In Situ Chemical Oxidation for Groundwater Remediation

Site-Specific Engineering & Technology Application

ESTCP Project ER-0623

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ISCO PROTOCOL

IP.1 INTRODUCTION

The ISCO Protocol is a decision support tool that was created to assist remediation professionals with making informed decisions about the implementation of in situ chemical oxidation (ISCO) to remediate contaminated groundwater. The protocol consists of a series of processes, where information is gathered or analyzed, and decision points where a course of action is decided. The ultimate goal is to improve the state of the practice and help remediation professionals achieve the best possible endpoint that ISCO can achieve. This work was funded by the Environmental Security Technology Certification Program (ESTCP) under project ER-0623. A companion component of this project is the In Situ Chemical Oxidation for the Remediation of Groundwater volume of the Strategic Environmental Research and Development Program (SERDP) / ESTCP Remediation Technology Monograph Series slated for publication by Springer Science+Business Media, LLC in 2011. Both this protocol and the companion Monograph Series volume are self-standing publications, but occasional references throughout the protocol indicate where additional detail may be found it in the book.

The ISCO Protocol provides guidance on four separate components of the ISCO process, which are: (1) ISCO Screening; (2) ISCO Conceptual Design; (3) ISCO Detailed Design and Planning; and (4) ISCO Implementation and Performance Monitoring. These four components, how they are related, and their similarity to other commonly used remediation milestones are shown on the Overall ISCO Protocol Flow Diagram.

The ISCO Protocol was created using a conceptual system of tiers, with each lower level providing more specific details on individual pieces of the ISCO Protocol. The Overall ISCO Protocol Flow Diagram, and the associated narrative that you are reading now, is the highest level tier (most broad, least detailed). Each of the four protocol components has its own flow diagram, and these represent the next level of detail. The flow diagrams consist of a series of decisions and processes to be carried out. The individual decisions and processes have narrative guidance, figures, tables, and/or decision support tools that provide guidance on how to consider each specific step (decision or process) within that component.

This electronic version of the ISCO Protocol includes the Overall ISCO Protocol Flow Diagram, flow diagrams for each of the four components, and the associated general guidance. Detailed supporting tools are attached as separate, linked files. The printed version of the ISCO protocol has the narrative attachments appended to the end, and electronic tools on the attached CD.

IP.2 HOW TO NAVIGATE THIS ELECTRONIC DOCUMENT

The files on this CD require Adobe® Acrobat v6 (or higher), and Microsoft Excel™ 2003 (or higher). This CD is compatible with either Microsoft Windows or Macintosh operating systems (excluding the CORT3D model program which requires a Microsoft Windows operating system). The spreadsheet tools must be copied from the CD onto the user's personal computer and the macros enabled in order to function properly (note, some versions of Microsoft Office for the Macintosh do not support visual basic macros).

The PDF version of this document has hyperlinks that are intended to assist users as they move through the document. These hyperlinks allow users to move to the associated page within this document (i.e., move downwards within the tiered system to more specific information) or open a separate supporting file that provides additional detail on the specific decision or process at hand. Hyperlinks appear as underlined blue or green text. When selecting a blue hyperlink to a location within this main index file, the view will "jump" to that location. Use "alt" left arrow "←" to return to the previous view within this index file (see View menu in Adobe®). Green hyperlinks to the attachments and supplementary information will open a new window which should be closed by the user. For reference, attachments are identified by

"Ax." prior to the attachment name. For example, the hyperlink "Conceptual Design Process 3b" will jump to that section of the index file in the same window while the hyperlink "A1. ISCO Site Characterization Needs" will open a separate window with Attachment 1 in addition to the index file.

A hyperlink to the Overall ISCO Protocol Flow Diagram (highest tier) is located in the bottom right corner of each page. Within each of the four protocol components, a hyperlink directing users to that component's flow diagram (second tier) is located in the bottom left corner of each page. The flow diagrams themselves also include hyperlinks. Users may click on the specific part of the flow diagram for which they would like further information, and the link will take them to the section of this document that contains more detailed information regarding that particular portion of the protocol.

To begin using this CD, user's familiar with ISCO may simply click on any of the hyperlinks in the Table of Contents, go to the "ReadMe First ER0623_CD_PRv1" (October 2010) file and click on any hyperlink, or open individual files within the file folders on this CD. User's new to ISCO may want to walk through the individual sections as outlined below which contain the step-by-step guide for site specific engineering and application of ISCO.

IP.3 FIGURE AND TABLE NUMBERING CONVENTION

The figures and tables are named for their position within that Component's flow diagram, with the Component name as a shortened prefix ("S" for Screening, "CD" for Conceptual Design, "DD" for Detailed Design and Planning, and "IM" for Implementation and Performance Monitoring. Figures and tables in the supporting attachments are named A1-1 (for Attachment 1, Table or Figure 1).

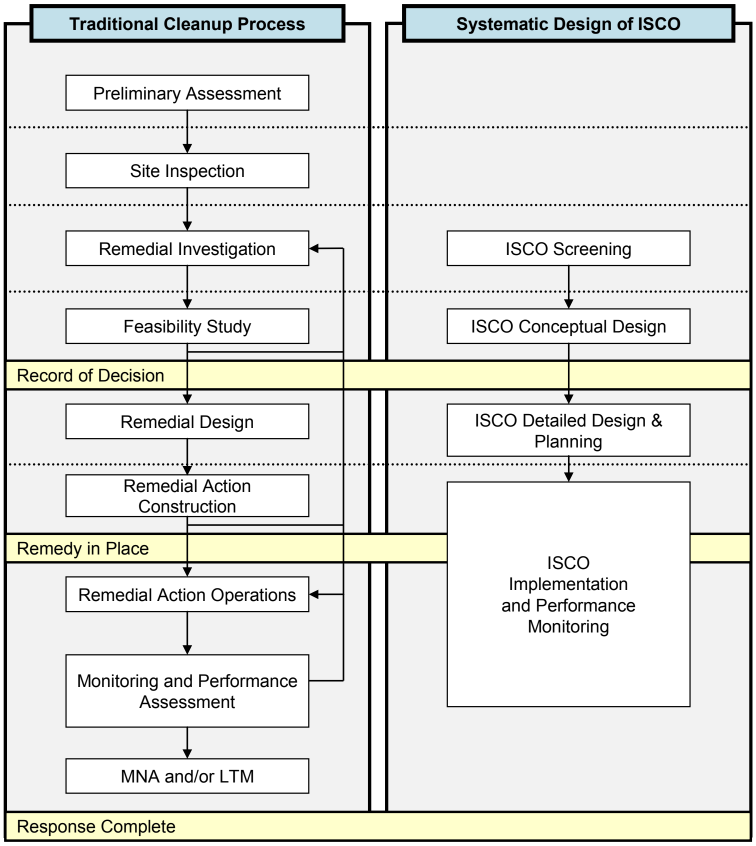


Figure IP-1: Overall ISCO Protocol Flow Diagram.
[To navigate the electronic version of this tool, click on one of the four Protocol Components (right side of the diagram) on which you would like more information and you will be directed to that location.]

Overall ISCO Protocol Flow Diagram

ISCO SCREENING

S.1 INTRODUCTION

ISCO Screening is a multi-step, iterative process to determine if ISCO is relevant to a site based on contaminant characteristics, groundwater and soil characteristics, and remedial goals. This narrative guidance explains the process that can be followed to screen ISCO applicability for a site. The instructions below correspond to the decisions and processes depicted on Figure S-1 (ISCO Screening Flow Diagram) and the numbers and letters of the subsequent sections correspond with the numbered process steps and lettered decision steps in that diagram.

It is important to note that while many of the processes and decisions throughout the ISCO Screening component are depicted in a linear fashion with some feedback loops incorporated; ISCO (and any remediation technique) should be approached using the Observational Method (Site Assessment and Remediation Handbook, 2nd ed,. Lewis Publishers', Boca Raton, FL, 2003). The Observational Method acknowledges that decisions must be made based on data that contains some degree of uncertainty, and that data collected throughout the site characterization and treatment processes are used to reduce uncertainty and refine design in an iterative fashion. The decisions described during the ISCO Screening component and throughout the ISCO Protocol are made to continuously address and reduce uncertainty. The general steps of the Observational Method for site remediation are as follows (adapted from Site Assessment and Remediation Handbook, 2nd ed,. Martin N. Saram, Lewis Publishers', Boca Raton, FL, 2003):

1.) Conduct an investigation to establish the general characteristics of a site.
2.) Establish the most probable site conditions and deviations from these conditions.
3.) Develop design based on these most probable conditions.
4.) Determine courses of action if conditions deviate from those predicted (contingency plans).
5.) Measure and evaluate actual conditions during technology implementation.
6.) Modify the design and implementation as needed to suit actual site conditions.

The first level of ISCO Screening (Screening Process 1 and Screening Decision A in the ISCO Screening Flow Diagram) is to determine if ISCO should be eliminated immediately from consideration based on key site attributes that dictate that ISCO will not be effective. Appropriate site characterization data must exist to determine if there are any clear indications that ISCO is not applicable. Guidance for data collection is provided as well as a tool for assessing decision uncertainty resulting from data uncertainty.

If there are no clear indications that ISCO is impracticable, the next step is to determine if a coupled approach (ISCO plus an appropriate pre- and/or post-ISCO remediation technology) deserves consideration based on necessity and/or improving cost-effectiveness. The next stage of ISCO Screening is a systematic, integrated evaluation of oxidants and delivery techniques based on multiple critical site characteristics. A series of data look-up tables are used to select appropriate ISCO approaches (a set of specific oxidant and delivery method combinations) that are based on contaminant and site-specific soil and groundwater characteristics. Details of this process are provided below.

The output of evaluation is a set of viable ISCO approach options for site-specific ISCO application that are scored and ranked through consideration of factors of effectiveness, implementability and user preference. The user may "stop" consideration of ISCO where the probability of success is unacceptable, or proceed to the ISCO Conceptual Design component with top-ranked ISCO approaches.

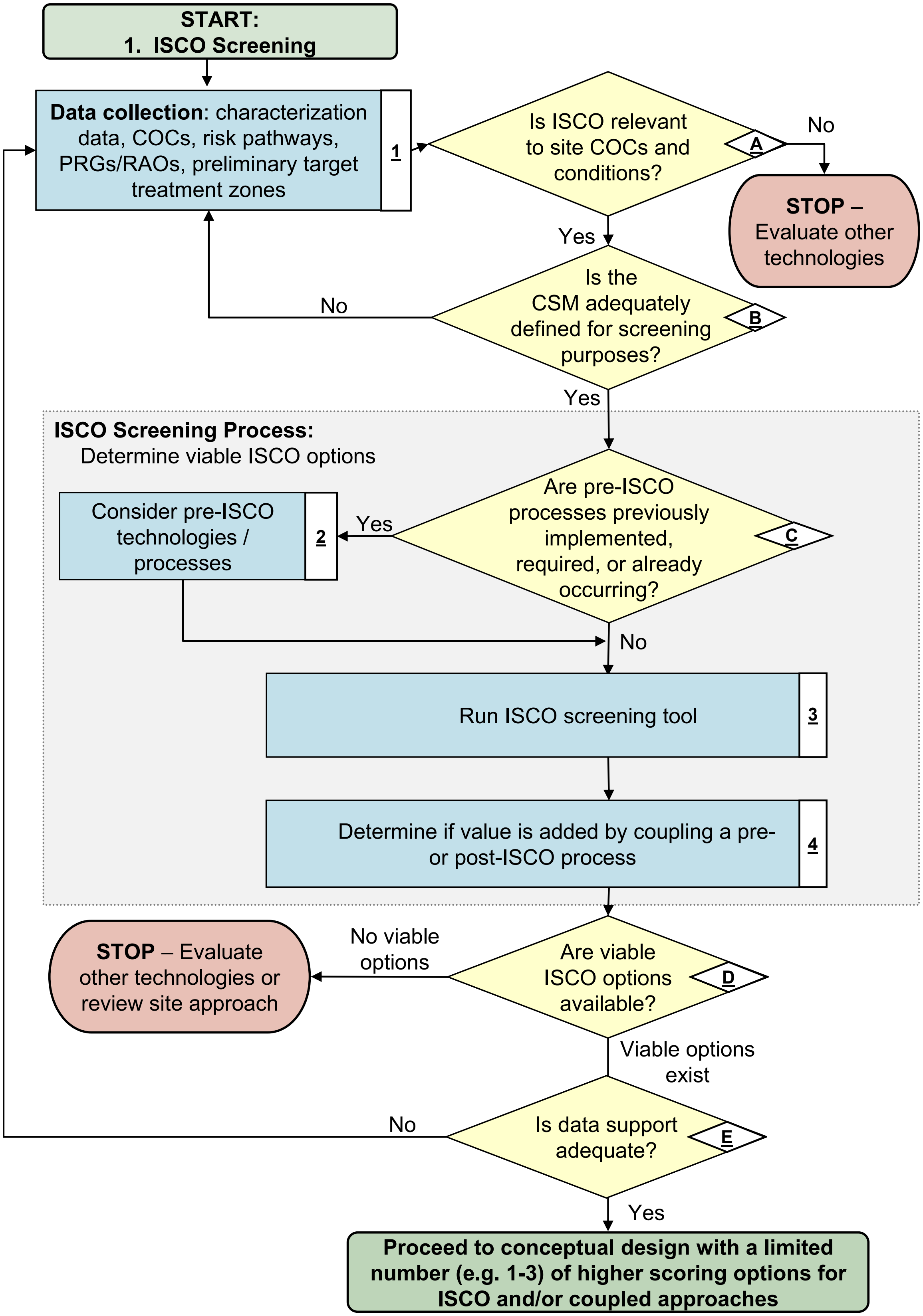


Figure S-1: ISCO Screening Flow Diagram.
[To navigate the electronic version of this tool, click on the Process (blue rectangle) or Decision (yellow diamond) on which you would like more information and you will be directed to that location.]

S.2 SCREENING PROCESS 1: ISCO Site Characterization Data Needs

Screening Process 1 entails the collection of site characterization data necessary for screening the contaminated site against various ISCO technology options. A1. ISCO Site Characterization Data Needs includes a checklist of typical conceptual site model (CSM) data as well as ISCO-specific information desired to complete ISCO screening. Since Screening Process 1 is also revisited at later points during the protocol, it also includes guidance for collection of adequate information to complete the ISCO screening and follow-on decision processes.

S.3 SCREENING DECISION A: Is ISCO Relevant to Site COCs, Geology and Goals?

From the information provided in Screening Process 1, the next step is to determine if ISCO is relevant or clearly not viable. There are two primary considerations at this entry-level point of ISCO Screening: (1) the primary contaminants of concern (COCs) must be degradable by at least one ISCO oxidant, and (2) there must be a practical likelihood of ISCO meeting the treatment goals set for the site, given the site's hydrology and contaminant mass. ISCO treatment goals are the desired endpoint to be attained after ISCO with respect to reductions in COC concentration and/or mass. ISCO treatment goals may either be numerical standards required by the applicable regulations (e.g., maximum contaminant level) or an interim standard that the site's management strategy considers acceptable given other COC management practices that will be implemented, such as monitored natural attenuation. A decision aid, containing guidance and two separate matrices, assist the reader in answering these questions and is provided as A2. ISCO Relevance to COCs, Geology, and Goals. These are generally coded with a "go" (coded green), "stop" (coded red), or "proceed with caution" (coded yellow).

S.4 SCREENING DECISION B: Is the Conceptual Site Model Information Adequate?

Throughout the ISCO Protocol, and according to the Observational Method to site remediation, the CSM is revisited to help make sure that an adequate amount of data has been collected and the CSM is adequately defined to make the decisions at hand. An Excel^{TM} based A3. CSM Certainty Evaluation Tool is provided to assist the understanding of the CSM, which is the foundation of remedial technology decisions. This semi-quantitative scoring procedure is intended for use by multiple, diverse (technical and management), knowledgeable members of the project team to assess the relative certainty present in the site understanding. The site understanding is divided into technical and management factors that consider the breadth of CSM issues from nature and extent of contamination to budget constraints of site management. Detailed instructions for use of the A3. CSM Certainty Evaluation Tool are provided within. The outcome is an average certainty "score". It is the adequacy of this average certainty score that is discussed by the project team prior to proceeding with decision making.

