oxygen will off-gas to the vadose zone. Also, the system injection rates will be optimized to prevent introduction of oxygen in excess of solubility limits and oxygen utilization rates.

Oxygen that off-gasses to the vadose zone will be captured by the T-SVE system, and/or will help promote aerobic degradation of COCs within the unsaturated interval. Soil gas monitoring will be conducted using the unsaturated zone vapor probes (installed as part of the T-SVE

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[11] Refer to Figures 3.1 to 3.7 (COC distribution in the 15-22 feet bgs interval), and Figures 4.1 to 4.7 (COC distribution in the 22-30 feet bgs interval) of the "*Former Chlorobenzene Process Area Characterization Report*", URS Corporation, February 2010.

performance monitoring network, see **Figure 4**) to assess oxygen levels in the vadose zone to aid in the optimization process.

An oxygen sensor will be installed at the inlet of the T-SVE system to detect if elevated oxygen concentrations are entering the T-SVE system piping, and will signal a shutdown of both the T-SVE and the EABR systems if oxygen concentrations exceed safe limits (23.5% by volume).

4.0 EABR DESIGN OVERVIEW

The overall remediation approach consists of injecting oxygen gas through a number of wells in the treatment area to promote aerobic bacterial activity, and rely on biodegradation to treat COCs in situ. The EABR system will include an oxygen supply system, an oxygen manifold distribution system and a number of injection wells. The manifold system will be equipped with electromechanical solenoid valves and mass flow control meters to control flow rates and distribute the oxygen to individual injection wells.

4.1 OVERVIEW OF DESIGN

The EABR Process Flow Diagram (PFD) is shown in **Figure 5**, and the key design elements are outlined below:

- EABR Wells: The EABR well layout has been developed based on the COC distribution and the design basis discussed in **Section 3.5** including a detailed geological review. The optimized design includes a total of 191 EABR wells (71 shallow and 120 deep locations). The EABR well grid is designed with 17 rows (**Legs A through Q**). The rows are oriented in a north-south direction, and the rows are approximately 40 feet apart. Along each row, EABR wells are spaced at approximately 30-feet center to center.

- Oxygen Supply: An oxygen supply system with a liquid oxygen tank and an ambient vaporizer with a maximum flow capacity of 3,000 standard cubic feet per hour (scfh) or 50 standard cubic feet per minute (scfm) at a minimum of 75 pounds per square inch gauge (psig) pressure will be used. The oxygen supply system includes:
    - Liquid oxygen tank system: A 9,000-gallon bulk tank for cryogenic liquid oxygen storage, and associated valves, regulators, safety devices, and a telemetry unit.

  - <u>Ambient vaporizer</u>: An ambient vaporizer capable of producing 50 scfm of oxygen gas from the liquid oxygen.
  - <u>Pressure control manifold</u>: Includes a pressure regulating valve and ball and check valves.

- <u>Oxygen Distribution/Pulsing System Manifold</u>: Oxygen distribution equipment will be housed in an oxygen distribution building, and manifolding will be extended to individual injection wells. Pulse injection is conducted by injecting into a number of wells using an "on/off" cycling approach (i.e., only a certain number of wells will be "on" at a time while the others are "off"). The volume of oxygen delivered during the injection "on" time needs to be sufficient to maintain the oxygen levels to support aerobic degradation, but should also not exceed the aquifer's capacity to solubilize the gas (pure oxygen solubility is typically in the 50 milligram per liter [mg/L] range). The oxygen manifold system will be used to distribute the oxygen to the individual wells in the well field as follows:

  1. The entire well field will be divided into 30 "groups" containing between 4 and 8 wells each.
  2. Each well within each group will be equipped with a solenoid valve to turn each well on or off, per the required pulsing cycle. Only one well within a group will be operated at a given time.
  3. Approximately 10 wells (one each from 10 groups) will operate at a given time.
  4. Each of the 30 groups will be equipped with its own single mass flow controller to maintain a steady oxygen flow rate. Since only one well will be allowed to operate at a time per group, each mass flow controller will effectively allow monitoring and control of oxygen to a single well at a time.

- Injection Rates: Individual well will receive an oxygen pulse flow rate of approximately 3 to 5 scfm (on average). Therefore, the total oxygen flow rate will be up to 30 to 50 scfm (i.e., assuming that 10 wells will be operating simultaneously). The system is designed to allow oxygen injection pulse flow rates of up to 10 scfm per well (with 5 wells operating simultaneously), if needed to enhance the oxygen distribution.

- Nitrogen Supply/Purging: Prior to introduction of O_2 into the manifold system, a nitrogen gas (N_2) purge will be conducted to flush out debris and/or vapors that could present a potential ignition hazard in the presence of pure oxygen. The nitrogen purging will be an infrequent operation (the major one-time event occurring during system start-up). However, nitrogen purging capability will be a permanent feature designed into the system in the event that piping repairs/equipment replacement is required, which would require system manifold purging. The system will also need to be purged at the completion of operations prior to decommissioning. The nitrogen supply consists of compressed gas cylinders (bottle-packs) for purging operations.

- Piezometers: Piezometer locations for monitoring are selected based on the distribution of COCs within the 15 to 22 and 22 to 30 feet bgs depth intervals[12]. Piezometers are generally installed in dual-level pairs, except in areas where impacts were absent in either the shallow or deep zones. Piezometers are positioned to provide coverage of the treatment areas, and locations are optimized to focus on the areas of highest impacts as necessary.

A summary of the EABR well counts and overall design parameters is presented in **Table 4**.

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[12] Refer to Figures 3.1 to 3.7 (COC distribution in the 15-22 feet bgs interval), and Figures 4.1 to 4.7 (COC distribution in the 22-30 feet bgs interval) of the "*Former Chlorobenzene Process Area Characterization Report*", URS Corporation, February 2010.

4.2 SYSTEM CONTROLS

A Supervisory Control and Data Acquisition System (SCADA) will operate and monitor the EABR system. The SCADA system will include a Programmable Logic Control (PLC), Human Machine Interface (HMI), data acquisition, and remote monitoring and control features. The PLC will control all automated functions of the EABR system. Data acquisition will record and monitor flows, pressures, and operating temperatures, as well as the position of safety sensors and controls (e.g., pressure switches, solenoid valves, etc.). The PLC will be programmed to control the appropriate system response to alarm conditions. The remote monitoring and control system will allow remote access to the system, and notifications to the operator of any alarm conditions. Key monitoring devices that will be integrated with the PLC program will include:

- Dissolved Oxygen Sensors: A total of ten DO sensors/data loggers will be installed in the piezometers within the CPA. The DO sensors will have flexibility to be moved from one piezometer to the other based on monitoring needs. DO readings will be accessible through the remote monitoring system.
- Ambient Oxygen Sensors inside Oxygen Distribution Building: The building will be equipped with two ambient oxygen sensors to detect potential leaks in oxygen or nitrogen manifolding causing unsafe conditions (oxygen enriched conditions of >23.5% and oxygen deficient conditions of <19.5%). If an unsafe condition is detected, the entire EABR (and T-SVE) system would be shut down. This alarm will also trigger the audio/visual alarm beacon (located on the interior and exterior of the building), and will send an alarm notification to the appropriate responders.
- Building Smoke/Heat Alarm: The EABR equipment building will be equipped with a heat/smoke alarm to detect potential fire. If smoke is detected, the entire EABR (and T-SVE) system would be shut down. This alarm will also trigger the audio/visual alarm beacon (located on the interior and exterior of the building), and will send an alarm notification to the appropriate responders.

- Oxygen Sensors on the T-SVE System: The EABR system will be introducing pure oxygen into the saturated zone at the same time that the T-SVE system is operating in the unsaturated zone. Oxygen sensors will be provided on the inlet to the T-SVE system to detect if elevated levels of oxygen are entering the system creating unsafe conditions (refer to the T-SVE design document). If elevated oxygen levels (i.e., >23.5%) are detected, the entire EABR and T-SVE systems would be shut down.
- Seismic Monitor: The T-SVE equipment building will be equipped with a seismic monitor that will shut down the entire system (EABR and T-SVE) in the event of a significant earthquake. This alarm will also trigger the audio/visual alarm beacon (located on the interior and exterior of the building), and will send an alarm message to the system operators.

4.3 SYSTEM CAPACITY AND FLEXIBILITY

Based on the high-end of the total demand of 62,000,000 CF, the system will operate at an average of 30 scfm over the project duration of four years. The total oxygen capacity of the oxygen supply (and therefore, EABR system) is designed to be 50 scfm to provide additional capacity to provide higher rate pulses as needed. Flow rates at individual wells can be set as high as 10 scfm.

The system operation will be optimized based on the oxygen distribution in the target area, oxygen utilization rates, and the level of treatment observed in different subareas. The optimization will include changes in injection rates, pulse "on" and "off" time intervals, grouping and sequencing of wells injecting at a time, etc. Therefore, the system design will have the flexibility to accommodate the changes in injection rates, pulse "on" and "off" times, and well grouping and sequencing.

4.4 GENERAL DESIGN CONSIDERATIONS

The following additional considerations were incorporated into the EABR system design:

- Automated systems to decrease operation and maintenance costs.
- Alarm schedule built into the SCADA to protect equipment and personnel.
- Chemical compatibility of components with oxygen gas.
- Location of overhead and subsurface utilities.
- Compliance with National Fire Protection Association Class 1 Division 2 requirements for an area where ignitable concentrations of flammable gases, vapors, or liquids are not likely to exist under normal operating conditions.
- Compliance with the facility's safety standards and Occupational Safety and Hazard Administration (OSHA) regulations (refer to **Section 9.0**).
- Adherence to Compressed Gas Association (CGA) guidelines for oxygen systems.
- All piping and injection system components in contact with oxygen will be cleaned for oxygen service.

4.5 APPLICABLE CONSTRUCTION AND SAFETY STANDARDS

The installation will be conducted in accordance with standard construction codes and guidance documents. Where applicable, the latest revisions of the following codes shall be met.