The acceptable level of certainty will be project-specific and should be based on project-team consensus. It will also depend upon the component of the ISCO Protocol that is being executed. For example, a lower level of certainty, perhaps less than 50%, may be acceptable during the ISCO Screening process, but an increased level of certainty, perhaps 60-70%, is preferred during the ISCO Conceptual Design process. Finally, during ISCO Detailed Design and Planning, a high degree of certainty is important to help guarantee success, preferably greater than 80%.

Through the iterative use of this A3. CSM Certainty Evaluation Tool during the implementation of the ISCO Protocol, the project team can explicitly assess certainty and then take steps to ensure that appropriate data gaps are addressed and uncertainty is reduced. This approach in turn can result in increased probability of remedial success.

If the outcome of Screening Decision B is that CSM certainty is deemed too low, then Screening Process 1 (A1. ISCO Site Characterization Data Needs) should be revisited to identify and close data gaps to help make sure that adequate data are collected to support the subsequent decisions. If CSM certainty is deemed adequate, the next step is to determine if pre-ISCO coupled processes are necessary, have been previously implemented, or are already occurring.

S.5 SCREENING DECISION C:
Are Pre-ISCO Processes Required, Previously Implemented, or Already Occurring

Screening Decision C assesses the viability and benefits of conducting a pre-ISCO treatment step. The purpose of such a pre-treatment step is to:

1.) Add "value" or increase cost-effectiveness through improved efficiency of mass destruction,
2.) Take full advantage of beneficial synergistic naturally-occurring biotic or abiotic attenuation processes, and/or
3.) Improve chances for success because ISCO alone may not be expected to reach the desired goals, for example, due to high contaminant concentrations (e.g., non-aqueous phase liquid).

Pre-ISCO processes may be already occurring (naturally, such as biological degradation, or by design) or have been implemented in the past, resulting in site conditions that must be considered while screening ISCO. A "YES" outcome of this decision results where:

1.) Another technology has already been implemented at the site and the side effects of prior treatments must be considered.
2.) Natural biotic or abiotic processes are evident at the site and resumption of these processes post-ISCO may be desired.

Consideration of whether a pre-ISCO treatment step may or may not be advantageous can also be assessed. A "YES" outcome where pre-ISCO treatment may be advantageous:

1.) A yellow scenario in exiting Screening Decision A (A2. ISCO Relevance to COCs, Geology, and Goals) for Table A2-1 or Table A2-2 outcomes.
2.) A green or yellow Table A2-1 outcome in combination with a yellow or red Table A2-2 outcome.

With a "YES" outcome to Screening Decision C, the next step is to complete Screening Process 2 (below) to evaluate pre-ISCO coupling processes for possible synergistic or deleterious interactions with ISCO.

A "NO" outcome of Screening Decision C results from a green scenario in exiting both Screening Decision A (Tables A2-1 and A2-2 in A2. ISCO Relevance to COCs, Geology, and Goals) and determination that the CSM is adequately defined in Screening Decision B (A3. CSM Certainty Evaluation Tool). The next step is to proceed with determining ISCO options, Screening Processes 3 and 4 described below.

S.6 SCREENING PROCESS 2:
Consider Pre-ISCO Coupling Processes (Pre-ISCO Coupled Processes Are Already Occurring or Are Needed to Achieve Desired Outcome)

There are many additional screening-level considerations that must be evaluated if ISCO is to be applied in the following three cases: 1) after another source zone treatment process has already been applied, or 2) if ISCO is to be applied to a site where future treatments are planned, or 3) natural biotic or abiotic processes are occurring. In the first case, it is important to ensure that previously implemented technologies will not interfere with ISCO effectiveness, and in the third case, minimization of disruption to any future technologies or attenuation processes should bolster post-ISCO polishing abilities. It is worth noting that at many complex sites, multiple technologies may be implemented in a "treatment train" approach to meet long-term remediation goals (e.g., remedial action objectives). If ISCO is implemented as part of the train, it must be compatible with the other processes in the train both before and after ISCO.

To assist with determining ISCO compatibility with such processes a table has been prepared (A4. Pre-ISCO Coupling Processes). This attachment contains a list that evaluates various synergistic and deleterious interactions between ISCO and a variety of other treatment technologies and processes. The information provided in the table offers guidance with respect to considerations for enhancing the coupling approach and/or cautions to consider in ISCO design and implementation. These considerations must be carried through the remainder of the ISCO screening process and design, as appropriate. The ISCO Protocol assumes that the user will initiate coupling design efforts, if appropriate, coincidentally with the ISCO Protocol procedures and decisions. The ISCO Protocol does not contain detailed coupling design and implementation guidance.

S.7 SCREENING PROCESS 3: Selecting Oxidants and Injection Methods using the ISCO Screening Tool

Screening Process 3 is an important component of ISCO screening where potentially viable oxidants and their respective injection methods are evaluated in light of site-specific conditions. The goal of this process is to identify ISCO approaches (i.e., a coupling of a specific oxidant with a specific injection method) that may potentially be viable for a site. Many tradeoffs may exist between approaches, as some may be better suited to certain site conditions than others. Ultimately, there is no universally applicable ISCO approach. Instead, ISCO approaches should be evaluated in a systematic manner, leading to the identification of approaches that maximize performance (i.e., ability to meet objectives). This evaluation generally must consider the ability of an approach to meet the following criteria:

1.) The oxidant must be able to degrade the contaminant.
2.) Effective contact between the oxidant and contaminant can be achieved through a distribution technology suited to site hydrology.
3.) The concentration, mass, or distribution of the contaminant to be treated should be reasonably suited to the approach.
4.) Site geochemistry will not interfere significantly with oxidant contact, activation or persistence.
5.) The approach can be implemented within cost and resource availability constraints.
6.) The ISCO approach must be compatible with stakeholder and institutional constraints.

These various factors must all be considered simultaneously to yield selection of the best possible ISCO approaches and minimize tradeoffs. It is beyond the scope of this guidance to cover issues related to remediation costs, resource availability or stakeholder and institutional constraints, mainly because they may be widely variable from site to site, but this does not diminish their importance in the screening process. However, the screening guidance and tool provided herein does allow for evaluation of the first 4 criteria, and is provided to help remediation professionals consider all of their options in a rapid manner and provide useful information needed to make decisions.

The A5. ISCO Screening Tool, an Excel™ spreadsheet tool developed by the ER-0623 team, is provided to help evaluate the viable ISCO approaches using site-specific characteristics as input and effectiveness and implementability as the primary screening criteria. It automates the ranking of ISCO approaches and lays them out side by side given a set of site-specific conditions. The A6. ISCO Screening Tool User's Manual provides more details on what the tool is designed to do and how the tool generates the ranked set of results. As many major screening criteria as possible were included in this automated tool. However, there are several additional factors that should be considered as part of the screening process (see A7. Additional ISCO Considerations) but which could not be fit into the screening tool construct (see also A8. ISCO Screening Tool Look-up Tables). These factors include permanganate natural oxidant demand (NOD), and the relative availability of the various ISCO approaches (as some are much more novel than others).

S.8 SCREENING PROCESS 4: Determine if Value is Added by Coupling ISCO with Other Technologies

Based upon the results returned by the A5. ISCO Screening Tool (Screening Process 3), users are urged to once again consider coupling ISCO with another technology. An example would be a scenario in which options that the screening tool considers “fair”, or “worse”, are returned. In this situation, a coupled approach may add value to the project and increase the overall likelihood of success. A variety of treatment processes may be proactively introduced to the site before, during, or after ISCO by design to improve the potential to reach remediation goals. The A9. ISCO Coupling Tables include considerations for ISCO applied as follows with respect to other technologies:

- After other technologies (as described for Screening Process 2),
- Adjacent to other technologies, and
- Before other technologies.

ISCO can feasibly be coupled concurrently (same time and location) with other technologies and has the potential to improve the ability to reach remediation goals. While there is limited information available in the literature and in field case histories, there is a theoretical basis for a range of approaches for coupling ISCO with other technologies concurrently including:

- Surfactant / cosolvent flushing to enhance contaminant dissolution, hence making it more available for destruction by oxidants in the aqueous phase.
- Thermal technologies which may act as an activator (e.g., for heat-activated persulfate) or to improve reaction kinetics during ISCO.
- Pump and treat, which may use existing infrastructure in ISCO recirculation systems or induce gradients to impact oxidant movement through the subsurface.
- Soil vapor extraction, which can help control vapor migration, particularly with aggressive or gas-evolving oxidants like catalyzed hydrogen peroxide.

Each of the A9. ISCO Coupling Tables should be consulted as appropriate to determine if there are opportunities to synergistically couple ISCO with other technologies to improve treatment efficiency or effectiveness. The tables offer guidance with respect to considerations for enhancing a coupled approach and/or cautions that must be considered in ISCO design and implementation. These considerations must be carried through the remainder of the ISCO screening process and design.

S.9 SCREENING DECISION D: Are Viable ISCO Options Available?

The basic decision process for Screening Decision D is straightforward. If the outcome of Screening Process 3 (A5. ISCO Screening Tool) and/or Screening Process 4 (A9. ISCO Coupling Tables) is that there are no viable ISCO or coupled-ISCO options, then other remediation alternatives must be considered. When there are viable options, the next step is to revisit the CSM to evaluate data adequacy in preparation for the conceptual design process.

S.10 SCREENING DECISION E: Is Data Support Adequate?

Prior to moving forward to ISCO Conceptual Design with the options emerging from ISCO Screening, it is important to revisit the A3. CSM Certainty Evaluation Tool to verify data adequacy. This tool was used in Screening Decision B, and instructions are provided within the tool itself. It is recommended that users consider the suggested weighting factors proposed for the ISCO Conceptual Design stage of the ISCO Protocol (see second worksheet on spreadsheet tool) as opposed to the ISCO Screening stage weights used earlier at Screening Decision B.

When the CSM uncertainty is acceptable to the project team, users should move to ISCO Conceptual Design, the next step in the ISCO Protocol. When the CSM uncertainty is unacceptably high, users should consider what aspects of the CSM are not well understood, and then should collect additional data to reduce the uncertainty to an acceptable level prior to proceeding to ISCO Conceptual Design.

ISCO CONCEPTUAL DESIGN

CD.1 INTRODUCTION

The ISCO Conceptual Design component provides an opportunity to explore specific ISCO approaches identified during ISCO Screening in more detail so that informed decisions can be made about their viability. The process consists of analyzing various commutations of each ISCO approach with the objective of honing in on a specific design. At this stage, design factors such as cost, well spacing, number of injection points, injection volume and others are taken into consideration. The process for conceptual design proposed herein consists of two tiers. The first tier consists of analyzing existing information from the site and making informed assumptions where necessary, with the objective of rapidly evaluating various designs and narrowing the range of options. An uncertainty analysis is then performed to determine if a second tier of conceptual design is necessary. If so, the second tier is implemented where additional information is collected from the site via laboratory testing, field pilot testing or modeling with the goal of reducing uncertainty to acceptable limits.

The following sections explain the suggested process to be followed to develop a site-specific ISCO conceptual design. These instructions correspond to the ISCO Conceptual Design Flow Diagram (Figure CD-1), with the numbers and letters of the subsequent sections corresponding to the numbered process steps and lettered decision steps in the ISCO Conceptual Design Flow Diagram.

CD.2 CONCEPTUAL DESIGN PROCESS 1: Select Target Treatment Zone

The target treatment zone (TTZ) can be defined as the area of the site to be treated. It should be defined both horizontally (e.g., points on a map) and vertically (depth to be targeted). Defining the TTZ is not necessarily an easy or clear-cut exercise. The overall site remedial objectives and time frame available to achieve them are often the driving factors in defining the TTZ. The following are possible considerations:

- If reaching maximum contaminant levels (MCLs) or a risk-based cleanup criterion in a short time period is the objective, then the TTZ should be defined based on the best available information as to the extent of groundwater exceeding MCLs. In this case attainment of MCLs is the ISCO treatment goal.
- If reaching MCLs or a risk-based cleanup criterion is a long term objective, then the TTZ can be defined as something smaller, with monitored natural attenuation used to manage the contaminated area outside of the TTZ. In this case, the ISCO treatment goal is a concentration that is deemed an acceptable ISCO endpoint and is anticipated to lead to the overall site remedial objective after a period of monitored natural attenuation.
- If mass removal is the ISCO treatment goal, the user needs to define the extent of mass removal that is desired. This may involve treating an area with groundwater or soils concentrations above some target concentration (e.g., 1,000 ppb). The target concentration is often based on judgment, or may be based on the area of known contaminant release.
- Reducing mass flux is a relatively new objective that may also be used. If mass flux reduction is the ISCO treatment goal, the TTZ should be based on fate and transport (attenuation) groundwater modeling of the contaminants from the target zone.

Defining the depth of the TTZ may also be challenging. Ideally, depth-specific soil or groundwater sampling has been performed to help identify the layer of the subsurface with the majority of the contamination. Membrane interface probes (MIP) or similar in-field tools may also be used to help understand the variation of the contamination with depth.

It is very unusual to have a perfect set of data from which to define the TTZ. There will always be some uncertainty. Additional data could be collected during the ISCO Conceptual Design component, according to ISCO Conceptual Design Process 5 below. An alternative is to follow the Observational Method and perform the first injection based on the available information. The TTZ for the second injection could be adjusted based on what is learned from the first injection and subsequent performance monitoring.

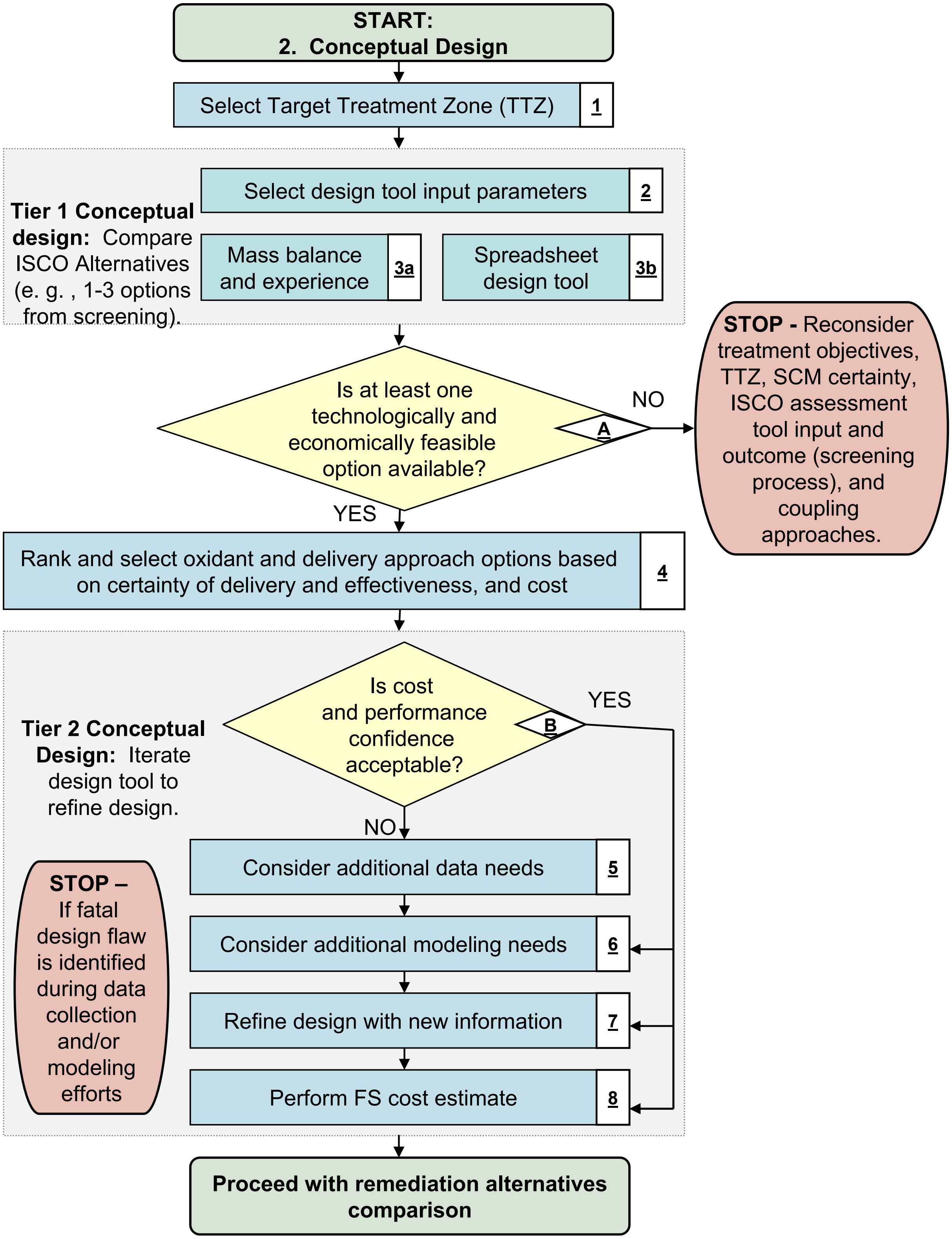


Figure CD-1: ISCO Conceptual Design Flow Diagram.
[To navigate the electronic version of this tool, click on the Process (blue rectangle) or Decision (yellow diamond) on which you would like more information and you will be directed to that location.]

CD.3 TIER 1 CONCEPTUAL DESIGN

The first tier of conceptual design is a preliminary run through of the conceptual design using the information available. The first tier provides:

1.) A preliminary evaluation of the cost and applicability of ISCO.
2.) A comparison of the ISCO approaches identified during ISCO Screening.
3.) Information on the uncertainty in the design, performance and cost that allows informed decision as to whether or not additional information collection is needed to reduce the uncertainty.

CD.3.1 CONCEPTUAL DESIGN PROCESS 2: Selection of Tier 1 Design Input Parameters

The first task in the Tier 1 ISCO Conceptual Design is to select appropriate design parameters. The design parameters will be specific to the design approach discussed below. For the A11. ISCO Spreadsheet Design Tool (described below in ISCO Conceptual Design Process 3b) the required design parameters can be found on the "Site Data Input" worksheet (or tab) of the spreadsheet. A brief discussion of each parameter and “typical ranges” for that parameter can be found as comment boxes in the Spreadsheet Design Tool. The following paragraphs highlight a few of the key design input parameters.

With permanganate, one of the most important design parameters is the natural demand the reduced subsurface materials have for the oxidant and is referred to as natural oxidant demand (NOD). During the Tier 1 ISCO Conceptual Design, actual NOD measurements may not be available. However, they can vary widely from site to site, as they have been found to be below 0.1 g/kg at some sites, and over 100 g/kg at others. High soil organic matter content, as well as substantial biomass, organic growth substrates or reduced minerals will generally increase NOD significantly. In the absence of NOD data, a range of values may be employed to determine how sensitive the conceptual design is to NOD, but the uncertainly will typically be high. To reduce uncertainty, a NOD test using the site media to be treated is strongly recommended as it is presently the only reliable way to quantitatively evaluate NOD.

Another key design parameter is the “thickness of the mobile zone”. This region is the portion of the formation through which the injected oxidant will actually flow. Because of the heterogeneities in soil properties, injected oxidants will only flow through a fraction of the formation. At some sites, this fraction is obvious from soil boring logs (e.g., flow will go predominantly through sand layers and not clays). But only small differences in hydraulic conductivities are required to cause flow to go through one layer and not another. These differences may not be noted on soil boring logs. Having a low thickness of mobile zone compared to the total thickness to be treated may negatively impact performance, if there is contamination in the lower permeability layers, since the oxidant is not likely to contact this contamination. But having a low thickness of mobile zone is likely to result in a larger radius of influence (ROI) since the injected fluid is likely to move out further from the injection well. This may result in a lower cost for achieving a given ROI. Information from soil boring logs is a first good estimate to use as a design parameter. However, the uncertainty associated with this factor should be taken into account, and the sensitivity to it should be evaluated in the conceptual design.

An additional key ISCO design parameter is the number of injections of the oxidants. Among 88 full scale case studies containing data on the number of treatment events, 75% used more than one delivery event, 45% used 2 or 3 delivery events, and 58% used between 2 and 4 delivery events. The mean number of delivery events was 2.8 (these statistics do not include ozone or peroxone applications which deliver oxidant continuously in one long delivery event). Additional details may be found in Krembs (2008), in the DISCO interactive case study database and in the ISCO volume of the SERDP / ESTCP Remediation Technology Monograph Series (Springer Science+Business Media, LLC, 2011). Multiple injection events obviously add to the cost, but they provide the opportunity to modify and optimize the design based on what is learned in the first application. This concept of apply, measure, and readjust the design is often called the Observational Method, and is discussed in more detail in the ISCO Detailed Design and Planning component.

It should be realized that the user will never know the actual values of these parameters with complete confidence. As stated above, one of the objectives of the Tier 1 ISCO Conceptual Design is to provide a preliminary evaluation of the cost and applicability of ISCO. This can be done with very little data to provide an idea of the applicability of ISCO. It may be found very quickly that ISCO is not applicable. In addition, design approaches using the A11. ISCO Spreadsheet Design Tool can be used to evaluate the sensitivity of the design (and cost) to the range of the parameters. If the cost impact of the varying parameter is large, then additional data collection may be necessary (as discussed in ISCO Conceptual Design Process 5 below).

CD.3.2 CONCEPTUAL DESIGN PROCESS 3: Selection of Tier 1 Design Approach

A number of approaches can be used to complete conceptual designs for ISCO. Two are discussed here. The appropriate approach depends on the oxidant to be used, the information available, and the objectives of the design team. It should be noted that the technical details in these design approaches are limited in their scope to oxidants that are delivered as a liquid, and injected via either conventional wells or direct push probes. As a result, the use of ozone (a gas-phase oxidant) or novel injection methods (e.g., fracturing, mixing, etc.) are not considered in detail in this section. This is because many of the technical facets of these technologies differ substantially from applications where liquid oxidants are injected using the relatively common approaches of vertical wells or probes, and have significant implications for design. However, at a higher level, many of the processes, concepts and decisions contained in the protocol from here onward are still applicable and insightful for these applications, and may be of benefit. For conceptual design of ISCO systems employing ozone, it is recommended that the user consult with engineers and vendors who have expertise in ozone as well as air sparging applications. There is also some information, including design criteria, available on these approaches in Krembs (2008), and the DISCO interactive case study database.

ISCO Conceptual Design Process 3a represents a commonly utilized approach that is applicable to all liquid oxidants and is based on a mass balance of the amount of oxidant assumed to be needed to dose a TTZ. Many simplifying assumptions are made during this approach, which increases its ease of use and reduces the information needed to employ it, but also increases uncertainty in the outcome.

ISCO Conceptual Design Process 3b is an approach that employs a spreadsheet design tool developed by the ER-0623 team to rapidly evaluate more design factors and reduce uncertainty. This tool also contains a kinetics package that considers oxidant persistence specifically for permanganate, assuming an instantaneous as well as a rate-limited 2nd-order NOD. This tool may have some application towards conceptual design of persulfate or hydrogen peroxide ISCO systems as well, but with some limitations outlined in the text of ISCO Conceptual Design Process 3b. Outputs of the tool include useful conceptual designs and evaluation, such as a rough estimate of cost, number of wells, spacing, injection volume, field time and others. These outputs can then be evaluated to narrow the field of design parameters to those that meet projection objectives and endpoints in an effective manner.

CD.3.2.1 CONCEPTUAL DESIGN PROCESS 3a: Tier 1 Mass Balance Design Approach

A mass balance approach coupled with experience is currently one of the most commonly used approaches in design of ISCO systems. The following are the major components of this approach. These components are not offered in a strictly chronological order, as they are often interrelated and multiple iterations of consideration may be necessary to hone in on a specific conceptual design.

Select delivery method. In the ISCO Screening section, a variety of delivery methods were evaluated. Permanent wells or direct push points are the most common methods as demonstrated by the case study experience (Krembs 2008), but other innovative methods may also be considered (e.g., soil mixing, fracturing, etc.). The selection of the approach is ultimately based on site constraints, experience and a rough cost estimate. For example, direct push points are typically cheaper per point, but more points are often required since less fluid can be injected into each point and results in smaller ROIs. Effectiveness is also a consideration in selecting the delivery method. For instance, the closer spacing of direct push points allows oxidant injection to occur on a much denser grid, and thus may improve coverage over the site, especially where heterogeneities are present. However, the lack of permanent well casings also means that subsequent oxidant doses require a remobilization of the push probe injection rig to the field.

Select injection well / point spacing based on experience with similar sites or conditions. There are many factors that impact injection point spacing, and it is impossible to provide detailed guidance on the spacing here as it will be very specific to the formation and the oxidant to be applied. As a result, consultation with experienced remediation professionals is recommended to determine realistic ROIs and injection point spacing for real sites. However there are several major criteria that impact the spacing that is achievable as briefly summarized below.

- **Permeability** – The permeability / hydraulic conductivity of the site impacts the maximum injection volume that a well or push point will accept, impacting the ROI. Since ROIs should be applied with some overlap for effective coverage of the entire TTZ, this limitation on injection volume will constrain injection point spacing.
- **Heterogeneity** – Maximizing delivery effectiveness in heterogeneous environments may entail customizing the injection point spacing accordingly. Tighter injection grids increase delivery certainty, but at increased cost.
- **Oxidant persistence** – Depending on the oxidant and the media to be treated, different oxidants will persist in the subsurface for differing amounts of time. If the oxidant is depleted rapidly in the formation, ROIs will be smaller requiring tighter spacing.
- **Contaminant mass and concentration** – Discrete areas within the TTZ that are known to have high contaminant masses or concentrations (e.g., dense non-aqueous phase liquid [DNAPL]) may require closer spaced injections or larger volumes to achieve effective contaminant degradation than other areas where contamination is dispersed at lower levels.
- **Cost** – Presumably adding more injection points and larger injection volumes will always increase remediation effectiveness in terms of contaminant removal, but at an added cost. Thus a point of diminishing returns is inevitably met and should be considered in design. No specific guidance here is possible as ultimately this is a decision for the key stakeholders in the project, including the client, the regulators and others involved in the project.

Select injection flows and concentrations based on experience with similar sites and the objectives. Again, this decision is a balancing act involving various site-specific factors, such as permeability (which influences volume), oxidant persistence (which influences oxidant mass or concentration), and injection spacing and overlap. Other factors might also need to be weighed. For example, the user may want to take advantage of the fact that high concentrations of oxidants will have a density greater than water. This difference may allow the oxidant to flow by gravity through preferential flow pathways that DNAPL-phase contaminants may be entrapped within.

Use a mass balance to calculate the mass of oxidant required. The mass balance approach requires a selection of the oxidant concentration required for effective ISCO after all of the above criteria are considered, then multiplying that by the volume of the TTZ. For permanganate, the mass balance should be based on the NOD of the site, because except when treating media with very high concentrations of COCs or very low NOD, the bulk of the oxidant will be consumed by NOD. Very simply, it is the volume of the TTZ, multiplied by the density of the soil, multiplied by the NOD. Some suppliers of oxidants can provide oxidant demand calculation tools. For other oxidants, such as catalyzed hydrogen peroxide (CHP), the mass of hydrogen peroxide required is often based on experience.

Oxidant-specific considerations. Each ISCO oxidant has unique attributes with implications for design that need to be considered at this stage. Some of these are outlined in A10. Oxidant Specific Design Considerations, which is provided to facilitate conceptual design of ISCO using any oxidant. However, this attachment is not all-inclusive and depending on the circumstances, there may be other considerations that are not included but may have significant design implications. A thorough review of the technical basis behind each oxidant is provided in the ISCO volume of the SERDP / ESTCP Remediation Technology Monograph Series (Springer Science+Business Media, LLC, 2011).

The design of some CHP, persulfate, percarbonate, and other oxidant systems can be challenging, since they depend on the distribution of activators as well as the primary oxidant (hydrogen peroxide or persulfate). Oxidant and activator (and/or chelating or "conditioning" agents) can be added sequentially as is the case most frequently with CHP and with heat or alkaline pH activated persulfate; they can also be added simultaneously, as is the case most frequently with iron-citrate activated persulfate. Experience is often used in these designs and the art and science of their application is constantly evolving. In addition, laboratory studies may be used to select optimal chemistry parameters to maximize oxidant distribution, contaminant degradation, and to avoid operational problems such as excessive heat or gas evolution. Many factors impact the effectiveness of these oxidants; specific factors examined in an optimization study may include the activator type, activator concentration, stabilizing amendments, oxidant concentration, and pH. Many reasons and procedures for optimizing these factors are discussed in more detail below in ISCO Conceptual Design Process 5. Because of the complexity of these oxidants' chemistry and implementation, with much of the knowledge base residing with those experienced in using these oxidants, companies specializing in the applications of these chemical systems are often subcontracted to perform their applications and treatability testing. For ISCO systems using ozone, the chemistry is still complex but there are fewer chemistry-related design parameters under the user's direct control, so treatability testing may be less complicated. Treatability studies with ozone may consist of sparging ozone gas through a column of contaminated media to verify contaminant degradation and economical oxidant distribution. In the field, ozonation may be adjusted using the Observational Method or by past experience with such systems by alterations of the flow rate, dose, and pulse cycle.

Table CD-1, which contains data culled from a review of field application case histories, provides a summary of the median values for the design parameters used in these case studies. [Additional details may be found in the ISCO volume of the SERDP / ESTCP Remediation Technology Monograph Series (Springer Science + Business Media, LLC, 2011), Krembs (2008), or in the DISCO interactive case study database.] While this information is of interest, it does not necessarily suggest that these are the "correct" values. Not all of these case studies were successful. "Good" design practices and site-specific considerations should be taken into account prior to selecting these parameters.

Table CD-1. Median Values for ISCO Design Parameters by Common Oxidant.

	Permanganate	**CHP**	**Persulfate**	**Ozone**
Median design ROI (ft)	15 (33)	15 (35)	12.5 (6)	25 (6)
Median observed ROI (ft)	25 (13)	15 (8)	20 (3)	40 (3)
Median oxidant dose (g oxidant / kg media)	0.41 (37)	1.2 (21)	3.4 (7)	0.041 (5)
Median number of pore volumes delivered	0.16 (34)	0.086 (27)	0.82 (7)	no data
Median number of delivery events	2 (70)	2 (63)	1 (11)	1 (16)
Median duration of delivery events (days)	4 (49)	6.5 (48)	4.5 (8)	280 (16)

(number of values)

More successful sites tend to have longer injection durations per injection event and a greater total volume of oxidant delivered. A review of 68 ISCO case histories revealed that the average volume of oxidant solution delivered to sites is only 0.10 pore volume (PV). A survey of professionals (Vironex, 2006) indicates that the average volume of oxidant solution injected is 0.10 to 0.30 PV. Interestingly, in the aforementioned review of 68 ISCO case histories it was observed that ~0.50 PV of oxidant was delivered, on average, at sites that met a 90% or greater concentration reduction metric.

CD.3.2.2 CONCEPTUAL DESIGN PROCESS 3b:
Tier 1 Design Tool Approach

An alternative conceptual design approach is to use calculation tools. An A11. ISCO Spreadsheet Design Tool has been prepared for this ISCO Protocol (a.k.a. “CDISCO”, Conceptual Design for In Situ Chemical Oxidation). Instructions for using CDISCO and a description of the governing equations are contained in the "START" worksheet. Other design tools may also be available from specific universities, oxidant vendors and design firms.