1. ANSI – American National Standards Institute
2. ASTM – American Society for Testing and Materials
3. CGA – Compressed Gas Association
4. FM – Factory Mutual
5. IBC – International Building Code

6. ICEA – Insulated Cable Engineers Association
7. IEEE – Institute of Electrical and Electronic Engineers
8. OSHA – Occupational Safety and Health Administration
9. NEC – National Electric Code
10. NEMA – National Electric Manufacturer’s Association
11. NFPA – National Fire Protection Association
12. UL – Underwriter Laboratories

5.0 WELL LAYOUT AND CONSTRUCTION DETAILS

The following construction and installation details are included in this section:

- EABR well and piezometer locations.
- Typical EABR well and piezometer construction details.
- Typical EABR well and piezometer surface completion details.
- Well construction tables (including well depth and well screen lengths).

5.1 EABR WELL AND PIEZOMETER LAYOUTS

The EABR well layout (including dual-level wells, where necessary, based on geology) is designed to cover the extent of the COC exceedences within the CPA (treatment area is shown in **Figure 2**). The actual screen depth intervals for individual shallow and deep zone EABR wells have been customized based on the actual variations in geology, as based upon the available CPA boring logs. The individual well screen depth intervals will be further refined as needed based upon confirmation soil borings which will be conducted in the CPA during well installation. The proposed screen depth intervals for each individual well are presented in **Tables 5** and **6** for the EABR wells and piezometers, respectively. A summary of the total number of wells and piezometers is presented below:

Well Summary

Treatment Interval	EABR Wells		Piezometers	
	Screen Interval[1]	Well Count	Screen Interval[1]	Well Count
Shallow	21-23.5 feet bgs	71	17-22 feet bgs	11
Deep	29-31.5 feet bgs	120	25-30 feet bgs	12

Notes: [1] = Average screen intervals are shown. Actual screen intervals will vary depending on geology observed during installation.

EABR Wells: The EABR well grid is designed with 17 rows (**Legs A through Q**), as shown on **Figure 4**. The rows are oriented in a north-south direction, and the rows are generally approximately 40 feet apart. Along each row, EABR wells are spaced at approximately 30-feet center to center. The well screen intervals have been optimized based on the available geological information and the EABR field testing data. Additionally, areas with only shallow or deep COC impacts include only shallow or deep wells, respectively. However, some deep wells installed in the appropriate geological conditions will treat both the shallow and deep treatment intervals (dual-level) due to the upward movement of oxygen following injection.

Piezometers: The piezometers will be installed in the shallow and deep target zones primarily to monitor DO distribution, depth to groundwater, and other performance parameters (i.e., VOC concentrations, field parameters such as pH, etc.). Piezometer placement is optimized based on the COC distribution (generally in the most impacted area), and to provide coverage of the target area. Piezometer locations are shown on **Figure 4**.

5.2 INJECTION PRESSURES

Table 7 provides the calculated injection pressure ranges for the shallow and deep injection wells. The calculated range of injection pressures for depth to groundwater ranging from 5 to 15 feet bgs were 3 to 17 psi, and 6 to 24 psi for shallow and deep wells, respectively. The observed injection pressures during the EABR field testing were within the calculated range of injection pressures.

5.3 WELL CONSTRUCTION DETAILS

Typical construction details for the shallow and deep EABR wells and piezometers are presented on **Figure 6**. The proposed screen depth intervals for each individual well are presented in **Tables 5** and **6** for the EABR wells and piezometers, respectively. The well screen depths have been customized based on the actual variations in geology, as based upon the available CPA boring logs. Well screen depths will be further refined during installation based upon actual geological conditions (to be verified by geological characterization, refer to **Section 4.4**).

5.3.1 *EABR WELL CONSTRUCTION DETAILS*

The EABR well screens will be 2.5 feet long (i.e., standard available screen length from the manufacturers) with 2 foot of blind sump at the bottom for collection of any silt accumulated due to pulsing of oxygen in subsurface. The shallow well screen will be typically set on top of the intermediate clay layer with the blind sump penetrating the clay layer. Based on the geological review, typical depth of the shallow screen interval is approximated to be 21 to 23.5 feet bgs. The deep well screen will be typically set from 29 to 31.5 feet bgs near bottom of the treatment interval (30 feet bgs). Once injected, oxygen gas is expected to travel upwards and distribute in the target vertical interval.

As shown on **Figure 6**, the EABR wells will be constructed of one-inch inside diameter (ID), stainless steel (SS). The well screens will be one-inch ID SS with 0.02-inch slots, and the blind sump and risers will be solid one-inch ID SS. Well screens will be 2.5 feet long. The filter pack will consist of #002 sand extending to 1 foot above the well screens. A minimum 3-foot granular bentonite seal will be placed above the sand pack. All boreholes will be completed to surface grade with a high temperature compatible cement grout mixture (this is required because the T-SVE system will be operating in this area, refer to the T-SVE design document).

All wells will be installed using either the rotosonic drilling or DPT techniques by an Illinois licensed driller. The EABR wells screened near the clay layer (refer to **Table 5** for locations) will be installed using the rotosonic drilling technique due to a silting issue observed during the EABR field testing (refer to **Appendix B**). It is anticipated that the rotosonic drilling technique will provide a better filter pack and reduce the potential for silting of the wells. The remaining EABR wells will be installed using DPT with 3¼-inch diameter drilling rods. At certain locations, subsurface obstructions (e.g., concrete) may prevent the DPT well installation. At such locations, the EABR wells will be installed using the rotosonic drilling technique.

5.3.2 *PIEZOMETER CONSTRUCTION DETAILS*

The piezometer screens will be 5 feet long with 2 foot of blind sump at the bottom for collection of any silt accumulated due to pulsing of oxygen in subsurface. The shallow well screen will be typically set from 17 to 22 feet bgs, and the deep well screen will be typically set from 25 to 30 feet bgs.

As shown on **Figure 6**, the piezometers will be constructed of two-inch ID, 0.01-inch slotted SS well screens (the larger well diameter is required to allow sample equipment access). The blind sump and risers will be solid two-inch ID carbon steel (CS). The filter pack will consist of #002 sand extending to two feet above the well screens. A minimum 3-foot granular bentonite seal will be placed above the sand pack. All boreholes will be completed to surface grade with a high temperature compatible cement grout mixture (this is required because the T-SVE system will be operating in this area, refer to the T-SVE design document). All wells will be installed using the rotosonic drilling by an Illinois licensed driller.

5.4 WELL SURFACE COMPLETIONS

All of the EABR wells and piezometers will be completed to 2.5 feet (+/- 6 inches) above surface grade to allow for subsequent installation of a thermal insulation cap (refer to the T-SVE design document). The EABR well and T-SVE riser pipes will be completed with Female National Pipe Thread (FNPT) adapters one-inch and two-inch in diameter, respectively.

5.5 GEOLOGICAL CHARACTERIZATION

The well screen depths in **Table 5** will be refined based on supplementary soil borings and geologic observations to be conducted during the drilling program (included in this scope of work). Prior to well installation, approximately 31 soil borings will be advanced to approximately 32 feet bgs using DPT methods. Continuous soil cores will be collected from each boring location using a MacroCore sampler. Soil cores will be examined visually for geological characteristics and logged, and will be compared to existing CPA boring logs. The Project Geologist may modify the locations and number of soil boring locations depending on the real-time analysis of the actual geology.

5.6 WELL DEVELOPMENT

EABR wells and piezometers will be developed using surge block and pumping techniques until the effluent is clear or until five times the borehole volume has been evacuated. Water and sediment generated during well development will be handled in accordance with the waste management procedures provided in **Section 5.7**.

5.7 WELL INSTALLATION LOGISTICS

5.7.1 *UTILITY CLEARANCE*

The W.G. Krummrich facility utility maps were used to identify the locations of known existing and/or abandoned utilities within the CPA. Well locations near known subsurface utilities will be cleared using an air knife and vacuum truck to either confirm locations of the utilities or confirm that well locations are clear of known utilities.

5.7.2 *PRE- AND POST-DRILLING SURVEYING*

EABR and piezometer locations were marked using a flag/stake or paint by a surveyor prior to the start of the drilling program. Actual drilling locations may be moved by the Project

Geologist to avoid overhead obstructions (e.g., pipe racks, etc.) or in the event that subsurface obstructions prevent installation in the desired location (i.e., drilling refusal due to concrete, cobbles, etc.).

A survey will be conducted after completion of the drilling program by Solutia/XDD to determine the as-built well coordinates and elevations.

5.8 DECONTAMINATION AND WASTE HANDLING/DISPOSAL

Soil, groundwater, and decontamination fluids will be generated during the work activities. A waste accumulation area and a decontamination area will be established within the work area. All wastes will be containerized and properly labeled. Waste material will be characterized and disposed of in accordance with all applicable regulations.

5.8.1 *EQUIPMENT DECONTAMINATION AND DECONTAMINATION AREAS*

Drilling equipment will be decontaminated prior to entry to the site. During drilling activities, all equipment and vehicles will be regularly inspected to ensure contaminated materials are not tracked outside of the work area. Drilling equipment will also be decontaminated prior to final demobilization from the site. Potable water for decontamination will be acquired from an on-site hydrant or spigot, and will be staged in close vicinity to the decontamination area. Tanks, water handling equipment, and all decontamination supplies will be provided by the drilling contractor.

Primary Decontamination Area: A primary decontamination area will be constructed by the drilling contractor within or near the CPA, and will consist of a bermed area with a 6-milliinches (mil) polyethylene liner (minimum), or equivalent. Decontamination of augers, drill rods, vehicles, or other large equipment shall be performed in this area using a pressure washer. The decontamination pad will be sufficiently sized to ensure that the largest piece of equipment can be adequately decontaminated. Also, the area shall be designed so that vehicles can be driven into and out of the area (if required) while maintaining containment of any accumulated fluids. The decontamination area shall also be constructed to allow for collection of decontamination fluids and sediments, and to facilitate transfer of these materials to drums or roll-offs as needed (e.g., a sump area with pump, etc.).

<u>Temporary Decontamination Area(s)</u>: Small drilling equipment (split spoon samplers, etc.), hand tools, and other miscellaneous equipment that comes in contact with soils or groundwater will be decontaminated over a temporary decontamination area. The temporary decontamination area may be located adjacent to the active drilling operations, and may consist of 6-mil polyethylene liners/berms, plastic trays, or equivalent. Decontamination of small equipment will be performed using two water buckets (i.e., one for gross decontamination and one for rinse), detergent (e.g., Alconox®), and brushes.