CDISCO is best suited for the conceptual design of a permanganate application since the governing equations include instantaneous and second-order rate-limited NOD reactions, as part of a kinetic approach for evaluating oxidant persistence that is unique to permanganate. However, with modification to the kinetic input parameters, it is possible that CDISCO can approximate pseudo first-order kinetics applied to oxidant persistence. Pseudo first-order oxidant decomposition kinetics are often observed with hydrogen peroxide in well-mixed batch systems, and under some conditions with sodium persulfate as well. Thus CDISCO may have some applicability to the conceptual design of these oxidants, including consideration of their decomposition kinetics. However, in practice, the use of these oxidants usually involves the injection of an activator (e.g., iron, base, another oxidant, heat, etc.), often in sequential order, and this application impacts kinetics and delivery in ways CDISCO does not consider. For instance, CDISCO cannot account for separate tracking of an oxidant and an activator. In general, the only situation where CDISCO may approximate the kinetics of oxidant persistence is where the activator and oxidant are mixed simultaneously at the injection point, and then the assumption must be made that the first-order rate stays constant from that time onward. It is also important to note that the reactive transport of these oxidants is also not as well documented as with permanganate, and thus there may be phenomena that impact their transport that CDISCO cannot simulate. For example, with hydrogen peroxide, an observed ROI is often larger than what would be expected based on fluid addition alone, in part because evolution of oxygen gas in the pore space increases the fluid displacement. Also, the lack of datasets suitable for verifying CDISCO with hydrogen peroxide or persulfate make it challenging to determine the accuracy of CDISCO in these applications. Thus, in most cases, it will not be practical to use CDISCO for predicting persulfate or hydrogen peroxide transport and persistence. Any user attempting to use the CDISCO tool for oxidants aside from permanganate should be forewarned that there is considerable uncertainty in how accurately the tool output will match real field processes, and caution is advised. In all cases, it is recommended that experienced engineers or vendors be consulted prior to selecting a final design. Also, regardless of the oxidant-specific kinetics, the tool may provide some design benefit in any circumstance by treating the oxidant as a conservative tracer and evaluating the impact of injection spacing, volume and other factors on cost, field time or other design considerations.

CDISCO is intended to assist with the conceptual design of injection systems. It “models” the transport and degradation of the oxidant during the injection period and for a short time after injection. It does not model down-gradient advective drift of oxidant after the injection period. It also does not incorporate kinetic contaminant degradation, and assumes that all contaminants present will be oxidized if sufficient oxidant is present. Heterogeneity is incorporated by a user-defined fraction of treatment zone that is considered mobile, which is a simplification of reality. CDISCO is designed primarily for short term injections and not well-to-well recirculation. However, it could be used to provide a preliminary idea of the delivery in this type of approach by using a longer term injection period. It estimates the ROI based on the output of the model equations and a user-defined minimum concentration of oxidant at that radius. The number of wells / injection points is then calculated based on a user-defined ROI overlap factor. A rough delivery cost estimate is then calculated based on user-defined unit costs for drilling, chemicals and labor.

CDISCO allows the user to insert site-specific data or assumed values of key site and design parameters. Design parameters, such as injection method (well versus direct push point), duration of oxidant injection, mass of oxidant injected, and volume of oxidant solution injected, can be varied and CDISCO will estimate well / point spacing and a preliminary cost estimate. This approach allows a preliminary design optimization to be conducted by performing various model runs with varied inputs and comparing the resulting cost. Graphical representations of the effect of the design parameters on project costs are generated. Users should have a good understanding of ISCO before using this model. It should be noted that CDISCO does not model or predict performance in terms of contaminant reduction, or even oxidant distribution in a complex environment. This aspect is discussed further in the next section. As with all computer models, the output of CDISCO should be checked against professional experience (i.e., perform a reality check).

A limited sensitivity analysis was performed to verify the output of CDISCO as it relates to ROI (as opposed to cost). The results are presented in A12. CDISCO Description and Sensitivity to Input Parameters, and describe which parameters impart the most sensitivity in the output, and thus are most important to refine to reduce uncertainty. Knowledge of the impact of certain parameters may help identify the most necessary additional site data collection activities in terms of reducing model uncertainty.

To illustrate the utility of CDISCO for optimizing costs, a number of runs were made for a hypothetical "Site A". Figure CD-2 below illustrates the primary conditions listed for "Site A".

- Contaminants
    - TCE at maximum 50 ug/L in groundwater
    - No indication of DNAPL or daughter products
    - TCE at 30 to 40 ft bgs
- Geology / Hydrology
    - Alluvial deposits
    - Permeable and heterogeneous
    - K = 50 ft/day
    - NOD = 0.3 – 1 g/kg
- Remedial Action Objective
    - MCLs

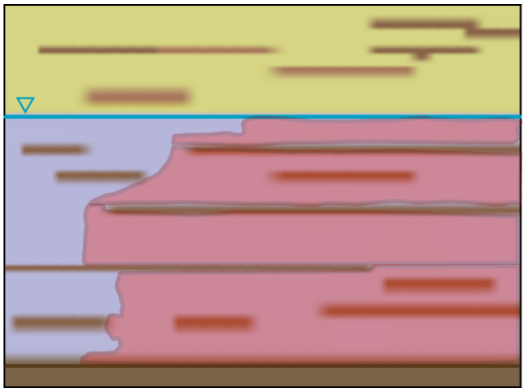
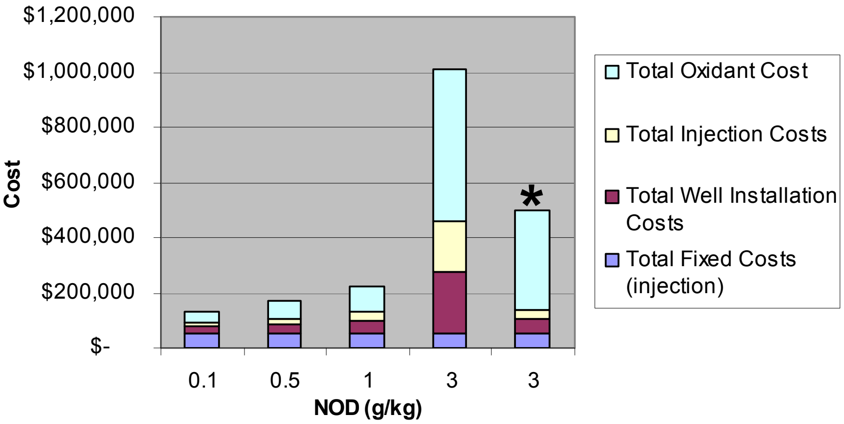


Figure CD-2: Summary of Hypothetical "Site A".

Two of the key parameters for ISCO with permanganate are NOD and thickness of mobile zone, as discussed previously. To demonstrate the impact that these factors can have on cost of an ISCO design, and how the design can be optimized using CDISCO, a number of iterations of the tool were run using the features of Site A as a reference. From these CDISCO runs, Figures CD-3 and CD-4 were generated from the output data, reflecting the impact of NOD and mobile zone thickness on cost, respectively.



CDISCO Input Parameters

Injection with Wells

Injection Conc = 8,000 mg/l

Injection Flow = 15,000 gal/well

Mobile Zone ratio = 0.8

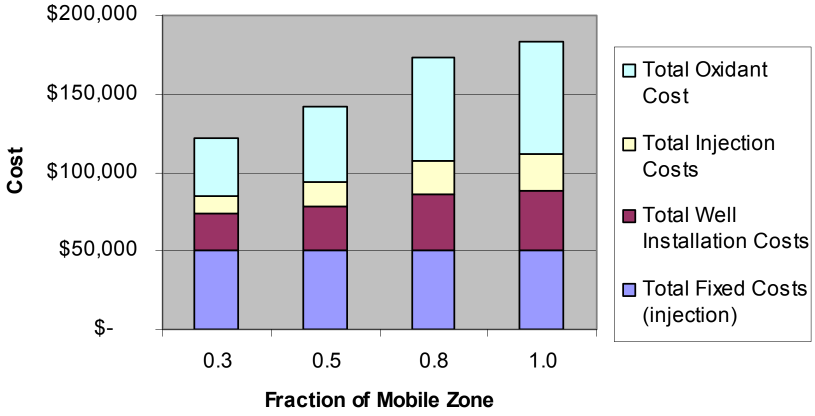
Number of Injections = 3

Run w/ asterisk differs by

Injection Conc = 20,000 mg/l

Injection Flow = 25,000 gal/well/

Figure CD-3: Impact of Increasing NOD on Cost at "Site A".



CDISCO Input Parameters

Injection with Wells

NOD = 0.5 g/kg

Injection Conc. = 8,000 mg/l

Injection Flow = 15,000 gal/well

Number of Injections = 3

Figure CD-4: Impact of Increasing Fraction of Mobile Zone on Cost at "Site A".

Figure CD-3 illustrates the impact of the NOD on the cost of ISCO designs for "Site A". The cost does not increase significantly with NOD between 0.1 and 1 g/kg. But the cost jumps dramatically if the NOD rises to 3 g/kg. As illustrated in this figure, the majority of the increase in cost is the result of more oxidant being needed to satisfy the demand. The costs for the high NOD case can be reduced by significantly increasing the oxidant concentration and the volume injected per date, but the costs are still much greater than they would be if the NOD were 1 g/kg or less. As will be discussed under ISCO Conceptual Design Process 5, if the NOD is unknown or uncertain and is in fact over 1 g/kg for "Site A", this example illustrates that large uncertainty in cost may result. This potential cost increase may warrant the collection of additional NOD data prior to proceeding beyond the conceptual design. Figure CD-4 illustrates the results of a number of runs varying the thickness (or fraction) of the mobile zone. As discussed previously, costs increase as the thickness increases because of the smaller ROI. Although the changes in costs in Figure CD-4 may be within the error of the estimates produced by CDISCO, they are much less dramatic than the cost increases resulting from increased NOD. Again, these results are specific to the example evaluated, and the results are likely to differ by site-specific conditions, but they do illustrate the utility of CDISCO.

The results of CDISCO must be transferred to a site layout and cross-section to assess the practicality of the design approach. The number of injection wells / points determined from CDISCO should be located on a map at the modeled spacing and overlap. From this exercise the practicality of the tool can be judged. For example, it may be impractical to locate the required number of wells across the site based on the presence of utilities, buildings, houses, and other infrastructure. The well layout should also be placed on a cross-section to evaluate the practicality. For example, it may be obvious from the cross-section that direct push methods may not be effective if the target depth interval is greater than 50 feet bgs. The volumes and mass of oxidant required should also be evaluated for practicality and cost.

CD.3.3 CONCEPTUAL DESIGN DECISION A:
Is At Least One Technologically and Economically Feasible Option Available?

Conceptual Design Decision A is a judgment of the technical and economic feasibility of viable ISCO options that emerge from Tier 1 ISCO Conceptual Design (ISCO Conceptual Design Process 3a or Process 3b above).

The decision is based on:

- Project budget constraints
- Estimated oxidant delivery effectiveness vs. treatment goals
- Ability to implement design; with considerations including
  - Practicality of delivery point spacing
  - Practicality of the volume and mass of oxidant required
  - Potential interference due to above or below ground infrastructure
  - Safe handling of design oxidant concentrations

It will be difficult at this stage to evaluate the potential performance of the conceptual design in terms of contaminant reduction. This difficulty results from the fact that the tools (e.g., CDISCO) at this stage are not able to accurately predict the distribution of the oxidant in the inherently heterogeneous subsurface. Nor can the tools predict reactions with NAPLs or sorbed contaminants, or back-diffusion of contaminants out of lower permeability layers that are not directly contacted by the oxidant. As a result, the project team takes another close look at available site information to evaluate the potential effectiveness of ISCO. For example, a detailed evaluation of the conceptual site model (CSM) should be performed to assess the potential detrimental effects that lithology could have on uniform oxidant delivery throughout the TTZ. If oxidant delivery can not be achieved in the zones containing the target contaminant concentrations, then alternative approaches may be required. If the preponderance of site data and project team experience indicates that the approach is technically and economically feasible, then the user can proceed to the next step of the ISCO Conceptual Design Process.

If no options are feasible, or the uncertainty is still too high, then the following options should be considered:

- Redefining the TTZ (ISCO Conceptual Design Process 1)
- Re-evaluating the Tier 1 design tool input (ISCO Conceptual Design Process 2)
- Re-evaluating the A3. CSM Certainty Evaluation Tool and collecting additional data as needed (see ISCO Screening Process 1 for a suggested list of data needs)
- Revisiting ISCO Screening, with particular attention to coupled treatment approaches (ISCO Screening Process 4) or more aggressive delivery processes such as soil mixing or recirculation systems (ISCO Screening Process 3)

If at least one ISCO treatment approach is technically and economically feasible, then ISCO Conceptual Design continues with ISCO Conceptual Design Process 4.

CD.3.4 CONCEPTUAL DESIGN PROCESS 4:
Rank and Select Oxidant and Delivery Options

ISCO Conceptual Design Process 4 compares the alternative ISCO approaches (i.e., oxidant / delivery approach combinations) evaluated in the Tier 1 ISCO Conceptual Design. It should be reiterated that by this stage of the ISCO Protocol, it has already been established that ISCO is a suitable remedial option based on the site-specific lithology and contaminant characterization data collected during ISCO Screening Process 1 (i.e., if you can achieve oxidant-contaminant contact, you will presumably achieve treatment). Therefore the ranking criteria for this process focus specifically on the effectiveness of and factors related to the oxidant delivery approaches evaluated with the A11. ISCO Spreadsheet Design Tool. These criteria are described as follows.

Delivery Effectiveness. This criterion relates to the ability of the alternative to achieve oxidant-contaminant contact, given the alternative-specific injection design factors evaluated in the Tier 1 ISCO Conceptual Design. It is a refinement of the effectiveness ranking performed as part of ISCO Screening Process 3. Many of these design factors are integrated into the A11. ISCO Spreadsheet Design Tool, and can be evaluated by performing multiple tool runs covering the possible range of site input parameters (e.g., NOD, hydrogeologic characteristics, and soil heterogeneity) and evaluating how the injection ROI of a given design can vary over the possible range of input parameters.

Treatment Performance Certainty. Treatment performance certainty is the likelihood that an ISCO design will achieve project-specific objectives given site factors that can affect treatment performance after oxidant delivery and reaction, such as the presence of DNAPL and back-diffusion of contaminants out of lower permeability layers. When evaluating this criterion, the primary question for the project team to consider will be: Is the injection design aggressive enough (i.e., accounting for the appropriate injection ROI overlap and sufficient number of injection events) such that treatment objectives will likely be achieved given the CSM uncertainties? This evaluation process will also be affected by factors beyond the CSM, such as regulatory cleanup requirements, the post-ISCO site management approach, and whether post-ISCO coupled remedial technologies will be implemented.

Cost. The screening-level costs from the A11. ISCO Spreadsheet Design Tool are compared for this criterion. These order-of-magnitude costs should be compared to project budgets to ensure financial sustainability of the delivery strategies.

Cost Certainty. Cost certainty is the likelihood that an alternative can be successfully implemented with minimal risk of unforeseen costs and change orders. Unforeseen costs can stem from the need for additional injection points, more aggressive injection approaches, higher oxidant dosage, and/or multiple injection events. As with performance certainty, cost certainty will be based on design factors such as NOD, contaminant mass / distribution, soil heterogeneity (i.e., thickness of the mobile zone during injection), and the aggressiveness of the injection design. A more quantitative method to evaluate cost certainty is to run the A11. ISCO Spreadsheet Design Tool multiple times for each alternative, using the low and high values for the range of possible design factors.

Implementability. This criterion is evaluated using the same factors considered under the implementability ranking performed as part of ISCO Screening Process 3, except the evaluation is refined for the alternative-specific injection designs evaluated in the A11. ISCO Spreadsheet Design Tool. The injection designs and strategies developed in the ISCO Spreadsheet Design Tool should be considered in the context of actual site conditions, such as access for well placement, interference with site activities, the presence of underground and above-ground infrastructure, and space constraints for temporary placement / storage of injection equipment.

Public and Worker Safety. This criterion considers potential hazards during the field implementation of an alternative. Safety factors considered include the potential for exposure to the oxidant during the oxidant mixing process, potential for exposure to the oxidant during injection (e.g., through surfacing or travel along utilities), potential for explosive conditions due to accidental mixing of oxidant with combustible / flammable materials and due to byproduct generation (such as oxygen from high concentrations of hydrogen peroxide) and self-accelerated decomposition (and resultant combustion of surrounding materials) when stored oxidants are exposed to heat and moisture (e.g., persulfate).

A A13. Conceptual Design Ranking Tool is provided to assist with ranking alternative ISCO approaches after completing Tier 1 ISCO Conceptual Design. For each of the above ranking criteria, each ISCO approach is given a score ranging from 0 to 5, relative to the other alternatives. The scores are multiplied by a user-defined weighting factor (percentage), and then added to give a final ranking score (based on a scale of 0 to 5). The sum of the criteria weighting factors should be 100 percent. The criteria weighting factors should be selected on a project-specific basis. In general, since scoring is relative to the other alternatives only and is based on project-specific values, the highest scoring alternative should normally be selected for additional design / cost refinement in subsequent processes of ISCO Conceptual Design.

CD.4 TIER 2 CONCEPTUAL DESIGN

The second tier is a more refined conceptual design based on additional data collected from a site. The objectives of the second tier are to:

1.) Refine the design, possibly with new data,
2.) Provide information to feed into a Feasibility Study (FS) (compare ISCO to other alternatives), and
3.) Provide a foundation for a refined design if ISCO is selected.

CD.4.1 CONCEPTUAL DESIGN DECISION B: Is Cost and Performance Confidence Acceptable?

ISCO Conceptual Design Decision B is the first step in the Tier 2 ISCO Conceptual Design. In determining if cost and performance confidence is acceptable, the need for collection of site-specific data is assessed. This is judgment is based on the level of confidence and uncertainty in the design input parameters used in the Tier 1 ISCO Conceptual Design and the range of potential conceptual design outcomes. As discussed previously, a number of iterations of the A11. ISCO Spreadsheet Design Tool should have been performed with the range of possible input parameters and the range of outcomes evaluated for uncertainty and risk.

A A14. Contingency Planning Tool is provided to assist with quantification of the magnitude of uncertainty in the conceptual design and help determine if the cost and performance confidence is acceptable. The results of the contingency evaluation can be used to assess whether to proceed with the existing conceptual model or revisit data and design basis. The results can also be used later for preliminary detailed design during ISCO Detailed Design and Planning Process 2. The A14. Contingency Planning Tool is an Excel™-based spreadsheet that provides a general framework for project teams to consider the range of potential reasonable treatment outcomes and estimate the cost and schedule impacts that may result if they occur. The first spreadsheet includes data entry for each potential treatment outcome. Data entry includes a description of the condition and consequence of occurrence, probability of occurrence, potential cost of impact, and potential schedule delay. All of these values are used in the following two spreadsheets to systematically estimate the magnitude of the life cycle cost and schedule impacts, and to judge the confidence in the conceptual design. If the range of cost and schedule impacts is too large or exceeds some allowable budget or schedule constraint, then the answer to this decision should be "NO." If the range of potential cost after considering the range of potential reasonable outcomes is acceptable and within project constraints, then the answer to this decision can be "YES." A15. Contingency Planning Example Exercise presents an example application for a persulfate direct injection treatment system. One additional useful feature of the Contingency Planning Tool is the last few columns on the first spreadsheet tab. These fields provide project teams the opportunity to include mitigation measures (to minimize the potential for occurrence), measurements and associated trigger levels to flag occurrence, and specify the contingency response action. Thinking through each of these design components early in the ISCO design process makes the design more robust and enables project teams to prevent and prepare for a multitude of possible ISCO treatment outcomes. The contingency planning process is discussed further in ISCO Detailed Design and Planning Process 2.

It should be noted that it is a somewhat rare circumstance when cost and performance confidence are acceptable at the preliminary design stage. These may include (for example):

- When a large amount of data (e.g., related to oxidant persistence) is initially available
- The Observational Method is to be used and the level of uncertainty is acceptable
- Low levels of dissolved contaminant in a well-defined treatment zone
- A relatively small TTZ (e.g., less than 2,000 square feet)
- Highly homogeneous and permeable porous media
- High certainty in the ability to achieve ISCO treatment goals
- Extensive experience with both site-specific and design conditions
- Flexible budget, or budget exceeds expected costs

Where there is a significant amount of uncertainty in the performance and cost estimated by the Tier 1 ISCO Conceptual Design, additional data should be collected (ISCO Conceptual Design Process 5). Where performance and cost certainty are judged acceptable, then additional modeling needs (ISCO Conceptual Design Process 6) or design refinements (ISCO Conceptual Design Process 7) should be considered prior to estimating the cost for the design (ISCO Conceptual Design Process 8).

CD.4.2 CONCEPTUAL DESIGN PROCESS 5: Consider Additional Data Needs

The purpose of collecting additional data is to refine ISCO design and reduce cost and performance uncertainty associated with the design. ISCO Conceptual Design Process 5, data collection, occurs until cost and performance confidence is acceptable and is thus an iterative step with ISCO Conceptual Design Decision B (above). It should be kept in mind that if the Observational Method is used for the full-scale application, additional data will be collected during the first full-scale injection. In other words, the first full-scale injection could be considered as part of this data collection process.

Data collection will support refinements to the CSM (see A3. CSM Certainty Evaluation Tool) and can also narrow the range of values used as design input parameters. The following data may be collected through laboratory bench testing or field scale pilot testing under site-specific and design conditions:

- Oxidant persistence (e.g., NOD)
- Contaminant or co-contaminant degradability

- Contaminant desorption / dissolution
- Appearance of intermediates and/or byproducts
- Metals solubilization
- Oxidant deliverability and fraction of the formation through which oxidant will flow.

Data may be collected at either the laboratory bench-test scale or the pilot scale in the field. The Additional Data Needs Flow Diagram (Figure CD-5) includes a decision process to aid in selecting the appropriate level of testing. In general, where uncertainty surrounds chemical processes (e.g., oxidant persistence, contaminant degradability, variation in outcome with different oxidant activation approaches, etc.), laboratory scale testing may be sufficient. Where uncertainty surrounds delivery and transport processes, field pilot scale testing is recommended.

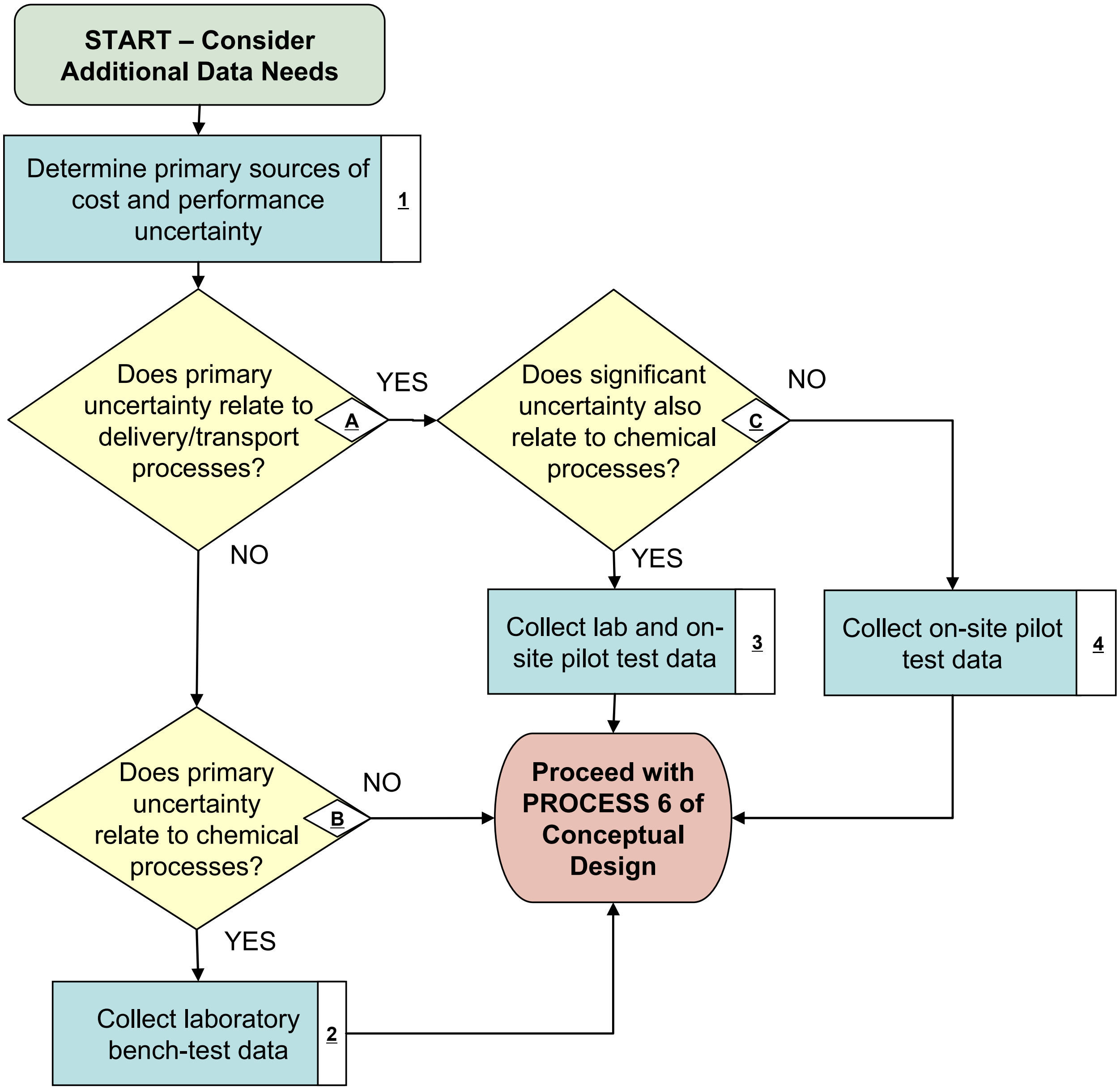


Figure CD-5: Additional Data Needs Flow Diagram
[Note: flow diagram does not contain hyperlinks.]

Additional guidance is provided for both A16. Laboratory Bench Testing for Oxidant Persistence and A17. Laboratory Bench Testing for Contaminant Treatability and Byproducts which includes guidance for conducting contaminant degradability, desorption / dissolution, intermediates / byproducts, and metals solubilization assessments. It is important to note that the oxidant persistence and contaminant treatability / byproducts determinations described in these two documents are not to be considered stand-alone, consecutive processes. They may be conducted side-by-side concurrently or consecutively in either order depending on the site-specific data needs. Data needs must first be carefully determined prior to initiating these laboratory-scale data collection processes. A18. Field-Scale Pilot Testing Guidance is provided that addresses field scale means of assessing the above (oxidant persistence, contaminant degradability, byproducts formation etc.), along with assessment of oxidant deliverability.

CD.4.3 CONCEPTUAL DESIGN PROCESS 6: Consider Additional Modeling Needs

Additional in-depth and complex modeling beyond the A11. ISCO Spreadsheet Design Tool may be appropriate if the level of certainty in design performance and cost is not acceptable. Prior to proceeding with additional modeling, data objectives must be carefully considered and site hydrogeologic and geochemical conditions determined as amenable to detailed modeling. Additionally, the data needed to increase performance and cost certainty should be closely considered. Examples of data needs for design refinement that can be addressed with more advanced modeling include:

- Impact of the presence of NAPL
- Effects of contaminant source architecture / geometry
- Oxidant contact efficiency
- Effects of soil heterogeneity
- Impacts of oxidation byproducts (e.g., MnO_2 generation with permanganate)
- Refined delivery approach (injection pattern, volume, and timeframe)
- Effects of NOD kinetics (fast and slow)
- Refined oxidant load and concentration
- Design input sensitivity analysis

It should be noted that the last three examples can be considered (for a simplified scenario) with the A11. ISCO Spreadsheet Design Tool. However, for a more complex scenario (such as one of the others on the list), the last three items may need to be revisited using the advanced modeling. The attached A19. Guidance for Additional Modeling Needs provides a flow diagram and associated narrative support to assist in this process.

CD.4.4 CONCEPTUAL DESIGN PROCESS 7: Refine Design Considering Cost and Performance Factors

ISCO Conceptual Design Process 7 involves incorporating data collected during ISCO Conceptual Design Processes 5 and 6 into all previously collected site-specific information to refine the treatment system design to optimize cost and performance. This step may involve:

- Reconsidering ISCO treatment goals where there is low probability of achieving them
- Redefining the TTZ (ISCO Conceptual Design Process 1)
- Repeating the full Conceptual Design process based on a refined CSM
- Reiterating the A11. ISCO Spreadsheet Design Tool with refined input values
- Incorporating sophisticated modeling output information into the design tool
- Reconsidering coupled ISCO treatment approaches (see ISCO Screening Process 4)

The goal of this process is to finalize the conceptual design by iterative application of the A11. ISCO Spreadsheet Design Tool using all new information learned from additional data collection and modeling, if applicable, and after revisiting the primary design basis. The A11. ISCO Spreadsheet Design Tool is used in an iterative manner, by changing input and viewing output, to prepare the optimized design which results in the desired performance at the lowest cost.

Looking ahead, after the cost estimating, this final conceptual design will exit the ISCO Protocol and enter the project-specific remediation alternatives analysis (such as in a FS). Therefore, it is important that all efforts be made in this process to ensure that the final ISCO conceptual design incorporates assumptions consistent with the site-wide remediation strategy including variable assignments (e.g., treatment performance levels) that are synergistic with coupling of other technologies (e.g., monitored natural attenuation). These efforts will allow ISCO to be judged in an apples-to-apples manner against the other technologies being considered in the FS.

CD.4.5 CONCEPTUAL DESIGN PROCESS 8: Perform Feasibility Study Cost Estimate

ISCO Conceptual Design Process 8 involves developing a FS cost estimate after finalizing the conceptual-level design (ISCO Conceptual Design Process 7 above), and is intended to refine the capital, operation and maintenance (O&M), and life cycle costs for implementing the preferred ISCO approach. These ISCO-specific costs can then be output to a FS (completed exterior to this ISCO Protocol) and compared to other remediation alternatives.

A description of the recommended components of a FS cost estimate for ISCO is provided in A20. FS Cost Estimate Guidelines. A21. FS Cost Estimate Example provides an illustration of a FS cost estimate worksheet for an ISCO project consisting of injection well delivery of activated persulfate and treatment of chlorinated benzenes in groundwater. Three successive data spreadsheet pages are presented and document a typical cost estimate process and format: (1) Cost Details; (2) Present Worth Details; and (3) Cost Estimate Summary.

The guidelines and sample exercise presented in this process reflect screening-level engineering estimates for alternative comparison purposes only and are not intended for construction budgeting. Note that when preparing engineering cost estimates, a qualified cost estimator should be involved. The expected accuracy range for the conceptual-level (e.g., FS-level) cost estimate is expected to be - 30 to + 50 percent. Therefore, factors such as unit costs and quantities, costs for professional and technical services, and contingency should be considered and evaluated carefully. Additional general information on cost estimating practices can be found in ISCO Detailed Design and Planning Process 5.

ISCO DETAILED DESIGN AND PLANNING

DD.1 INTRODUCTION

The primary purposes of the ISCO Detailed Design and Planning component are to: (1) complete an ISCO design based on the recommendations of the remediation alternatives comparison (completed exterior to the ISCO Protocol, typically as part of a FS), and (2) prepare operation and contracting documents that can be used to implement the ISCO treatment. This ISCO Detailed Design and Planning component is followed by the ISCO Implementation and Performance Monitoring component, which is the last process in the ISCO Protocol and completes implementation of the ISCO remedy.