5.8.2 *WASTE ACCUMULATION AREAS AND WASTE HANDLING*

Soil roll-offs and drums will be staged in the designated area within the CPA. Soil roll-offs will be liquid tight and lined with 6-mil (minimum) polyethylene roll-off liners. Soil roll-offs will be equipped with rain covers with an appropriate water-shedding design to prevent pooling of water on the surface of the cover, and will be equipped with appropriate tie downs. Roll-offs will be secured at the end of each day's activities. Drums will be United States Department of Transportation (USDOT)/United Nations (UN) rated, open-top steel construction with lid gasket seal and bolt rings.

A temporary satellite accumulation area will be established for staging of 55-gallon drums. As needed, all 55-gallon drums will be moved to the existing waste storage warehouse (BBU Building) located to the south of Big Mo area.

- Soils and Decontamination Derived Sediments: Soils/drill cuttings, sample cores, and sediments from equipment decontamination will be contained in the lined/covered roll-off containers, or in 55-gallon drums, as needed. Drums of soil accumulated at the point of the drilling activities may be consolidated within the soil roll-off containers. However, soils containing Non-Aqueous Phase Liquid (NAPL) may be segregated and remain within drums to be disposed of separately, if required. Any drums of soil that are not consolidated within the roll-off containers will be transferred to the waste storage warehouse (BBU building) at the facility. All soils/sediment containers will be properly labeled, and will be characterized for disposal.

- Groundwater and Decontamination Water: Impacted liquids from decontamination of equipment and impacted groundwater from well purging/sampling will be contained in 55-gallon drums. Drums will be properly labeled and placed in the satellite accumulation area. When a drum is full, it will be transferred to the waste storage warehouse (BBU building). Drums will be characterized for disposal.

- Uncontaminated Bulky Waste: Uncontaminated bulky waste (i.e. general trash and other debris) will be kept separated from impacted soil and groundwater, or other hazardous waste streams. These wastes will be bagged, as necessary, and disposed of in a dumpster as directed by Solutia.

- NAPL Segregation: NAPL, if encountered, will be segregated to the extent possible during waste accumulation, and transferred to separate 55-gallon drums. Drums will be properly labeled and placed in the satellite accumulation area. When a drum is full, it will be transferred to the waste storage warehouse (BBU building). Drums will be characterized for disposal. DNAPL drums will be electrically grounded during filling using a grounding rod (installed by a certified electrician).

6.0 OXYGEN AND NITROGEN SUPPLY SPECIFICATIONS

Oxygen and nitrogen bulk gas supplies will be provided for the EABR operations. The following design details and equipment specifications are included in this section:

- Piping and instrumentation diagram (P&ID), layout and specifications for the oxygen supply system (liquid oxygen).
- Layout and specifications for the bulk nitrogen (compressed gas) supply.

6.1 OXYGEN SUPPLY

The oxygen supply includes a bulk cryogenic liquid oxygen tank, an ambient vaporizer and a pressure control manifold (PCM). The liquid oxygen tank will have a capacity of 9,000 gallons, and will be staged on a concrete pad along with the vaporizer unit and the PCM. The concrete pad specifications provided in this section may be refined pending the results and recommendations of soil geotechnical testing.

Diagrams of the oxygen supply system are presented in **Figures 7** and **8**. The oxygen supply system will have the following specifications.

- <u>Oxygen Tank</u>: 9,000 gallon double-walled tank with necessary pressure and temperature relief valves and manifold.
- <u>Oxygen Output</u>: Continuous flow rate of 3,000 scfh (50 scfm), and peak flow rate of 5,000 scfh (83 scfm), with a minimum of 75 psig pressure. The output is designed sustain the peak flow rate of 83 scfm for one hour per day.
- <u>Oxygen Purity</u>: Oxygen purity will be approximately 99.5%.

- Oxygen Storage Tank Set-Up: Cryogenic bulk liquid storage tank for the oxygen supply ready for injection to the EABR system.
- Ambient Vaporizer: This device is a passive atmospheric heat exchanger that converts oxygen from liquid to gaseous phase. Cryoquip VAI-872 FXL 12 or equivalent ambient vaporizer that is rated for continuous flow rate of 3,000 scfh or 50 scfm.
- Pressure Control Manifold: The control manifold controls the pressure to the primary supply line and protects the line from excessively pressure. It includes a pressure control valve, block-and-bypass valves, a pressure indicator, and a check valve.
- Remote Telemetry System: A wireless inventory management system that allows monitoring of liquid oxygen storage levels and usage rates, and notifies the operator when tank refill is needed.
- Energy Requirements: Total system power requirements are for the telemetry system (120 volts alternating current (VAC), 60 Hertz, 20 Amp service).

The oxygen supply equipment will be supplied to the project on a contract basis by Air Products and Chemicals, Inc (Air Products) that owns and operates the storage, evaporation, pressure control manifold, and interconnecting piping. Air Products will also remotely monitor the oxygen level, and supply oxygen to refill the tank as necessary. The storage tank is large enough to accommodate the equivalent of approximately two delivery truck loads (4,500 gallons) in case there is any delay in delivering the oxygen to the site.

Figure 9 shows the assembly (oxygen supply assembly) that will connect the PCM (of oxygen supply) to the oxygen distribution system (specifications provided in **Section 7.0**). The assembly will include a normally closed solenoid valve, isolation ball valve, check valve and two pressure relief valves. The solenoid valve will be controlled by the EABR control system, and will be turned off in alarm conditions as deemed necessary by the control logic. The pressure relief valves will be set at 100 psig and rated for handling upset flow of the PCM pressure regulator.

As shown in **Figure 9**, the oxygen supply assembly will also include a connection for nitrogen assembly shown in **Figure 10** (rationale discussed in **Section 6.2**).

A 1¼-inch diameter copper tubing will be used to connect the assembly to the oxygen distribution system. The tubing will be installed above grade on pipe supports (refer to **Figure 11** and **Section 8.2.1** for details). The specified pipe for oxygen supply piping is 1¼-inch nominal diameter flexible, plastic–coated, Type-K copper tubing (ASTM B88 with inside diameter (ID) of 1.245 inches, outside diameter (OD) of 1.375 inches and wall thickness of 0.065 inches). General material compatibility and assembly specifications are provided in **Section 10.0**.

6.2 NITROGEN SUPPLY SYSTEM

Prior to introduction of O_2 into the manifold system, a nitrogen (N_2) gas purge will be conducted to flush out debris and/or vapors that could present a potential ignition hazard in the presence of pure oxygen. The nitrogen purging will be an infrequent operation (the major one-time event occurring during system start-up). However, nitrogen purging capability will be a permanent feature designed into the system in the event that piping repairs/equipment replacement is required, which would require system manifold purging. The system will also need to be purged at the completion of operations prior to decommissioning.

The nitrogen supply will consist of compressed gas cylinders (bottle-packs):

- Compressed gas cylinder assemblies of 6- and 12-pack with nitrogen capacity of 1,368 and 2,736 cubic feet, respectively, at 2,200 psig.
- If larger nitrogen capacity is required, multiple bottle-packs may be supplied.
- A pre-assemble manifold system with a shutoff valve is a standard equipment with the bottle-packs (manufacturer supplied equipment).

Figure 10 shows the assembly (nitrogen supply assembly) that will connect to the bottle-pack. The assembly will include a pressure regulator, pressure relief valve, fusible plug, and isolation ball valve. The pressure regulator will be set at 75 psig, and the pressure relief valves will be set at 100 psig and rated for handling upset flow of the pressure regulator. A ¾-inch diameter hose will be used to connect the nitrogen assembly to the oxygen assembly or the oxygen distribution system. As shown in **Figure 10**, the oxygen supply assembly will also include a connection for nitrogen (a ball valve, check valve and fittings) for purging the 1¼-inch copper tubing.

Based on the total system internal piping volume of the EABR system, a single 6 bottle-pack will provide enough nitrogen purge capacity for approximately 20 manifold pipe volume exchanges, and a 12 bottle-pack will provide 40 manifold pipe volume exchanges. Multiple bottle-packs will be required for the initial purging operations. Diagrams of the N_2 bottle packs are presented in **Figure 12.** Final nitrogen supply equipment specifications will be provided by the compressed gas supplier. **Table 8** provides the nitrogen purge gas requirements.

7.0 OXYGEN DISTRIBUTION DESIGN AND CONTROLS

The oxygen distribution manifold will be installed inside an oxygen distribution building, and will control the distribution of oxygen (or nitrogen) to the outdoor manifold system. The following components are included in this section:

- Oxygen distribution manifold process piping inside the distribution building.
- Mass flow controller specifications.
- PLC and instrumentation specifications, including the control/interlock, input-output schedule, and safety requirements for the PLC.
- System instrumentation (including flow, pressure, temperature gauges and sensors, pressure regulators, relief valves, etc.).

7.1 OXYGEN DISTRIBUTION DESIGN

The oxygen distribution system will include the valves and instrumentation that will control the oxygen flow rates to all wells. The P&ID for this system is shown in **Figure 13**.

7.1.1 *MAIN FEED LINE*

The main feed line will connect the oxygen distribution manifold to the main gas supplies (refer to **Section 6.0**). As shown in **Figures 13** and **14**, this main feed line includes:

- Main System Pressure Control: The system includes one oxygen (O_2) and one nitrogen (N_2) pressure regulator to reduce the respective supply pressures down to the desired manifold operating pressure (i.e., 50 psig).