It should be noted that, prior to executing the ISCO Detailed Design and Planning component, a firm selection of the oxidant and delivery approach must be made to avoid costly iterations in design documents and work plans. If selection is uncertain, then the user is advised to revisit the ISCO Conceptual Design component and affirm the ISCO treatment approach.

This narrative guidance explains the process to be followed to finalize an ISCO design and prepare the project work planning documents that will be followed during ISCO Implementation and Performance Monitoring. The instructions correspond to the decisions and processes depicted on the ISCO Detailed Design and Planning Flow Diagram (Figure DD-1), and are divided into three phases: the preliminary design phase, the final design phase, and the planning phase. The numbers and letters of the subsequent sections correspond with the numbered process steps and lettered decision steps in the flow chart protocol.

While it is expected that the specified steps of this process are prudent for most ISCO projects, some aspects of this process may or may not be applicable and depend significantly upon project-specific needs/goals and contracting approaches. The user is advised to carefully consider the content of this process prior to execution and tailor it as needed to meet their needs. For example, if a project requires design deliverables at the 30-, 60-, 90-, and 100-percent complete stages, then the process herein must be adapted. This process prescribes a more streamlined approach to design consisting of preliminary (approximately 30% design) and final (100%) designs only.

The process prescribed herein focuses on best practices for technical design and documentation for ISCO implementation and does not specifically address regulatory documentation required for design approval. Since regulatory requirements vary significantly, no attempt has been made to tailor the process. However, in many cases, the Preliminary Basis of Design Report can be used to obtain regulatory approval for the remedial action. If regulators want additional detail, then approval may be obtained using the Final Design instead (see ISCO Detailed Design and Planning Process 3a or Process 3b).

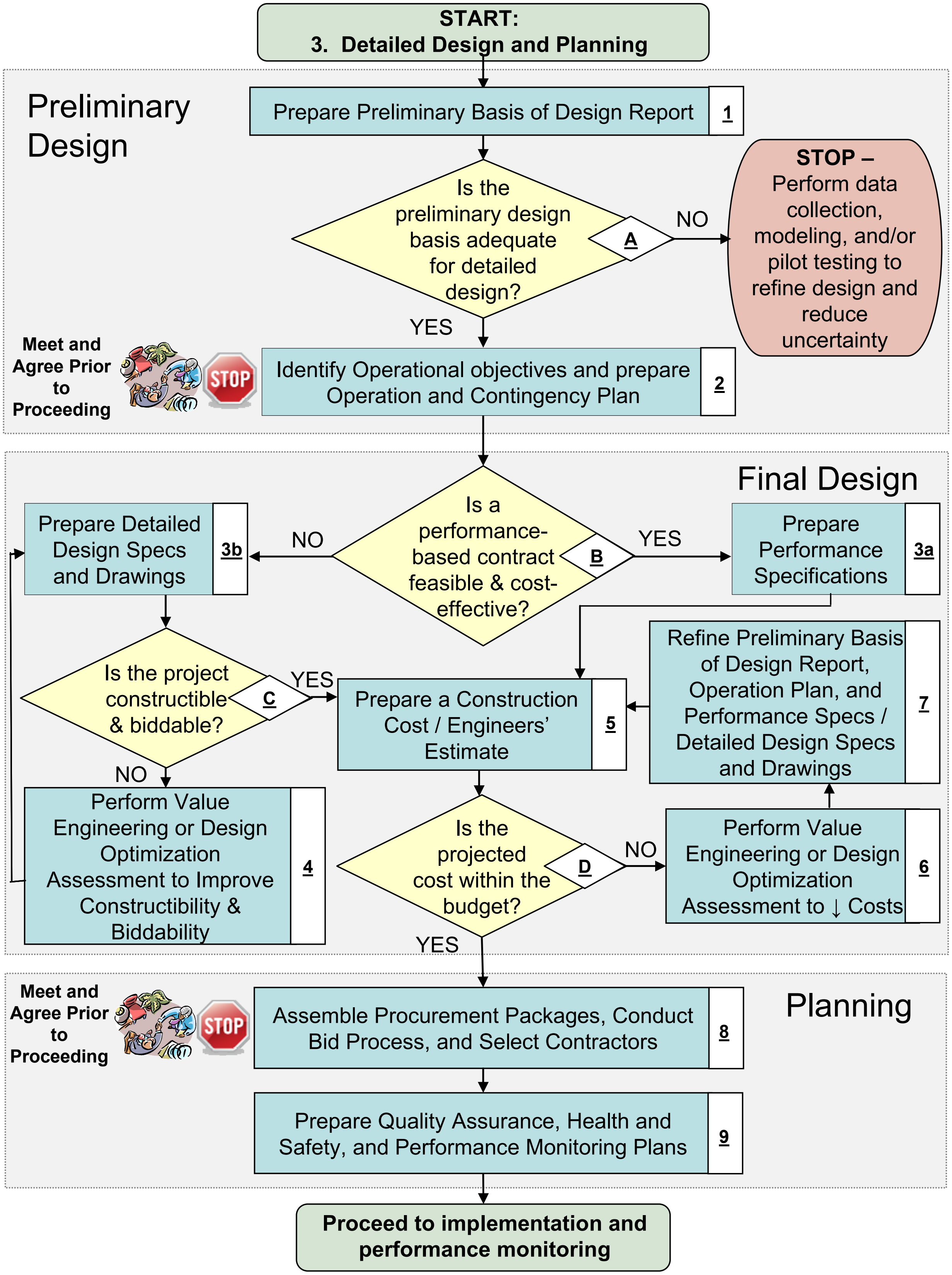


Figure DD-1. ISCO Detailed Design and Planning Flow Diagram.
[To navigate the electronic version of this tool, click on the Process (blue rectangle) or Decision (yellow diamond) on which you would like more information and you will be directed to that location.]

DD.2 PRELIMINARY DESIGN PHASE

DD.2.1 DETAILED DESIGN AND PLANNING PROCESS 1: Prepare Preliminary Basis of Design Report

Using the results from the previous ISCO Protocol components, a Preliminary Basis of Design Report is prepared as the initial step in the ISCO Detailed Design and Planning process. The purpose of the Preliminary Basis of Design Report is to formally establish and describe the design parameters in text format, which can then be used for the Final Design phase. The Final Design typically prescribes the design in construction contract terms (specifications and drawings). The Preliminary Basis of Design Report is typically reviewed and approved by all project stakeholders to ensure consensus on critical design parameters is built prior to proceeding with the Final Design of ISCO implementation.

This report inherently incorporates all previous screening and conceptual design work done in the ISCO Protocol. The Preliminary Basis of Design Report specifies details related to the following ISCO-related design parameters:

- Hydrogeochemical setting and contaminant geometry (e.g., a summary of the conceptual site model [CSM])
- Target treatment zone (TTZ)
- Treatment goals
- Oxidant selection and ISCO treatment technology description
- Desired reaction chemistry
- Lithologic setting and oxidant delivery / contaminant contact design
- Oxidant dosage and injectate volume
- Description of injection point / well construction methods and requirements for oxidant storage, transfer, mixing and delivery equipment (sizing, chemical compatibility, safety features, and user interfaces
- Description of oxidant delivery process (including injection probe / well layout; process flow diagram for injectate mixing and transfer and monitoring; oxidant delivery concentration; target injection volumes, rate, pressure, and operating hours)
- Preliminary delivery and treatment performance monitoring program (including monitoring locations, measurements, and frequency)
- Engineering controls required to maintain health and safety
- Permitting requirements
- Waste management requirements
- Implementation cost estimate

Basic design drawings are typically included with the Preliminary Basis of Design Report. At a minimum, the preliminary design drawing package includes the following:

- Process and Instrumentation Diagram
- ISCO Treatment System Layout
- Preliminary Piping Layout
- Well Construction Details

A A22. Preliminary Basis of Design Report Outline Example for a direct-injection permanganate treatment project is attached. It should be noted that certain components of the Preliminary Basis of Design Report specified above may be omitted if a performance-based contracting approach will be adopted (see ISCO Detailed Design and Planning Decision B). Examples of omitted design components include the oxidant volume / dosage, injection infrastructure, and injection well design.

DD.2.2 DETAILED DESIGN AND PLANNING DECISION A: Is the Preliminary Design Basis Adequate for Detailed Design?

Prior to the Final Design phase, the project stakeholders review the Preliminary Basis of Design Report to evaluate the effectiveness of the design and assess the adequacy of the data upon which the preliminary design is based. In this ISCO Protocol, this is the last time that the design basis is reviewed prior to construction. Therefore, it represents an opportunity for project teams to reconsider the approach and identify additional data collection activities which may help reduce uncertainty in the design. This decision is centered on a thorough review of the preliminary design from the standpoint of (1) revisiting the confidence of CSM understanding, (2) evaluating if the design parameters are adequately defined, and (3) assessing the probability of success and consequence of failure of the preliminary ISCO treatment design. These evaluations are further discussed below. The intent of this process is to maximize the chance for ISCO treatment success by decreasing uncertainty in the design basis.

Is the certainty in the CSM adequate for detailed design? The CSM should be revisited to evaluate if site conditions are adequately understood or similar to that understood during the ISCO Conceptual Design (if significant time has passed and new data is available) so that design parameters can be confidently assigned. The A3. CSM Certainty Evaluation Tool contained in ISCO Screening Decision B can be used to re-assess the current level and detail of understanding of site conditions as they pertain to estimation of design parameters.

If the answer to the question is “No”, then additional data collection activities should be identified and conducted to refine the CSM and reduce uncertainty in the design. Refer to ISCO Conceptual Design Process 5 and Process 6 for guidance on identification of additional data needs.

Are design parameters adequately defined? Many of the design parameters used for the Preliminary Design come directly from the ISCO Conceptual Design process where additional data needs were already considered to reduce the cost and performance uncertainty. Often times, however, the conceptual design is changed during remedial alternative comparison negotiations (e.g., during the FS, completed exterior to the ISCO Protocol). As a result, it is often prudent to reconsider the design basis and ensure that parameters are refined within a reasonable range of uncertainty. For example, the fluid injection rates may be unknown if field testing has not been conducted previously. Furthermore, geotechnical samples collected from the TTZ may be needed to specify the most appropriate injection well screen type and slot size. Since the chemical delivery rate and injection well performance have a large effect on the potential effectiveness and cost of the ISCO treatment, additional data collection from injection tests may be deemed necessary to reduce the risk of design failure or significantly increased timeframe for implementation.

If the answer to the question is “No”, then additional data collection may be needed in the form of a field-scale pilot test and/or modeling to refine design and reduce uncertainty in the predicted performance of the ISCO treatment. Refer to the ISCO Conceptual Design Process 5 and Process 6 for guidance on identification of additional data needs.

Is the potential for remedial success high and consequences of failure manageable? This question should be answered using project-specific metrics that were originally developed during the detailed analysis phase of the FS process (completed exterior to the ISCO Protocol), which may differ from those considered during the conceptual design process. Remedial success can be considered within the context of its ability to meet the prescribed treatment goals (numeric or non-numeric). This process may include addressing the question of whether treatment goals are realistic. If the project team consensus, based on prior experience and/or published literature, is that they are not realistic, then the treatment goals should be reconsidered. Recognizing that no environmental remediation is 100-percent certain, the decision also addresses the performance monitoring and the ability to identify problems requiring operational adjustments to maximize the potential for success. Consequence of failure is considered within the context of a probability assessment that looks at the range of possible ISCO implementation outcomes and the effects each might have on human health and the environment and the site management program, financial or otherwise. The results of the contingency evaluation performed as part of ISCO Conceptual Design Decision B can be used to answer this question. If the probable range of outcomes is practicable and manageable, then the user may proceed onto the next step in the Detailed Design and Planning process.

If the project team consensus answer to this question is “No”, then data collection may be needed in the form of a field-scale pilot test and/or modeling to refine design and reduce uncertainty in the predicted performance of the ISCO treatment. Refer to the ISCO Conceptual Design Process 5 and Process 6 for guidance on identification of additional data needs.

DD.2.3 DETAILED DESIGN AND PLANNING PROCESS 2: Identify Operational Objectives and Prepare Operation and Contingency Plan

Upon project team agreement on the adequacy of the data used to support the ISCO design basis and endorsement of the Preliminary Basis of Design Report, the Operation and Contingency Plan is prepared. The Operation and Contingency Plan is intended to formally document the following:

- Operational metrics and objectives
- ISCO treatment milestones
- Contingency plan, including:
  - Operation decision logic
  - Optimization approach
  - Treatment cessation plan

It is important that these items be considered, agreed upon, and documented in the Operation and Contingency Plan prior to the Final Design phase so that (1) regulatory approval of the operation strategy and decision logic can be obtained up-front, and (2) planning can be initiated for appropriate labor and material provisions during the contracting stage. The specific components of a typical Operation and Contingency Plan are described below.

DD.2.3.1 Operational Metrics and Objectives

Operational metrics are defined as a set of specific operation-related objectives which, if achieved, increase the likelihood of meeting the treatment goals for the ISCO treatment process. ISCO treatment goals are described in ISCO Screening Process 1 and established exterior to the ISCO Protocol (e.g., during the FS). These operational metrics will be measured and assessed during the performance monitoring program to determine ISCO performance effectiveness and success. These metrics can be used as a basis for performance specifications (see ISCO Detailed Design and Planning Process 3a). For example, operational metrics and objectives which may be considered for an ISCO application are:

1.) Delivery of a minimum permanganate concentration of X mg/L throughout the TTZ.
2.) Maintenance of a minimum of X days of permanganate residence time within the TTZ for the oxidation reaction to occur.
3.) Minimize loss of oxidant from the TTZ during the delivery process due to day-lighting or short-circuiting.
4.) Utilize a real-time measurement and data analysis routine to optimize and adapt the injection or monitoring program and ensure cost-effective treatment.
5.) Zero health and safety incidents.

Establishing operational metrics and objectives is a project-specific decision. In most cases, they are beneficial for use as a metric for performance measurement and as a basis for follow-up optimization activities to improve ISCO treatment efficiency. For example, an oxidant recirculation project may want to include a minimum X-percent runtime operational objective. If runtime does not meet the objectives, then optimization activities are needed to improve its operation.

Care should be taken to ensure that the operational objectives are realistic and achievable and, if achieved, will lead to successful ISCO treatment. Consultation with prospective ISCO treatment vendors may be beneficial at this Preliminary Design phase. Often times, vendors have developed unique knowledge of ISCO treatments and certain hydrogeochemical and contaminant settings. If appropriate vendors have been identified as valuable to a project, then they should be consulted during the operational objective setting process. This will help ensure that the objectives are practical and realistically achievable. In so doing, the vendor becomes vested in the process and, if contracted appropriately, jointly or wholly responsible for achieving the objectives.

DD.2.3.2 ISCO Treatment Milestones

ISCO treatment milestones are temporal goals that are geared toward maintenance of ISCO treatment progress. Milestones are highly site-specific and dependent upon site owner needs and contractual / regulatory requirements. ISCO-related milestones are typically integrated with the type of treatment goal. For example, if 90-percent mass flux reduction is the treatment goal, then the milestones may include a

50-percent intermediate milestone in addition to the use of 90-percent as the final ultimate milestone. Use of intermediate milestones helps project teams measure progress and make midway adjustments (e.g., it may take 90% of the total effort to obtain the last 10% of the mass flux reduction), if needed, to improve treatment efficiency.

Other ISCO milestones may include:

- Remedy-in-Place (DoD-specific goal) upon initiation of ISCO treatment
- Oxidant delivery complete (e.g., achieved Objective 1 above)
- Oxidant reaction complete (e.g., achieved Objective 2 above)
- Rebound period complete (e.g., oxidant reacted and aquifer redox state returned to baseline conditions)
- 50-percent of treatment goal achieved (dissolved concentration, contaminant mass, mass flux, etc.)
- 100-percent of treatment goal achieved and ISCO treatment complete

Ideally, if a performance contracting approach is used (ISCO Detailed Design and Planning Process 3a), these milestones can also be used as a basis for periodic progress payments.

DD.2.3.3 Contingency Plan

The Contingency Plan is developed with input from all project stakeholders and is based on the results of a revised contingency evaluation; the original was performed during ISCO Conceptual Design Decision B. At this point in the Preliminary Design process, the contingency evaluation should be revisited and revised following similar procedures described in ISCO Conceptual Design Decision B. After the contingency evaluation is complete, its results are used to prepare the Contingency Plan.

The Contingency Plan is designed to (1) define project uncertainties related to CSM, design performance, and operation logistics, and (2) develop action plans to respond to the possible range of project implementation outcomes in order to optimize treatment performance, mitigate undesirable side-effects of system operation, and/or ensure that treatment goals are ultimately met. The Contingency Plan is typically produced as a regulatory agency deliverable document and contains sections describing the operation decision logic, optimization approach, and treatment cessation criteria. Each of these components is described in detail below.

Operation Decision Logic. The first element of the Contingency Plan is the operation decision logic which charts the course of the desired treatment process from implementation to goal achievement as well as the range of potential courses that the ISCO treatment may take. Inherent with design uncertainty, there is operational uncertainty. This plan seeks to explicitly address this uncertainty and provides a framework for decision making as the monitoring data is collected and analyzed to ensure that data is used in as real-time of a manner as possible to optimize ISCO performance.

The operation decision logic can be developed with and provided to the regulators as part of the preliminary design deliverable. The advantage of obtaining regulatory approval of the decision logic prior to ISCO implementation is that it will allow a more streamlined and expedited implementation process. It essentially seeks approval for not only the desired endpoint at the ISCO treatment goal, but also alternative endpoints such as an asymptotic groundwater concentration driven by contaminant back-diffusion or technical impracticability. It is a proactive approach that can significantly expedite projects that do not proceed as planned by providing pre-approved contingency response actions. In so doing, time is saved during implementation and the project may advance to a practical and regulatory-approved alternative endpoint for the ISCO implementation.

An A23. Example of Operation Decision Logic for a short-term delivery ISCO treatment system (e.g., direct injection or injection wells) is attached. This single visual illustrates an operation plan and optimization decision logic that includes prescription of a monitoring and data analysis routine where data is compared to treatment goals and operational adjustments are made based on the results. In this example, the ideal ISCO treatment system will progress straight down the left side of the flow chart. If rebound occurs (i.e., the second decision diamond fails), however, then the ISCO project proceeds to the optimization leg of the flow chart. The optimization leg (i.e., the branch of the flow chart directed to the right) steps the user through a series of questions and based on the answers to those questions, redirects the ISCO treatment process. The optimization outcome, in order of least to most severe, can range from:

- Cessation of ISCO at some level short of the treatment goal, but acceptable for the planned coupled technology such as monitored natural attenuation.
- Implementation of additional ISCO injections.
- Technical impracticability and consideration of alternative treatment goals or alternative site exit strategies.

Because of the inherent uncertainty associated with in situ treatment, the operation decision logic is an important component to maximize the potential for success of the ISCO implementation. This series of decision logic steps seeks to compare actual monitoring data to the treatment goals. Using a series of "IF-THEN-ELSE" statements, the site-specific decision logic guides the operator to their next step in the ISCO treatment process. The ultimate goal of the decision logic is to provide the operator with a step-by-step roadmap for data interpretation and ISCO implementation and cessation.

The content and level of detail of the operation decision logic will be project-specific, and will also depend on the subcontracting approach adopted by the project team. For maximum utility, it should include content and decision points directly relevant to the selected operational objectives and treatment milestones.

Optimization Approach. The second element of the Contingency Plan is the optimization approach. This element is developed to execute the decision logic and allow operational flexibility to respond to data being collected during ISCO delivery and treatment, includeing at times when treatment goals are not being met. It may include a series of additional injections, installation of new injection wells, refinement of the TTZ to be targeted for follow-on injections, or treatment cessation. The purpose of the optimization approach component of the Contingency Plan is to gain up-front consensus with the regulators on the approach that will be used to fine-tune the ISCO treatments as data is collected and analyzed during performance monitoring. Examples specific to typical ISCO-related operational issues and field contingency measures are summarized in Table DD-1.

Table DD-1. Examples of ISCO Operational Issues and Contingency Measures.

Operational Issue	Contingency Measures
Oxidant surfacing / day lighting (minor)	• Reduce injection rate • Continue injections, and neutralize surfaced oxidant with water after injection is complete • If designed ROI is being met (e.g., oxidant reaching monitoring points), consider reducing volume of injectant per linear vertical foot, thereby increasing the concentration
Oxidant surfacing / day lighting (significant)	• Stop injection and assess potential damage or risk pathways • Continue injection with lower rate and pressure (can inject at alternative location to allow dispersion of fluids and return to location later in time) • If surfacing continues, cease injections, grout injection point, and re-locate injection point 3-7 feet away (depending on lithology) • After injection, neutralize and/or remove excess accumulated oxidant in an appropriate manner.
High continuous injection pressures	• Increase oxidant concentration and decrease injection flow rate and volume • If ROI is compromised, advance additional injection points to increase TTZ coverage
Low injection flow rates	• Increase oxidant concentration and decrease injection flow rate and volume • If ROI is compromised, advance additional injection points to increase TTZ coverage
No evidence of oxidant in delivery performance monitoring well	• Employ secondary methods for monitoring presence of oxidant • Increase injection duration / volume, or increase overall oxidant concentration throughout the TTZ, increase number of injection points

Treatment Cessation Criteria. The third element of the Contingency Plan is the Treatment Cessation Plan, which is intended to provide firm endpoint criteria for ISCO treatment and monitoring. Similar to the decision logic and optimization approach components of the Contingency Plan, the purpose of the Treatment Cessation Plan is to gain up-front consensus with the regulators on the process that will be used to determine when the ISCO treatment will be deemed complete. Possible treatment cessation endpoints are shown in orange “STOP” process boxes on the A23. Example of Operation Decision Logic. Multiple treatment cessation endpoints are prudent given the uncertainty of in situ remediation. In the A23. Example of Operation Decision Logic, the best-case scenario is that ISCO operation proceeds as planned and achieves the design treatment goals (“STOP – ISCO Treatment Complete”). An alternative endpoint, shown as “STOP – Proceed to implementation of post-ISCO coupled technology,” does not meet the design goals, but can be further treated using the planned post-ISCO coupled technology. The last resort endpoint, shown as “STOP – Consider alternative ISCO treatment goals and/or remedies,” occurs after all optimization options are exhausted. At this point, the project team must revisit the remediation strategy and decide whether ISCO should be further considered or if other treatment technologies are more appropriate.

At a minimum, the Treatment Cessation Plan should include the basic cessation criteria components summarized in Table DD-2. The criteria used to evaluate each cessation plan component will be site-specific. Examples of each (numeric and non-numeric) are also provided in Table DD-2.

Table DD-2. Recommended Content for ISCO Treatment Cessation Plan.

Contingency Plan Component	Example Criteria
Rebound assessment procedure	Duration of rebound monitoring, may be a fixed time period after cessation of ISCO reaction or procedural-based on stabilization of monitoring parameters within range of natural variability to demonstrate when a quasi-steady state aquifer re-equilibration is achieved.
Criteria for application of post-ISCO coupled treatment technology	Allowable initial contaminant concentration or mass flux for post-ISCO coupled technology to be cost-effectively implemented
Treatment efficiency monitoring and analysis procedures	Asymptotic groundwater concentration driven by contaminant back-diffusion
Contingency procedures for technical impracticability designation for ISCO technology	Maximum number of ISCO injections or duration of ISCO treatment prior to technical impracticability assessment

The rebound assessment procedure is important to demonstrate that an adequate amount of time will be allowed post-ISCO reaction (i.e., after the oxidant is consumed) to allow for re-equilibration of the aquifer prior to final sampling and treatment complete determination. Several methods can be used to assign the duration of post-ISCO monitoring. Regardless of the method selected, site-specific negotiations will likely be required based upon regulatory requirements and site owner drivers.

One method to evaluate rebound assessment procedures (e.g., monitoring frequency and duration) is to use numeric modeling software code (Clement, 1997). Results of complex numeric modeling are reported in the literature to estimate the effects of rebound and back diffusion following application of source treatments such as ISCO and physical containment (Mundle et. al., 2007, and Chapman and Parker, 2005). However, application of these models remains at the education and research institutions and has not widely been used by ISCO practitioners. Therefore, the literature should be reviewed for general guidance and only be considered for complex DNAPL sites, for example, where the benefit outweighs the cost.

Because numeric model estimation of the re-equilibration timeframe is complex, uncertain, and expensive, many projects choose to collect multiple post-ISCO rounds of groundwater samples and use these results to show aquifer stability. Numeric criteria are required to define aquifer stability and re-equilibrium. A change of less than 10 percent in the field parameters and contaminants of concern concentrations between consecutive monitoring events has been used to demonstrate re-equilibration at some sites. The amount of time required to wait for the above may be significant depending upon the speed of desorption, back-diffusion, and dissolution processes that occur in complex lithologic and hydrogeochemical settings. Numeric definition may also be required for the area to be sampled and perhaps the use of statistics to prescribe that re-equilibration within the 95-percent confidence interval for the average baseline geochemical parameter concentrations will be achieved at all wells.

For practical reasons, other projects chose to assign a fixed time limit for post-ISCO monitoring. This is largely because of the impractically large amount of time to achieve steady-state re-equilibrium at some sites. Most state regulations specify a minimum amount of time for post-treatment monitoring prior to site closure and this guidance can be used to justify assignment of post-ISCO monitoring duration. The Interstate Technology & Regulatory Council (ITRC) prescribes a minimum of one year following the completion of treatment to ensure no rebound occurs and to determine the effectiveness of treatment and to evaluate whether the desired degree of oxidation and desorption was achieved in both saturated soils and the aqueous-phase contaminant (ITRC, 2005).

Another treatment cessation criterion is achievement of a maximum allowable contaminant concentration or mass flux below which the planned post-ISCO coupled technology can be applied. These values can typically be estimated using analytical modeling or pilot-test results. Use of this criterion will ensure that ISCO will only be complete when the site conditions are appropriate for effective implementation of post-ISCO coupled technologies.

The procedures to be used to analyze the monitoring data should also be explicitly described. TTZs often include a large volume of contaminated media and numerous upgradient, source, and downgradient monitoring wells. Statistical methods to analyze the data should be considered so that it is clear to the regulators, for example, what initial pre-ISCO and final post-ISCO values will be used to estimate treatment efficiency. Example treatment efficiency determination methods are as follows:

- **For ISCO with a Concentration Reduction Treatment Goal:**
    - Treatment goals achieved at all monitoring well locations within the TTZ upon re-equilibration using the single monitoring well sampling event prior to ISCO implementation as the baseline.
    - Average of all post-re-equilibration ground water sampling data within the TTZ using an average of one year pre-ISCO treatment sampling data as the baseline.
    - Comparison of the 95-percent upper confidence limit for the average post-re-equilibration groundwater contaminant concentration data within the TTZ, with the 95-percent upper confidence limit for the one-year average pre-ISCO treatment baseline contaminant concentration data.
    - Comparison of the geospatially-weighted average of all post-re-equilibration groundwater sampling data within the TTZ using a similarly geospatially-weighted average for one year of all pre-ISCO sampling data as the basis.

- **For ISCO with a Mass Flux Reduction Treatment Goal:**
    - Comparison of the post-re-equilibration mass flux across one control plane immediately downgradient of the TTZ to the single baseline sampling event at the same control plane using the Mass Flux Toolkit (from GSI Environmental, http://www.gsi-net.com/en/software/free-software/mass-flux-toolkit.html) as the method for estimating it.
    - Assuming no change in the groundwater flux, comparison of the post-re-equilibration spatially-weighted average concentration across the mass flux measurement control plane immediately downgradient of the TTZ to the same results from the single baseline sampling event.

The last recommended component of the ISCO Treatment Cessation Plan is to prescribe criteria for an impracticability designation of the ISCO treatment technology when achievement of the ISCO treatment goals is impracticable from an engineering, treatability, and economic perspective. This ISCO exit strategy is intentionally a close parallel to the U.S. EPA process for a technical impracticability waiver (EPA, 2003). However, the process prescribed herein does not pertain to the inability to meet applicable and relevant or appropriate requirements. Rather, it is solely intended as an option for ISCO cessation when it becomes clear that it can not meet its treatment goals and triggers a time to move onto another treatment technology in the site remediation treatment train. Specification of criteria to initiate the impracticability designation process, if necessary, is important to provide an upper bound limit on the extent of the ISCO effort. For example, a maximum number of injections, maximum injectate volume, or maximum duration of ISCO treatment may be prescribed to set the bounds of the effort. Regulatory approval of these limits during the Preliminary Design process will ensure that ISCO treatments do not continue in perpetuity, or more importantly, ensure that no/limited arguments will be had concerning impracticability during the implementation phase.

Methods used to quantify the numeric criteria for the Treatment Cessation Plan components cover a large range of complexity, and can include:

- Simple statistics
- Analytical solutions for simple contaminant partitioning equations
- Contaminant fate and transport modeling performed as part of other project activities
- Field testing / sampling performed to assess equilibrium timeframes

Since most of these methods are not unique to ISCO, discussion of these methods is not included in the ISCO TPM. The reader is referred to the various references available on these topics as listed below.

- EPA's Center for Subsurface Modeling Support (CSMoS) modeling guidance (http://www.epa.gov/nrmrl/gwerd/csmos/)
- ProUCL statistical software (http://www.epa.gov/esd/tsc/software.htm)
- GSI Environmental's Mass Flux Toolkit (http://www.gsi-net.com/en/software/free-software/mass-flux-toolkit.html)
- RemChlor for source zone time-of-remediation modeling under remediation scenarios (http://www.epa.gov/ada/csmos/models/remchlor.html)

DD.3 FINAL DESIGN PHASE

For the purposes of this e-protocol, the following terminology is used:

- Owner – Site owner responsible for site remediation and regulatory compliance.
- Engineer – Consultant responsible for design of the ISCO treatment system.
- Contractor – ISCO contractor responsible for physical implementation of the ISCO treatments.

DD.3.1 DETAILED DESIGN AND PLANNING DECISION B: Is a Performance-Based Implementation Contract Feasible and Cost-Effective?

The Final Design phase of the ISCO Detailed Design and Planning process starts with the determination of an implementation contracting approach and design type. The contracting approach determines the level of detail that is included within the design. The two basic options described in this document include:

1.) A performance-based contract, and
2.) A traditional owner-engineer and owner-contractor execution with detailed design specifications and drawings (i.e., a prescriptive design).

The need or desire to use an Observational Method should be considered when selecting a contracting approach. As initially discussed in ISCO Conceptual Design Process B, an Observational Method is based on the assumption that field conditions will vary from the CSM and the implementation plans will be dynamic and require modification based on monitoring data results. Most modifications can be predetermined during the contingency planning phase (see ISCO Detailed Design and Planning Process 2) and are included in the design. Therefore, both performance-based and detailed / prescriptive contracting approaches can be adapted to the Observational Method.

Performance-based contracts are also known as design-build-operate contracts. This type of contract does not provide detailed information on what equipment is required or the means to achieve the project goals. Rather, it provides a set of minimum performance criteria (i.e., certain milestones, endpoints, and/or desired outcomes) that the contractor is expected to achieve with any methods and materials they chose. A combination of performance requirements may be included in a performance contract, along with other standard contract requirements / specifications, such as construction quality control and health and safety requirements.

A detailed and prescriptive contract requires that a set of specifications and drawings be prepared that detail the exact and complete scope of work required of the contractor. There are typically no performance requirements for a traditional detailed design. The detailed / prescriptive specifications typically include the northing / easting location of wells, well completion and development details, oxidant and activation method selection, volume and mass of oxidant to be injected, oxidant mixing means and methods, and duration of injection and post-injection monitoring.