- Check Valves: Check valves will be provided on the supply lines to prevent potential back-flow of gas.
- Shutoff/Isolation Valves: Shutoff valves to isolate the gas supplies from the distribution manifold are provided with a double-block and bleed arrangement for relieving manifold pressures and flushing for maintenance.
- Pressure Relief Valves: Pressure relief valves will be provided in the event of a regulator failure or sudden buildup of pressure in the system from other causes (such as improper valve settings). The relief valves will be vented outside the building at safe heights/distances away from personnel and/or nearby buildings/air intakes (e.g., the air intake/dilution air inlets of the oxygen generator system or the T-SVE system).
- Process Instrumentation: Pressure, flow, and temperature sensors are included, and will be interlocked with the PLC. These sensors/switches will be used to ensure that the system is operating within design parameters, and detect any potential leaks. If potential leak conditions are detected, the PLC will signal a system shutdown, including shut down of the solenoid valve at the oxygen supply (discussed in **Section 6.0**).
- Main Line Shutoff Solenoid Valves: This solenoid valve will close the main gas supply line in the event of an alarm condition (per the PLC program). A second solenoid valve, controlled directly via an analog relay from the pressure and temperature transducers will also be included, for redundancy purposes.

7.1.2 *BRANCH PIPING ASSEMBLIES*

The main feed line will distribute into 30 branch piping assemblies. Each branch of the piping assemblies will feed groups of approximately 4 to 8 wells (located on **Legs A through Q** as shown on **Figure 4**). Branch piping assemblies will control the oxygen flow and pulsing cycle for wells in each group.

As shown in **Figures 13** and **14**, each of the 30 branch piping assemblies will be individually equipped with the following components.

- Mass flow controllers (MFCs) to monitor and regulate the oxygen flow to each group of EABR wells.
- A direct-read variable area flow meter (Key Instruments FR4A65SVVT, or equivalent) on a bypass loop with isolation valves for flow rate readings and independent confirmation of the MFC readings.
- Pressure transducers to monitor pressure in the branch pipeline, and also to detect high or low pressure conditions (potentially indicating a pipe leak or break) which will trigger the appropriate alarm response (e.g., system shutdown).
- Flow switches to monitor potential a pipe leak or break, which will trigger the appropriate alarm response (system shutdown).
- Shutoff/isolation ball valves to shut the group off, or isolate it for maintenance purposes.

7.1.3 *CLEAN-OUTS/PURGING TEES*

Clean-out tees with ball valve/plug assemblies will be placed at the ends of all pipelines, and at the ends of pipeline direction changes (i.e., 90 degree bends) to allow for nitrogen purging operations.

7.1.4 *EXPANSION JOINTS/FLEX JOINTS*

The oxygen distribution manifold system will be installed in a temperature controlled building (see **Section 11.0**), and therefore, large temperature swings and related thermal expansion/contraction are not anticipated. However, in the event of power failure, temperatures inside the building could vary. The normal high temperature in July is 90°F (32°C), and the normal low temperature in January is 21°F (−6°C), as measured at the St. Louis regional airport. Thermal expansion will be less than 0.8 to 1 inches per 100 feet of pipe (refer to **Table 9**).

To allow for minor potential expansion/contraction, expansion joints (Metraflex Metraloop or equivalent) will be provided in key locations as shown on **Figure 15**.

7.2 SYSTEM INSTRUMENTATION

The system will be equipped with various electronic sensors, flow meters, flow switches, and pressure transducers to ensure the system is operating within design specifications. This instrumentation will be interlocked with the PLC system (see **Section 7.3**).

7.2.1 *MANUAL READ INSTRUMENTATION*

Flow meters, pressure, and temperature gauges are located along the system process piping to monitor operating parameters. Instrumentation for manual readings is shown on **Figure 13**, and specifications are provided in **Table 10**. Instrumentation includes:

- Rotameters (RM) – Direct read instruments for measuring flow rates at the specific process location.
- Pressure Indicators (PI) – Direct read instruments for measuring pressure at the specific process location.
- Temperature Indicators (TI) – Direct read instruments for measuring temperature at the specific process location.

7.2.2 *ANALOG/DIGITAL INSTRUMENTATION*

Electronic sensors, flow meters, pressure/flow/temperature switches, etc. are included in the system process piping to:

- Provide real-time remote monitoring data and ensure that the system is operating within design specifications.
- Control the automated systems.
- Trigger alarm-responses if required.

Analog/digital signal equipped instrumentation is shown on **Figure 13**, and specifications are provided in **Table 10**. A summary of the EABR system PLC input-output and alarm schedule is also included in **Table 11**. Instrumentation includes:

- Mass Flow Controllers (MFC) – These are designed to control flow rate to each individual branch, and therefore, group of wells. Using the SCADA, the operator will be able to set and adjust desired oxygen flow rate for each injection well.
- Flow Sensors/Switches (FS) – These are designed to indicate an alarm condition of flow due to break/leak of the process piping.
- Pressure Switch/Pressure Transducer (PS/PT) - These switches are designed to indicate an alarm condition of high pressure or low pressure (due to pipe blockage/breakage, high injection pressure or improper valve settings in the process piping, etc.). Injection pressures approaching the maximum calculated in **Section 5.2** will trigger an alarm condition and shutoff injection in that well.
- Temperature Transducer (TT) – These switches are designed to indicate an alarm condition of high and low temperatures due to operational issues with the system.

7.3 SYSTEM INSTRUMENTATION AND REMOTE MONITORING

The SCADA will operate and monitor the EABR system. The SCADA system will include a Programmable Logic Control (PLC), Human Machine Interface (HMI), data acquisition, and remote monitoring and control features.

The PLC will control all automated functions of the EABR system. The primary function of the PLC system will be to control the pulsing "on/off" cycles for the wells within each group. The PLC will be programmed to control the appropriate system response to alarm conditions (for example, if the high-oxygen sensor alarm is triggered, this would shut the appropriate system(s) down in a controlled fashion).

Data acquisition component will record flows, pressures, and operating temperatures, as well as the position of safety sensors and controls (e.g., pressure switches, solenoid valves, etc.). The remote monitoring and control system will allow remote access to the system, and notifications to the operator of any alarm conditions.

The oxygen supply system (see **Section 6.0**) will include a separate, dedicated telemetry system to notify the oxygen supplier of the oxygen levels in the tank. The oxygen supply tank telemetry will be interlocked with the main EABR PLC system to track oxygen levels in the tank.

7.3.1 *PROGRAMMABLE LOGIC CONTROLLER*

System operation and responses to instrumentation and alarm conditions is controlled via a Safety-rated PLC interface (Allen-Bradley GuardLogix, or equivalent). The system interlocks, control schedules, and input/output response table is presented in **Table 11**.

- PLC Inputs: The PLC interface accepts the inputs from the applicable process instrumentation. It also accepts the electronic outputs that are integral to several pieces of equipment (such as MFC readings, pressure transducer readings etc.).

- PLC Outputs: The PLC interface provides outputs that will operate the solenoids for pulsing of EABR wells, and also trigger a specific response depending on the various input signals.

The PLC will communicate with the HMI for inputs/outputs, and the system will be setup for the auto-dialer and remote access to equipment/instrumentation parameters.

7.3.2 *HUMAN MACHINE INTERFACE, REMOTE ACCESS, AUTO-DIALER AND DATA ACQUISITION*

The HMI software will allow the operator to access the PLC, as well as monitor the operating parameters and other system features. The system will also provide remote access to monitor and control system operation status via the internet.

The control system will also include an auto-dialer with battery backup to transmit specific system status and alarm conditions to the system operator. The data acquisition component will record flows, pressures, and operating temperatures, as well as the position of safety sensors and controls (e.g., pressure switches, solenoid valves, etc.).

7.3.3 *EMERGENCY STOP BUTTONS*

Emergency Stop buttons will be provided at the system PLC control panels (1-button), and outside the building (1 location). Shutting off the EABR system will automatically send a control signal to shut down the T-SVE system. **Figure 15** shows the locations of the emergency stop buttons.

7.3.4 *BACK-UP RELAY SYSTEM*

A redundant shutoff solenoid valve is provided on the main feed line. This solenoid valve will be controlled using an electromechanical relay system, independent of the primary PLC program.

In the event of a system controls failure, this relay system will provide a back-up gas supply shutoff control.

The solenoid valve will be normally-closed (closed in the event of a power failure). The relay control will be hardwired to the pressure and temperature transducers (see **Section 7.2.2**).

7.4 EXTERNAL SENSORS/INSTRUMENTS

The following additional monitoring and/or safety sensors are not directly connected to the EABR process, but will be used to monitor the status of the building atmosphere and related operating systems (such as the T-SVE system). These monitoring devices will be integrated, and as appropriate, interlocked with the EABR PLC control system.

7.4.1 *OXYGEN SENSORS ON THE T-SVE SYSTEM*

The EABR system will be introducing pure oxygen into the saturated zone at the same time that the T-SVE system is operating. Oxygen sensors will be provided on the inlet to the T-SVE system to detect if elevated levels of oxygen are entering the system (refer to the T-SVE design document). If elevated oxygen levels (>23.5%) are detected, the entire EABR (and T-SVE) system would be shut down.

7.4.2 *DISSOLVED OXYGEN DATA LOGGERS*

A total of 10 subsurface DO sensors/data loggers will be provided for real-time monitoring of aerobic conditions using selected piezometer locations. The DO sensors will have flexibility to be moved from one piezometer to the other based on monitoring needs. DO readings will be accessible through the PLC and remote monitoring system.

7.4.3 *BUILDING OXYGEN MONITOR*

Oxygen atmospheres greater than 23.5% by volume are considered “oxygen enriched” and may increase flammability. Also, if oxygen levels drop below 19.5%, they are considered “oxygen deficient” and can result in asphyxiation.

Two oxygen sensors will be provided to monitor the atmosphere within the oxygen distribution building (refer to **Section 11.0**). If oxygen concentrations of greater than 23.5% are detected, this could indicate a leak within the oxygen process piping. If oxygen concentrations of less than 19.5% are detected, this could indicate a leak within the nitrogen purging system.

In this event, the entire system (including the T-SVE system) will be shut down and the system operators will be notified via the auto-dialer. An audible/visual alarm (beacon light/alarm sirens, both inside and outside the building) will be activated to notify on-site personnel of this condition so that proper procedures can be followed.

7.4.4 *WATER LEVEL TRANSDUCERS*

Because the operation of the T-SVE in the lower silty sand unit will be contingent upon the seasonal fluctuations of the water table, water level transducers will be installed in selected piezometers for real-time monitoring of groundwater elevations. This will allow forecasting of conditions and prompt re-configuration of the T-SVE to optimize treatment in the lower silty sand unit. Water levels will not significantly affect the operation of the EABR system.

7.5 PROCESS CONTROL STANDARDS

Solutia requires that all controllers, sensors, and electro-mechanical actuated valves which are used to control a process be evaluated and classified in a Level of Protection Analysis (LOPA).

The purpose of the LOPA is to ensure that safety-critical instruments and controls are designed, tested, and/or certified to perform with a required level of reliability (i.e., "Integrity Level" or "IL"). The LOPA evaluation is conducted to assess the safety, environmental, and/or property damage that could occur as a result of a potential failure of each control/interlock. Based on this assessment, the required IL classification of each control/interlock is determined. A LOPA analysis has already been conducted by Solutia for this system and all the system controls and interlocks have been classified.

Based on the LOPA assessment, the following requirements are part of this 100% design:

Sensors: Sensors include flow, level, temperature, etc. switches and transmitters that are used as part of a Basic Process Control System (BPCS) interlock.

1. Sensor failure must not initiate the hazard, which means the sensor is separate and independent of control functions.
2. The sensor should be certified to IEC61508 with an integrity level claim limit that matches the classification. A BPCS requires an "IL-1". Sensor manufacturers may have certifications other than IEC that will be satisfactory. We will evaluate those on a case by case basis.

Final Elements: Final elements include solenoid valves, process valves, dampers, etc. that are used as part of a BPCS interlock.

1. Final element failure must not initiate the hazard, which means the final element is separate and independent of control functions.
2. The final element should be certified to IEC61508 with an integrity level claim limit that matches the classification. A BPCS requires an "IL-1". Final element manufacturers may have certifications other than IEC that will be satisfactory. We will evaluate those on a case by case basis.

Controllers: Controllers are programmable controllers that run the system, including the processor and input/output modules.

1. The controller must have redundancy or on-line diagnostics to achieve a PFD (Probability of Failure on Demand Final) = 0.01 and have the program logic and set points password protected.

General Requirements: Sensors, final elements and controllers must fail to a safe state on loss of signal, power or instrument air.

8.0 LATERAL PIPING DESIGN

The oxygen distribution building (discussed in **Section 7.0**) connects to the solenoid banks using the lateral piping, and the solenoid banks connect to wellheads installed on EABR wells using individual wellhead piping (discussed in **Section 9.0**). The layout and P&ID of the lateral piping and wellhead piping (including solenoid banks and wellheads) system are shown on **Figures 16** and **17**, respectively. The following construction and installation details are described in this section:

- Lateral piping layouts and specifications.
- Isolation/purge valves, pipe supports and thermal expansion/contraction details.

8.1 LATERAL PIPING OVERVIEW

The overall layout of the lateral piping is presented in **Figure 16**. The lateral piping will provide the connection between the oxygen distribution building and the solenoid banks on the wellhead piping, and is designed as follows:

- The EABR manifold consists of 30 separate pipelines carrying oxygen from the oxygen distribution building and connecting to the wellhead piping (refer to **Section 9.0**).
- Up to three separate pipelines will be installed within each row of wells (i.e., **Legs A through Q**, refer to **Figure 16**). Each pipeline will connect to the solenoid banks and wellhead piping connections that connect to between 4 and 8 individual wellheads (refer to **Section 9.0**).
- All piping will be installed above grade on pipe supports (refer to **Figure 11**).
- The field piping will be equipped with shutoff/isolation valves in the solenoid banks, and will be terminated with clean-out tee assemblies for nitrogen purging purposes.

8.2 LATERAL PIPING DETAILS

A summary of the pipe sizing calculations based on a maximum velocity of oxygen at 100 feet per second (fps) is presented in **Table 12**. Based on the calculations, the design includes a ½-inch nominal diameter pipe. The specified pipe for lateral piping is ½-inch nominal diameter flexible, plastic–coated, Type-K copper tubing (ASTM B88 with ID of 0.527 inches, outside diameter of 0.625 inches and wall thickness of 0.049 inches). The flexible copper tubing is typically available in 100-foot rolls, and will be connected using brass compression fittings where connections are necessary. Head loss calculations are summarized in **Table 13**. General material compatibility and assembly specifications are provided in **Section 10.0**.

8.2.1 *PIPE SUPPORTS*

Pipe supports are shown on **Figure 11**. Pipe supports will be shared with the T-SVE system (refer to the T-SVE design document). Pipe supports will be placed at 10 feet center to center (per the T-SVE design) along all lateral lines (wider spacing of 15 feet will be used for the main trunk lines).

Pipe supports will be of channel strut design, and will be fabricated to support the weight of the EABR piping (and the T-SVE piping). The copper tubing will be supported using “J-hooks” or equivalent on the pipe supports. Electrical conduit piping for all solenoid valves will also be installed on the pipe supports.

8.2.2 *THERMAL EXPANSION/CONTRACTION*

The copper tubing will be installed to allow for thermal expansion/contraction under the typical range of temperatures for the area. The normal high temperature in July is 90 °F (32 °C), and the normal low temperature in January is 21 °F (−6 °C), as measured at the St. Louis regional airport. Thermal expansion will be less than 0.8 to 1 inches per 100 feet of pipe. A summary of the thermal expansion calculations are presented in **Table 9**.

To allow for the minimal anticipated thermal expansion/contraction, the copper tubing will be installed with approximately 8 inches of sag between the pipe supports (as shown on **Figure 11**). The copper tubing will be supported using "J-hooks" or equivalent on the pipe supports.

9.0 WELLHEAD PIPING DESIGN

All EABR wellheads and associated piping are designed with individual electromechanical solenoid valves, manual shutoff valves, pressure gauges, and vent/nitrogen purge valves to allow for individual controls of the wells for optimization. The oxygen distribution building (discussed in **Section 7.0**) connects to the solenoid banks using the lateral piping (discussed in **Section 8.0**), and the solenoid banks connect to wellheads installed on EABR wells using individual wellhead piping. The layout and P&ID of the solenoid banks, wellhead piping, and wellheads along with the lateral piping are shown on **Figures 16** and **17**, respectively. The following construction and installation details are included in this section:

- Solenoid bank design and specifications.
- Wellhead piping design and specifications including pipe supports.
- EABR and Piezometer wellhead design and specifications.

9.1 SOLENOID BANK DESIGN

The solenoid banks will connect the lateral piping system to the EABR well groups (via piping and wellheads). A solenoid bank will contain between 4 and 8 solenoid valves to control the “on” or “off” status of each well in the “group.” The typical solenoid bank assembly is shown on **Figure 18**. Solenoid valves will be “normally-closed” when de-energized. Solenoid valves will be controlled by the PLC. An additional Safety Integrity Level 1 (SIL-1) rated solenoid valve will be located at the inlet of each solenoid bank to assure that there is a high reliability for shutting off the entire oxygen line when necessary.

The solenoid bank will also include an isolation valve, and a clean-out/vent valve. Clean-out tees with ball valve/plug assemblies will be placed at the ends of the pipeline to allow for nitrogen purging operations.

9.2 WELLHEAD PIPING DESIGN

The solenoid banks will be connected to the EABR wellheads using flexible piping (copper tubing). A summary of the pipe sizing calculations based on a maximum velocity of oxygen 100 feet per second (fps) is presented in **Table 12**. Based on the calculations, the design includes a ½-inch nominal diameter plastic-coated copper tubing. The flexible copper tubing is typically available in 100-foot rolls, and will be connected using brass compression fittings where connections are necessary.

9.2.1 *PIPE SUPPORTS*

The copper piping runs will be supported by a pipe support system presented in **Figure 11**. Pipe supports will be shared with the T-SVE system (refer to the T-SVE design document). Pipe supports will be placed at 10 feet center to center (per the T-SVE design) along all lateral lines (wider spacing of 15 feet will be used for the main trunk lines).

Pipe supports will be of channel strut design, and will be fabricated to support the weight of the EABR piping (and the T-SVE piping). The copper tubing will be supported using “J-hooks” or equivalent on the pipe supports. Electrical conduit piping for all solenoid valves will also be installed on the pipe supports.

9.2.2 *THERMAL EXPANSION*

The copper tubing will be installed to allow for thermal expansion/contraction under the typical range of temperatures for the area. The normal high temperature in July is 90 °F (32 °C), and the normal low temperature in January is 21°F (−6°C), as measured at the St. Louis regional airport. Thermal expansion will be less than 0.8 to 1 inches per 100 feet of pipe. A summary of the thermal expansion calculations are presented in **Table 9**.

To allow for the minimal anticipated thermal expansion/contraction, the copper tubing will be installed with approximately 8 inches of sag between the pipe supports (as shown on **Figure 11**). The copper tubing will be supported using “J-hooks” or equivalent on the pipe supports.

9.3 WELLHEAD DESIGN

The wellhead assemblies for the EABR wells are shown on **Figure 19**. Each wellhead will be equipped with:

- A ball valve for manual shutoff.
- A check valve, to prevent back-pressure related de-gassing into the wellhead.
- A pressure gauge for monitoring injection pressures.
- A nitrogen purge/vent port assembly (ball valve) to conduct the required purging operations.

The piezometer wellhead assemblies are also shown on **Figure 19**. The piezometer wellhead will consists of a camlock adaptor with a plug for installation of a semi-permanent down-well monitoring device (i.e., water level transducer and/or DO probes/data loggers, discussed in **Section 7.0**). The piezometer wellhead also includes a pressure gauge and a vent valve to relieve pressure buildup, if any, prior to opening the camlock fitting.

As appropriate lengths of the casings will be purchased during the well installation, a majority of the well stickups will have a threaded connection. The wellheads will be connected to the wells via the threaded connection. Brazing and flange connections will be used as an alternative to the threaded connections for installing the wellheads.

10.0 GENERAL SYSTEM SPECIFICATIONS

10.1 GENERAL MATERIAL COMPATIBILITY SPECIFICATIONS

General materials of construction are as follows:

- EABR piping will be constructed of poly-coated, Type-K copper tubing (compliant with ASTM B88), with brass compression-type fittings. Soldered fittings may also be substituted.
- Fittings will be of oxygen compatible material including copper, brass, or SS construction with polytetraflouroethylene (PTFE) or Viton® seats/gaskets, as needed.
- Seals, gaskets, and seating materials in contact with oxygen will be of compatible fluoroelastomer (FKM/FFKM) materials (e.g., Viton®, Kalrez®) or PTFE materials (e.g., Teflon®), etc. Thread sealants, including pastes and tapes, will also be of compatible PTFE formulations.
- Solenoid valves will be of oxygen compatible material including brass body, PTFE seals and disks, SS core tube, SS springs, and copper shading coil design.
- Control valves/check valves will be of oxygen compatible material including brass or SS body construction with PTFE or Viton® seats/gaskets.
- Wetted parts of sensors, transducers, transmitters, pressure gauges, flow meters, or any other in-line instrumentations shall be of chemically compatible/temperature compatible materials (brass, SS, PTFE, FKM/FFKM, or approved equivalents).

10.2 GENERAL ASSEMBLY SPECIFICATIONS

<u>General Piping Assembly</u>: The piping shall be constructed to the following specifications:

- All piping, manifolding, assemblies, and components for oxygen service will be pre-cleaned for oxygen service (refer to **Section 10.3**).

- Piping assemblies shall be leak-tight (refer to **Section 10.4**).
- Pipes may be joined using soldered, threaded, or flanged connections. Flanged connections shall be equipped with Viton® or equivalent oxygen compatible gaskets.

Control Valves/Isolation Valves and Vent Valves: The control valves and vent valves will be constructed to the following specifications:

- Valves shall be copper, brass, or SS with PTFE or Viton® seats/gaskets. Valves may be threaded, soldered or socket-brazed connections.
- Cleanout tees will be of copper, brass, or SS, and will be equipped with ball valves of brass or SS with PTFE or Viton® seats/gaskets.

10.3 CLEANING FOR OXYGEN SERVICE

10.3.1 *PRE-CLEANING FOR OXYGEN SERVICE*

All piping, manifolding, assemblies and components for oxygen service will be pre-cleaned for oxygen service. Oxygen cleaning will be in accordance with the following standards:

- ASTM G93, "Standard Practice for Cleaning Methods and Cleanliness Levels for Material and Equipment Used in Oxygen-Enriched Environments"
- CGA G-4.1, "Cleaning Equipment for Oxygen Service"

10.3.2 *FINAL CLEANING FOR OXYGEN SERVICE*

After final assembly, a final cleaning may be required. The cleaning, if required, will be performed in accordance with the ASTM and CGA standards noted in **Section 10.3.1**. The cleaning procedure shall include flushing with hot water and detergent or approved non-toxic cleaning solution followed by a clean water rinse and drying with nitrogen flushing. The system is equipped with clean-outs/purge valves which will be used to flush the system. Valves, meters, filters, and other process components that create restrictions should be installed after final pipe cleaning, if possible.

The oxygen supply and nitrogen supply systems will not require final cleaning, with the exception of the field-installed process piping connection to these units.

10.4 LEAK TESTING REQUIREMENTS

All piping assemblies will be pressure and leak tested at the completion of the field assembly. The testing will be completed using one of the following leak test solutions, including:

- Sherlock Leak Detector, Type CG – Winton Products Company, Inc.
- Snoop Leak Detector – Nuclear Products Company.
- OXEQUIP 17-A Oxy-Leak – OXEQUIP Health Industries.
- F-33 Detergent – Dow Chemicals, Inc.
- Leak-Tec - American Gas and Chemicals, Inc.

Prior to oxygen injection all piping connections will be checked for leaks using Snoop Leak Detector (or equivalent), a non-organic chemically-inert soap. Each joint in the system will be sprayed with the solution to test for leaks. Elimination of the leak shall be accomplished by making sure connections are tight within the system. If tightening a system component is insufficient, the system will be shut down and removed from service immediately. The leak(s) will be repaired, parts replaced, if need be, and the system will be re-tested prior to placing it back in service.

10.5 FREEZE PROTECTION

No heat trace or insulation is required for the oxygen service piping inside or outside the oxygen distribution building, however, heaters will be provided for the oxygen distribution building (refer to **Section 11.0**). As a part of the system operation and maintenance, nitrogen purge of all lateral and wellhead piping will be completed prior to winter on an annual basis. The nitrogen purge will help remove any moisture condensate from within the piping prior to freezing temperatures of winter.

10.6 APPLICABLE CONSTRUCTION AND SAFETY STANDARDS

The installation will be conducted in accordance with standard construction codes and guidance documents. Where applicable, the latest revisions of the following codes shall be met:

1. ANSI – American National Standards Institute
2. ASTM – American Society for Testing and Materials
3. CGA – Compressed Gas Association
4. FM – Factory Mutual
5. IBC – International Building Code
6. ICEA – Insulated Cable Engineers Association
7. IEEE – Institute of Electrical and Electronic Engineers
8. OSHA – Occupational Safety and Health Act
9. NEC – National Electric Code
10. NEMA – National Electric Manufacturer’s Association
11. NFPA – National Fire Protection Association
12. UL – Underwriter Laboratories

10.7 NATIONAL FIRE PROTECTION ASSOCIATION REQUIREMENTS

The EABR system, associated equipment, and wiring will be constructed to Class I, Division II Standards, where flammable gases and vapors (e.g., oxygen or COC vapors) may accidentally accumulate in quantities sufficient to produce explosive or ignitable mixtures. Class I, Division II equipment shall be constructed of the non-incendive, non-sparking, purged/pressurized, hermetically sealed, or sealed device types as per National Fire Protection (NFPA 496) and Underwriter Laboratories (UL 1604) standards.

Requirements of NFPA codes specific to oxygen-enriched atmosphere and compressed and cryogenic fluid will also be followed, which include:

- NFPA code 53: Recommended Practice on Materials, Equipment, and Systems Used in Oxygen-Enriched Atmospheres
- NFPA code 55: Compressed Gases and Cryogenic Fluids Code

11.0 INFRASTRUCTURE

11.1 EQUIPMENT LAYOUT

EABR system infrastructure includes an oxygen distribution building, a concrete pad for oxygen supply (tank) setup and a second concrete pad for the nitrogen supply (cylinder pack) setup. As shown in **Figure 20**, the EABR system equipment will be installed west of Falling Springs Road between 2nd and 3rd Streets. Equipment on the oxygen supply concrete pad will consist of the liquid oxygen tank, ambient vaporizer, and pressure control manifold (refer to **Section 6.0**). The oxygen distribution building will be a pre-fabricated steel-type building that will house the instruments and equipment discussed in **Section 7.0**. The nitrogen supply concrete will store the compressed nitrogen cylinder packs outdoors in open air. Other general specifications are provided in **Table 14**.

11.2 OXYGEN SUPPLY CONCRETE PAD

The oxygen supply equipment will be installed on a 14 foot by 28 foot concrete pad with an adjacent 10 foot by 14 foot trailer apron, as shown on **Figure 8**. The pad and associated surrounding features will require, at a minimum, the following specifications:

- Conformance to all state and local building and safety codes, as applicable as well as NFPA 55.
- Installation of bollards around the concrete pad to prevent damage from vehicles/delivery trucks.
- A stone base inside the fence area.

11.3 OXYGEN DISTRIBUTION BUILDING

The oxygen distribution equipment will be installed in a dedicated pre-fabricated steel building. The equipment building/container will require, at a minimum, the following specifications:

- Conformance to all state and local building and safety codes, as applicable.
- Conformance to NFPA 53 (Recommended Practice on Materials, Equipment, and Systems used in Oxygen-Enriched Atmospheres) and NFPA 55 (Compressed Gas and Cryogenic Fluids Code).
- Constructed of heavy-gauge corrosion-resistant, non-combustible steel that is earthquake resistant and noise-dampening. Steel shall be painted with industrial epoxy gray primer/urethane top coat. All seams will be caulked with polyurethane sealant.
- Two (2) 36" man doors. Man doors will be lockable, capable of fully opening with holdbacks, and 36 inches wide per NFPA 101, Section 7.3.4.1(2) (**Figure 15**). The egress must be unobstructed, clearly visible and marked and lighted as needed.
- Entire building shall be water and weather tight.
- Smoke alarm system with one (1) optical/ionization detection or high-temperature sensor.
- Indoor/outdoor audio/visual alarm beacon (smoke-alarm and/or oxygen-sensor triggered) as indicated in **Figures 15**.
- Two (2) building oxygen sensors (Advanced Micro Instruments, Inc. Percent Oxygen Analyzer, Model 201RSP, or equivalent) for indoor atmospheric checks (**Table 10**).
- Two (2) emergency stop buttons as indicated in **Figures 15**.
- Interior and exterior shall be free of obstructions to allow for oxygen and nitrogen feed inlets and exterior vents as depicted by **Figure 15**.

11.3.1 *ELECTRICAL SPECIFICATIONS*

Power supplied to the oxygen distribution building will be 480V; a transformer will be provided for the 120V and other power needs. The following are additional specifications.

- Electrical wiring shall meet Class I, Division II standards/NFPA 85 where oxygen or COC vapors could accumulate.
- Fabrication of electrical panels and connections for one (1) 480V power service. A transformer to accommodate system's 120V electrical needs, and additional 20 amperes of 120V to be wired to the oxygen supply tank.
- Exterior grounding and lightning rod protection.
- Fluorescent overhead lighting in accordance with National Electric Code (NEC) illumination requirements.
- Two (2) GFI outlets on each main wall.

11.3.2 *HEATING AND VENTILATION*

A thermostatically controlled ventilation unit with inlet vent and electric exhaust fan is designed to ventilate the building and maintain temperatures within design limits. During summer months, the interior temperature of the enclosure will be thermostatically controlled with ventilation fan(s) capable of ventilating at a minimum of 10 building exchanges per hour capacity, or a similarly adequate means. The ventilation system shall be capable of keeping the interior temperature within the operating limits of all equipment as specified by the contractor but not to exceed 140°F. A heat detector/alarm is also provided in the event that temperatures exceed design parameters within the building. If the set point is reached inside the building, the entire system will shut down.

One (1) thermostatically controlled electrical heater is included for thermal protection of the building. The Site location frequently experiences temperatures below freezing [32 degrees Fahrenheit (°F)]. Since the enclosure will contain equipment that is temperature-sensitive, a thermostatically controlled heating system will be installed by the contractor keeping the interior temperature within the operating limits of all equipment as specified, but not below 50°F. The electrical connection associated with the heater will be pre-wired so it is can be easily connected to the electrical breaker panel in the field by others.

Vents will be located to discharge above the roofline of the building with sufficient stack height to allow dispersion. Vents will be equipped with rain hats and screens (to prevent animal entry/nesting). All equipment will be leak tested to ensure that oxygen/nitrogen is not leaking into the enclosed building.

11.3.3 *BUILDING OXYGEN MONITOR*

Oxygen atmospheres greater than 23.5% by volume are considered “oxygen enriched” and may increase flammability. Also, if oxygen levels drop below 19.5%, they are considered “oxygen deficient” and can result in asphyxiation.

Two oxygen sensors will be provided to monitor the atmosphere within the equipment building. The oxygen sensors will be equipped with sampling pumps (Advanced Micro Instruments, Inc. Percent Oxygen Analyzer, Model 201RSP, or equivalent). If oxygen concentrations of greater than 23.5% are detected, this could indicate a leak within the oxygen piping process. If oxygen concentrations of less than 19.5% are detected, this could indicate a leak within the nitrogen purging system, or a leak associated with the concentrated nitrogen blow-down process from the oxygen generator system. In this event, the entire EABR system (including the T-SVE system) will be shut down and the system operators will be notified via the auto-dialer. An audible/visual alarm (beacon light/alarm sirens, both inside and outside the building) will be activated on-site to notify personnel of this condition so that proper procedures can be followed.

11.3.4 *MISCELLANEOUS REQUIREMENTS*

11.3.4.1 *Emergency Eyewash Station*

An emergency eyewash station will be mounted to the inside of the personnel door of the T-SVE building, to allow unimpeded access.

11.3.4.2 *Fire Extinguishers and First Aid Kits*

Multipurpose fire extinguishers (for Class A, B, and C fires) will be maintained within the oxygen distribution building and carried on personnel vehicles at all times. These extinguishers will be capable of extinguishing ordinary combustibles, flammable liquids and gases, and electrical equipment fires. Two 20-pound ABC fire extinguishers will be maintained (one inside the oxygen distribution building and one mounted on the power pole closest to the Main Power Panel).

A first aid kit will also be maintained within the oxygen distribution building and will be inspected on a periodic basis to ensure the contents are current.

11.3.4.3 *Outdoor Signal Beacon*

An audible/visual alarm (beacon light/alarm sirens, both inside and outside the building) will be activated to on-site notify personnel of this condition so that proper procedures can be followed.

An alarm beacon/strobe light is located above the height of the building, above the control panel location, and is set to turn on in the event of any alarm condition.

11.3.4.4 *Smoke Alarm/Heat Detector*

A smoke alarm (either optical/ionization detecting or heat sensing) will be provided in the building. If the smoke alarm is triggered, the audio/visual alarm beacon/siren (located both inside and outside of the building) will be activated to notify the system operators.

The auto-dialer on the PLC will also send a direct message to the W.G. Krummrich plant fire department. The entire system (EABR and T-SVE) will also be shut down.

11.4 BARRICADES/BOLLARDS

Concrete barriers will be placed in key areas to protect critical utilities (such as nitrogen gas supply and oxygen storage tank).

12.0 ELECTRICAL DESIGN

The electrical service for the entire system will originate from the substation to the east of Falling Springs Road (refer to **Figure 21**). Electrical cables will be connected to Substation #1, and will be installed on the existing overhead pipe rack and cable trays, and utility poles, as necessary. A single 13.8 kilovolt (kV) feeder cable will feed a transformer to provide 480 V service for all the equipment. A power pole will be installed (as shown in **Figure 22**) to provide a drop to the main system power panel (PP-1).

12.1 ELECTRICAL SYSTEM DETAILS

The electrical service will be 480-volt three phase. A dry type transformer will be installed in the oxygen distribution building for 120-volt power needs. The electrical classification where oxygen or COC vapors could accumulate will be Class I Division II specification. Approximate electrical loads for the EABR system components are summarized on **Table 15**.

12.1.1 *MAIN POWER AND SUB-PANEL LAYOUT*

The locations of the main power and sub-panels to feed all the equipment is shown on **Figure 22**. The main power panel (PP-1) will provide power to various sub-panels, as shown in the electrical line diagram on **Figure 23**.

12.1.2 *SENSORS AND INTERLOCKS WIRING DIAGRAM*

The PLC for each of the main systems will be interlocked with one another to provide automated control/alarm/shutdown functions. Interlock wiring is shown on **Figure 24** and will include:

- EABR PLC connection with the T-SVE PLC.
- Oxygen supply tank connection with the EABR PLC.

- T-SVE PLC connection with the ThermOx PLC.
- T-SVE PLC connection with the Scrubber PLC.

In addition, the following instruments in the well field will be interlocked with the EABR PLC:

- 221 solenoid valves in 30 solenoid banks.
- 10 DO sensors installed in ten piezometers within the well field.

12.1.3 *BUILDING ELECTRICAL*

The general layout of the EABR equipment building is shown in **Figure 15**. The layout includes:

- Thermostatically controlled ventilation louvers and fans.
- Emergency Stop button locations.
- Audio/visual alarm beacon location.
- Heater.
- Heat/Smoke Alarm.

12.2 ELECTRICAL GROUNDING

The oxygen tank and distribution building will be grounded per Air Products and Solutia requirements. Grounding rods will be installed by a licensed electrician.

13.0 IMPLEMENTATION TASKS

13.1 PERMITTING

The following permit notification will be required for this project. The permit requirements will be renewed/updated as necessary for each phase of work and are summarized below.

13.1.1 *UNDERGROUND INJECTION CONTROL NOTIFICATION*

Injection of oxygen into the subsurface may be subject to the Illinois Environmental Protection Agency's Underground Injection Control (UIC) Program. A Class V notification will be submitted for this activity.

13.2 DESIGN AND PROJECT OPERATIONS PLANS

The design and project operations plans described in the following sections will be developed for work at the site. The plans will be updated as required.

13.2.1 *HEALTH AND SAFETY PLAN*

A site-specific Health and Safety Plan (HASP) will be developed. The HASP will cover work activities, and will integrate with the facility-specific safety requirements.

13.2.2 *OPERATIONS, MAINTENANCE, AND MONITORING MANUAL*

An Operations, Maintenance, and Monitoring (OM&M) Manual will be developed including area-specific details. This manual will include staffing requirements, standard procedures for work activities, and other instructions for the operations staff. This manual will focus on how to track performance, general maintenance procedures, and how to determine when operations are complete.

13.2.3 *SAMPLING AND ANALYSIS AND QUALITY ASSURANCE PROJECT PLANS*

A combined Sampling and Analysis Plan (SAP) and Quality Assurance Project Plan will be developed for the work activities described in this document.

13.3 MOBILIZATION

Staff, materials, and equipment will be mobilized to the site to implement the scope of work, per the schedule as discussed in **Section 15.0**. Basic mobilization and site preparation activities include the following tasks:

- Fabrication of necessary components (oxygen distribution building, etc.).
- Perform survey and utility marking.
- Mobilize temporary facilities (office trailer, storage container, restroom facilities, etc.).
- Construct equipment pads (gravel and/or concrete) as required.

Staffing during the mobilization phase is expected to consist of a Construction Manager and up to two field technicians. Local subcontractors may also be contracted to perform site construction tasks, as required.

13.3.1 *WELL INSTALLATION*

Installation of all EABR wells and piezometers will be conducted using the DPT or rotosonic drilling technology. Refer to **Section 5.0** for a description of the EABR wells and piezometer construction details.

Drill cuttings will be transferred to appropriate containers, analyzed, and disposed of off-site at an appropriate disposal facility.

13.3.2 *MANIFOLD INSTALLATION*

A qualified mechanical contractor will be subcontracted to install the manifold systems (including lateral piping, solenoid banks, wellhead piping and wellheads, and connections as necessary), and oxygen distribution building.

13.3.3 *EQUIPMENT INSTALLATION*

The equipment installation will include installation and set-up of oxygen supply system (including oxygen tank, vaporizer and PCM) and oxygen distribution building that has been pre-fabricated by equipment vendor/supplier. Qualified mechanical and electrical subcontractors will be contracted for the field piping/electrical connections.

13.4 SYSTEM START-UP/EQUIPMENT SHAKE-DOWN

Equipment shakedown will be performed to ensure all automation and safety controls are fully functional. The system shake-down activities will include:

- A pre-startup safety review meeting will be conducted to confirm that the system construction and final installation satisfies the Solutia Process Hazard Analysis (PHA) review.
- Pressure and leak test all major piping.
- Check solenoids and instruments for proper operation.
- Verify and calibrate all instrument signals.
- Verify all analog and discrete signals to/from the PLC.
- Set all valves to the proper pre-start positions.

13.5 SYSTEM OPERATION

The system operation phase will include general operation, monitoring, and maintenance which is discussed in **Section 14.0** of this document.

13.6 SYSTEM DEMOBILIZATION

After completion of operations, the EABR system will be either demobilized/decommissioned.

Well Abandonment: As treatment is completed, the EABR wells and piezometers will be abandoned per 35 Illinois Administrative Code 920 and other applicable Illinois EPA regulations and guidelines.

Site Restoration: Prior to demobilizing, rough grading will be performed as needed to maintain adequate drainage, and generally return the site to a condition substantially similar to its condition prior to the start of construction.

14.0 OPERATION AND MONITORING

This section provides a description of the overall operation strategies, groundwater monitoring programs, and soil sampling programs to meet the remediation objectives. This section also includes a brief description of the anticipated day-to-day operation tasks, including process monitoring, general maintenance, and logging/reporting requirements. These activities will be fully outlined in the OM&M manual for the project (refer to **Section 13.2.2** of this document).

The overall schedule and operational sequence for the project is provided in **Section 15.0** of this document.

14.1 GENERAL SYSTEM MONITORING

The general system operations include routine process monitoring, and performance monitoring (no permit compliance monitoring is anticipated). The goal of monitoring is to record EABR system data to assess the overall progress towards the remediation objectives. Additional details regarding the system monitoring activities will be included in the OM&M manual (refer to **Section 13.2.2**).

14.1.1 *PROCESS MONITORING*

Process monitoring includes measurement of oxygen injection flow rates, pressures, pulse cycling times in the sub-groups, and temperature data at multiple points within the EABR process stream. This data will be used to estimate the mass/volume of oxygen injected into the EABR wells.

The process monitoring data will be used to evaluate the mechanical performance of the system to ensure that equipment is operating within the desired performance range (i.e., target flow rates) and within design specifications. In addition, this data will aid in identifying mechanical issues and/or for system troubleshooting purposes.

14.1.2 *PERFORMANCE MONITORING*

Performance monitoring data generally includes:

1. Field measurement of DO concentrations, pH levels, and oxidation-reduction potentials (ORP), etc. using field multi-parameter instruments and the piezometer well network (see **Figure 4**). In addition, dissolved oxygen probes/data loggers will also be installed to allow for real time monitoring of DO levels by the engineering and project management.
2. Groundwater levels will be monitored in the active treatment area using the piezometers during routine site checks.
3. Oxygen levels in the vapor probes (associated with the T-SVE monitoring network, see **Figure 4**) to assess potential off-gassing of oxygen to the vadose zone.

The primary goal of the performance monitoring is to ensure that DO levels are maintained to provide conditions favorable for aerobic biodegradation, and to ensure that oxygen is being delivered at the optimal rates. This data will also be used to optimize oxygen injection as needed.

In addition, DO data will be used to assess oxygen utilization rates to confirm aerobic bacterial uptake of oxygen is occurring, and to indicate when oxygen utilization rates begin to decrease, which can indicate that COCs are becoming depleted and/or mass-transfer rate limited. This is discussed in more detail in **Section 7.2**.

14.1.3 *GROUNDWATER SAMPLING*

Groundwater sampling will be conducted at piezometers within the EABR area (see **Figure 4**). A baseline event will be conducted prior to start-up, and monitoring will be conducted on an annual basis thereafter. Groundwater data will be assessed to provide lines of evidence that conditions for biological treatment have been created, and remain favorable to support the aerobic degradation processes.

In general, the additional lines of evidence will be based on observation of COC mass reductions (i.e., groundwater and soil concentrations reductions), and assessment of oxygen utilization rates. In addition, microbial population assessments (using groundwater and/or soil samples) can also be performed periodically to provide direct evidence that bacteria populations are present.

Other biological parameters, such as nutrients (e.g., nitrate and phosphorus) would likely be assessed using soil samples to confirm that adequate nutrient mass is present to support the aerobic biodegradation process, and are not generally included in a routine groundwater monitoring program.

A detailed groundwater sampling plan will be included in the OM&M manual (refer to **Section 6.2.3**). This program primarily include monitoring of VOCs using USEPA Method 8260B, and measuring groundwater field parameters (i.e., DO, ORP, pH, conductivity, etc.) using low flow sampling techniques.

Note that a long-term groundwater monitoring program (LTMP)[13] is currently being conducted at the site to assess ongoing MNA processes. Beginning in the fourth quarter (November) of 2011, groundwater monitoring for the CPA will be conducted on a semi-annual basis. The initial groundwater sampling events will include: fourth quarter of 2011, first quarter of 2012 (optional), second quarter of 2012, fourth quarter of 2012, etc. The sampling network will include one upgradient and three downgradient (a total of four) well clusters; and each well cluster includes three monitoring wells, one screen each in SHU, MHU, and DHU. The groundwater samples will be analyzed for VOCs (specifically benzene, MCB, 1,2-DCB, 1,3-

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[13] Solutia Inc, 2009. Revised Long Term Monitoring Program, Solutia, Inc., W.G. Krummrich Facility, Sauget, Illinois, May 2009.

DCB, and 1,4-DCB and 1,2,4-TCB) and MNA parameters consistent with the LTMP. Samples collected from the deep wells will also be analyzed for phospholipid fatty acids (PLFA) and stable isotope probes (SIP).

14.2 WELL FIELD OPTIMIZATION

The following well flow optimization strategies will be employed during the operation phase of the EABR system:

- Optimization of oxygen injection rates and pulsing "on/off" cycles to efficiently distribute oxygen in the target intervals. This will be conducted by evaluating DO distribution data collected during performance monitoring (**Section 7.1.2**).
- Evaluation of oxygen utilization rates, using the following protocol[14]:
    - Oxygen utilization will be measured by temporarily halting the injection of oxygen in select areas for short duration and observing the rate of oxygen depletion.
    - This assessment would be conducted within the first six months of EABR operation (after the bacterial population is acclimated) to establish initial oxygen utilization rates. Oxygen utilization rates will be assessed quarterly thereafter.
    - As COC mass is depleted over time and becomes mass-transfer limited, the oxygen utilization rate would be expected to decline. A reduction in oxygen utilization rates can be considered the primary line of evidence for anticipating the completion of EABR operations within areas of the CPA.

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[14] The oxygen utilization rate evaluation protocol is based upon the memorandum entitled "*Protocol for Completing Enhanced Aerobic Bioremediation Operations*", April 13, 2011, XDD, LLC.

As remediation progresses, and sub-areas (and/or specific depth intervals) within the CPA begin to require less oxygen, reduction of oxygen injection rates and/or shutdown of portions of the EABR system in a phased manner will be appropriate. Details and the anticipated intervals of optimization events will be included in the OM&M manual (refer to **Section 6.2.3**).

14.3 SOIL SAMPLING

In general, soil sampling will be conducted using a Geoprobe. Soil cores will be collected and field-screened for total organic vapors at discrete intervals using a PID and jar vapor-headspace methods. Screening results will be considered when selecting the soil interval to be submitted for laboratory analysis of VOCs by USEPA Method 8260.

The soil data will be used to assess overall COC mass reduction on the soils over the course of the remediation process. A brief description of the proposed soil sampling program is included in this section. A more detailed soil sampling program, with soil sample counts, depths, locations, and selection criteria, will be discussed in the SAP (refer to **Section 6.2.4**). Soil sampling will be conducted annually.

14.3.1 ***BASELINE SOIL SAMPLING***

The 2009-2010 soil characterization sampling data (refer to the *Characterization Report*) will be used as the baseline soil concentrations. The initial benzene mass in each treatment area was based on this data and was discussed in **Section 2.3.3**.

14.3.2 ***INTERIM SOIL SAMPLING***

Interim sampling will be performed to demonstrate the progress of soil treatment. Interim soil samples will be collected annually following start-up of the EABR system, as applicable (refer to the schedule in **Section 13.0**). Samples will be co-located with selected baseline soil sample locations.

14.3.3 *FINAL SOIL SAMPLING*

As oxygen utilization rates decline and other lines of evidence indicate that EABR operations are nearing completion (i.e., COCs are depleted and/or COC are approaching mass-transfer limiting conditions, as discussed in **Section 1.4**), a final soil sampling event will be conducted to determine the overall level of COC mass reduction on the soils.

14.4 DATA EVALUATION

Process and performance monitoring data (including groundwater and soil sampling data) will be entered into a spreadsheet or other interpretational software to track trends in the data. Review of this data (with graphical presentation of trends as applicable) will allow evaluation of:

1. Overall contaminant mass removal and oxygen utilization.
2. Changes in operational parameters of system process equipment (such as increasing or decreasing flow rates, pressures, temperatures, etc.) that may indicate changes in the remedial process, or impending maintenance issues.
3. Well field performance (including changes in DO and COC levels in portions of the treatment area). This data will be used to assess if well field optimization is necessary for optimal oxygen delivery.

Additional monitoring can be conducted if warranted based on observed data trends (for example, if pH data suggests that conditions are becoming acidic and may not be favorable for aerobic biodegradation, this can be further evaluated).

14.5 REPORTING

A *Construction Completion Report* will be generated upon completion of the construction phase of the EABR system.

In addition, general status reporting will be conducted on a quarterly basis. The status reports will detail:

- Soil COC mass reductions and groundwater concentration trends (on an annual basis).
- Laboratory sample results and the associated laboratory and data validation reports (on an annual basis).
- Oxygen mass/delivery rates to the subsurface.
- DO distribution assessments.
- Oxygen utilization rates, as measured during optimization events.
- Process parameters recorded during site visits and downloaded via the telemetry system (including general flow, pressure, temperature, groundwater level measurements, etc. collected in the field).
- Any system outages and corrective measures taken.
- Scheduled maintenance, reconfiguration, or other system optimization events.

As the EABR system attains the remedial objectives, an assessment will be conducted to determine if the EABR system should be shut down and potentially transitioned to MNA. This is discussed in **Section 7.6**. A final completion report will be provided to USEPA upon approval of shutdown, and completion of EABR operations.

14.6 EABR SHUTDOWN PROTOCOL

The EABR shutdown protocol is provided in **Appendix D**. When the EABR system has reached a condition where oxygen utilization has declined and/or COC mass reduction has reached a mass-transfer limited condition, there may be little additional benefit of continuing EABR operations.

Therefore, after a minimum of two years of EABR operation, and on an annual basis thereafter, an evaluation of potential impacts to groundwater and/or potential human health risks associated with the residual COC concentrations will be conducted. Based on the results of these risk evaluations, there are two potential options:

- If the risk evaluations indicate that there is an acceptable level of risk and/or residual risks can be addressed by institutional controls, then a recommendation would be made to shut down the EABR system.

- If the risk evaluations indicate the need for further action, an evaluation to determine if EABR operation should continue, or if Monitored Natural Attenuation (MNA) will address the residual soil concentrations in the saturated zone, will be conducted.

As previously discussed in **Section 7.5**, a report will be prepared for USEPA making the appropriate recommendation to either shut down the EABR system and/or transition into an MNA program. Upon USEPA's approval of either recommendation, the appropriate action would be taken.

15.0 SCHEDULE

This section outlines the anticipated project schedule. The schedule will be dependent upon actual EABR system performance. The proposed project schedule for construction and the EABR system operation is presented in **Figure 25A and 25B**, respectively. Based on the oxygen utilization rate estimates and COC mass, it is anticipated that the EABR system will operate for a four-year period.