Very often a combination of performance and prescriptive elements are included in an ISCO implementation contract. For example, performance specifications can be imbedded in an overall prescriptive contract. Certain activities, such as oxidant mixing and delivery, can be performance-based. However, overlapping performance and prescriptive elements on individual scope items should be avoided.

Contractors who specialize in ISCO delivery and chemistry must be used for performance-based contracts. Some specialty contractors may charge a premium fee for a performance-based contract, depending on the performance specifications, contract structure, and the level of financial risk imposed on the contractor.

Trade-specific contractors such as drillers could be used if a detailed / prescriptive design is developed. This may allow a larger field of contractors to bid and may reduce the bid cost. However, a general contractor with limited experience is also likely to require more oversight and direction from the engineer, therefore increasing overall project cost.

For all types of contracting, close coordination with the potential contractors is suggested during the Preliminary Design stage so that the specification is written in a way that is consistent with the desired delivery and oxidant activation methods and also includes an appropriate amount of flexibility to allow the contractor to do their best.

Table DD-3 presents a comparison of the advantages and disadvantages of performance-based and detailed / prescriptive contracting approaches to aid the user in selection of an implementation contract approach.

Table DD-3. Comparison of Performance-Based and Detailed / Prescriptive Contracting Approaches.

Selection Criteria	Performance-Based	Detailed / Prescriptive
Specification level of effort	Low	High
Contractor selection	Highly selective	Low to moderately selective
Level of CSM understanding	Moderate to high	Moderate to low
Amenable treatment goals	More amenable to numeric goals, such as achieve 90-percent mass flux reduction	More amenable to non-numeric goals, such as achieve source mass reduction
Size of TTZ	Small to moderate	Moderate to large
Amenable oxidation chemistry	Activated persulfate, catalyzed hydrogen peroxide, or proprietary formulas	Permanganate, ozone
Amenable delivery methods	Patented or proprietary systems	Standard DPT or well systems
Overall implementation cost	Moderate to high	Low to high
Degree of risk	Variable depending upon contractor knowledge and contract language	Variable, depending upon CSM understanding and design certainty
Potential for change orders	High if contract language is not tight	Low

DD.3.2 DETAILED DESIGN AND PLANNING PROCESS 3a: Prepare Performance Specifications

If a performance-based contract will be implemented, contractor performance specifications will be prepared to document the set of minimum performance criteria (i.e., project milestones, endpoints, and/or desired outcomes) that the contractor is expected to achieve. The objectives of the performance specifications are to:

- Define the roles and responsibilities of site owner, engineer, contractor(s).
- Prescribe ISCO treatment goals.
- Ensure that pertinent details are included such that the contractor has detailed knowledge of the site conditions to maximize chances of achieving ISCO treatment goals.
- Maximize contractor flexibility.
- Hold the contractor accountable for their treatment effectiveness claims.
- Ensure that proper data is collected to document treatment effectiveness.
- Prescribe a payment milestone process consistent with anticipated treatment milestones.
- Require compliance with the Operation and Contingency Plan including post-ISCO re-equilibration monitoring and treatment effectiveness determination procedures.

In general, the performance requirements should be written to be consistent with the ISCO operational objectives and treatment goals. They could include:

- Deliver a target mass of oxidant over a certain area.
- Achieve a target ROI around the injection points.
- Achieve a target concentration of oxidant in the subsurface in certain monitoring wells.
- Avoidance / minimizing of groundwater and/or oxidant surfacing / day lighting
- Achieve a target contaminant concentration, mass reduction, or mass flux reduction over a certain area.

The performance specifications should be prepared as part of a Scope of Work and Bid Sheet to send to prospective contractors. Separate scopes of work and bid sheets should be prepared if the ISCO implementation work is to be performed by more than one specialty contractor (e.g., driller, controls and mechanical equipment, oxidant injection), each with its own task-specific health and safety requirements.

Care should be taken to avoid writing conflicting performance-based specifications that, for example, specify a certain performance in terms of contaminant reduction and at the same time specify the number of wells and mass of oxidant to be used which may not be adequate to meet the performance objectives. In general, selection of materials, means, and methods should be left up to the contractor. In some cases, minimal materials and methods specification is acceptable to meet site-specific requirements. For example, bench testing may have been performed and dictated that alkaline-activated persulfate be used to oxidize the mixture of contaminants while another site may have low permeability media and field testing might dictate the need for pneumatic fracturing to deliver the oxidants.

As discussed in ISCO Detailed Design and Planning Process 2, achieving a certain concentration or contaminant mass reduction is extremely difficult to predict. Likewise, it is difficult to predict the ROI that can be achieved, unless pilot tests or previous injections have been performed. Consequently, most contractors will charge a premium if a performance contract is written with either of these conditions specified. The prospective ISCO contractors should be consulted during this stage to ensure that performance criteria are realistic and achievable and that a cost-effective performance-based contract is prepared that is agreeable to both the owner and contractor.

DD.3.3 DETAILED DESIGN AND PLANNING PROCESS 3b: Prepare Detailed Design Specifications and Drawings

A detailed set of design specifications and drawings will be required for a prescriptive contract. The level of detail and format is typically as prescribed by the Construction Specification Institute (CSI, http://www.csinet.org/). The level of detail of the design specifications and drawings will vary depending on the contract structure and the level of expertise possessed by the contractor. For example, a prescriptive contract for a simple direct-push ISCO design that will be implemented by an experienced contractor may include minimal design specifications such as the northing / easting location of wells, well completion and development details, oxidant and activation method selection, volume and mass of oxidant to be injected, oxidant mixing means and methods, and duration of injection and post-injection monitoring.

For a more complicated ISCO design that will be constructed / operated by one or more trade-specific contractors, a complete set of detailed design specifications and drawings is required. An A24. Example Design Specifications and Drawings for direct injection and more complex automated recirculation delivery ISCO treatment systems are attached.

Regardless of the complexity of the ISCO design or the level of detail included in the design document, the design specifications and drawings should include all necessary information under a single document. In addition, design requirements for specific components should be specified in detail for the project, rather than deferring to general vendor specifications or cut sheets.

DD.3.4 DETAILED DESIGN AND PLANNING DECISION C:
Is the Project Constructible and Biddable?

A constructability review should be conducted to evaluate if cost-effective and practicable approaches for field implementation have been included in the detailed / prescriptive design. If after review by the construction team, it is determined implementable and cost-effective, then it is deemed constructible and biddable. The scope of the constructability review will vary based on project requirements. At a minimum, it can involve a pre-bid site walk with the site representative and prospective contractors to identify site conditions and logistical issues (e.g., vehicular and equipment access, terrain, existing site activities, working hours, etc.) that may complicate implementation of the design. If a higher-level constructability review is performed, it should be conducted by a constructability review team (typically consisting of the design team and other affected project participants such as the client, technical consultants, and prospective contractors) and incorporate the following processes described below.

Review Design Concepts – The team reviews the design objectives for the project, the probable sequence of field implementation, and other aspects of the project. The preferred method of accomplishing this exchange of information is through a “workshop” session wherein the design leads can explain the design and address any specific design issues or elements that may affect field implementation.

Screen Available Lessons Learned – The team reviews any available lessons learned for the project type, and consults with appropriate participants of other similar projects to identify any special constructability considerations that may be applicable to the project.

Review Performance / Site Conditions – The team reviews site conditions, logistical constraints, and other potential contractual mandates to understand their implications on the field implementation. Schedules, restrictions on working hours, concurrent site operations, and availability of oxidants and materials all have an impact on the field implementation and can affect the sequence of field implementation.

A Constructability Implementation Guide prepared by the Construction Industry Institute (CII, http://www.construction-institute.org) provides a detailed guidance on implementing constructability principles on a project, including updated case studies.

DD.3.5 DETAILED DESIGN AND PLANNING PROCESS 4:
Perform Value Engineering or Design Optimization Assessment to Improve Constructability / Bidability

If the project constructability or bidability is determined to be low based on the outcome of ISCO Detailed Design and Planning Decision C, value engineering (VE) can be applied to evaluate and select easily integrated design and field enhancements to simplify the design and operations, and/or improve system reliability. Examples of VE that could apply to an ISCO project include:

- Evaluate different oxidant mixing options that may better suit site requirements: diluting oxidant in simple batch tanks on site, inline dosing of oxidant into injection water line, or diluting oxidant off-site and delivering solution to site in tank.
- Including automation, reliability, and maintainability in design features to minimize the need for field staff to be present on site, if site access or work hours are a factor.
- Use of modular designs with treatment capacity that can be easily downsized / increased without significant additional disruption of the site.

As was the case for the constructability review process, the scope of the VE process will vary based on project requirements. If a high-level VE evaluation is performed, it should be conducted by a VE team (typically consisting of the design team, client, and technical consultants) and incorporate the following processes described below.

Information Workshop – This first step includes familiarization and orientation activities including: (1) overview of project's mission, (2) presentation from design team, (3) input from other project stakeholders, and (4) question and answer session. The primary objective of the information workshop is to identify the constructability issues with the design and confirm that VE is the appropriate corrective action.

Criteria Development – The VE team brainstorms numerous evaluation criteria against which each alternative will be compared in a subsequent phase of the VE Study. The VE Team then rates each criterion in terms of its relative importance to constructability / bidability issues, as follows:

A = Essential
B = Important (but not essential)
C = Low Importance
D = Not Rated

The A, B, C ratings assign a different numerical priority value to each criterion, with A being the highest at 9 points, B being the middle score at 6 points, and C being the lowest score at 3 points. If a criterion is found to be not applicable, it is assigned a "D" rating and receives a value of zero.

Concept Ranking – The VE Team recaps and discusses key advantages and disadvantages, any fatal flaws, and potential refinements of each conceptual alternative, some of which were prepared and presented by the design team during the information workshop. Additional alternatives are brainstormed and developed by the VE team. Some alternatives drop out because of apparent fatal flaws. Others survive the initial discussions and are rated against how well they meet the criteria. Consensus is reached among the VE team members as to the rating of each alternative against the criterion. Alternatives are then sorted by criteria priority and rated.

Concept Refinement – The VE Team systematically compares differing scores between alternatives in an effort to further screen the alternatives, leading to selection of a preferred alternative or alternatives. The VE team also reviews the lowest point scores applied to the highest priority "A" and moderately important "B" criteria to attempt to find ways to refine each concept, making them better alternatives and improving the scoring total. The key reasons for keeping the preferred alternatives, and dropping other alternatives, are summarized for inclusion in the subsequent VE Study Report.

Following the study, a follow-up VE Study Report for presentation to other project stakeholders as applicable, and for documentation purposes is prepared. Guidance for executing VE is provided by SAVE International (http://www.value-eng.org/).

DD.3.6 DETAILED DESIGN AND PLANNING PROCESS 5:
Prepare a Construction Cost / Engineer's Estimate

This process is a detailed refinement of the FS-level cost estimate prepared as part of the ISCO Conceptual Design Process 8. The level of detail and accuracy of the construction cost / engineer's estimate is expected to increase to -15 to +20 percent, and be suitable for bid estimates, establishing contract value, and serving as a control baseline against which actual costs and resources will be monitored. This cost estimate is comparable to a Class 2 cost estimate as defined by the American Association of the Advancement of Cost Engineering International (AACEI, http://www.aacei.org/).

The level of effort and internal review required for preparing the construction cost / engineer's estimate depends on project-specific requirements. One option is to update the FS-level cost estimate (ISCO Conceptual Design Process 8) with refined quantities and unit-prices, listed assumptions and clarifications, and updated equipment and contractor quotes. The ultimate method, however, is typically unique to a project team's experience and owner requirements.

DD.3.7 DETAILED DESIGN AND PLANNING DECISION D: Is the Projected Cost Within the Budget?

This decision is simply a comparison of the construction cost / engineer's estimate to the budget allotted by the site owner. At this stage of the ISCO design process, the level of accuracy of the cost estimate (-15 to +20 percent) has already been refined by reducing uncertainty in design input parameters during the Conceptual Design process. If the answer to this question is "YES", then user proceeds to ISCO Detailed Design and Planning Process 7. If the answer is "NO", then further efforts to reduce projected costs will be accomplished through VE (ISCO Detailed Design and Planning Process 4).

DD.3.8 DETAILED DESIGN AND PLANNING PROCESS 6: Perform Value Engineering or Design Optimization Assessment to Reduce Costs

If the project cost is determined to be unacceptably high based on the outcome of ISCO Detailed Design and Planning Decision D (above), VE, as described in ISCO Detailed Design and Planning Process 4, can be applied to evaluate and select integrated design elements and field methodologies to reduce cost. Examples of VE that could apply to an ISCO project include:

- Evaluate different oxidant mixing options that may reduce labor costs: diluting oxidant in simple batch tanks on site, inline dosing of oxidant into injection water line, or diluting oxidant off-site and delivering solution to site in tank.
- Including automation, reliability, and maintainability in design features to minimize the need for field staff to be present on site and reduce labor costs.
- Use of modular designs with treatment capacity that can be easily downsized / increased while minimizing additional subcontractor, equipment, and labor cost.
- Use of rental equipment for short-term applications that typically incur high costs (e.g., generators, pumps, and field monitoring equipment).

The VE process will vary based on project requirements. If a high-level VE evaluation is performed, the same concepts for a formal VE team assessment presented in ISCO Detailed Design and Planning Process 4 can be applied.

DD.3.9 DETAILED DESIGN AND PLANNING PROCESS 7: Refine the Operation and Contingency Plan, Performance Specifications, and Detailed Design Specifications and Drawings

If beneficial design / operation changes were identified during the VE exercises conducted to improve constructability and/or reduce costs, the Operation and Contingency Plan (ISCO Detailed Design and Planning Process 2) and the Performance Specifications / Detailed Design Specifications and Drawings (ISCO Detailed Design and Planning Process 3a and Process 3b) should be revised to reflect these changes.

DD.4 PLANNING PHASE

DD.4.1 DETAILED DESIGN AND PLANNING PROCESS 8: Assemble Procurement Packages, Conduct Bid Process, and Select Contractors

The services of contractors will typically be required for certain project activities such as: well installations, soil and groundwater sample analyses, supplying oxidant, direct-push injection of oxidants, fabrication of injection equipment (depending on injection design), and mixing and injection of oxidants into injection wells (if injections will not be self-performed by the engineer). The procurement process is critical for identifying qualified contractors who have the qualifications to meet (at a minimum) the project's technical, health & safety, and schedule requirements. The following outlines the basic steps that should be followed during the subcontracting process:

1.) Prepare a contract / bid package and send to contractor(s) who have been pre-qualified based on relevant technical experience and acceptable health & safety records (as appropriate based on project requirements).
2.) Receive bids and conduct thorough review of price and technical approach; ensure contractor(s) can meet technical, schedule, and health & safety requirements.
3.) Award contracts to winning contractor(s).

Consider payment requirements during the contracting process. Contracts can be written to be fixed-price (lump-sum) or time-and-materials. Under a strict fixed-price performance-based contract, the contractor is only paid if they achieve the performance specified. Under a time-and-materials contract, the contractor is paid for the hours that they work and for the materials they provide. A combination of fixed-price and time-and-materials can also be used. For example, unit pricing can be used for installation of and injection into a single well, or injection of a unit quantity of oxidant. Incentives can also be written into a contract to reward the contractor for achieving certain performance. Unit price-based contracts with incentives may resolve the issue of motivating the contractor to achieve the desired outcome, while still providing flexibility. The payment schedule needs to account for changes in project activities and schedule, as defined in the Operation and Contingency Plan (ISCO Detailed Design and Planning Process 2). As such, unit price-based contracting may be the most appropriate contracting mechanism for a project that is heavily designed around an Observational Method strategy.

DD.4.2 DETAILED DESIGN AND PLANNING PROCESS 9:
Prepare Quality Assurance, Health and Safety, and Performance Monitoring Plans

The last step in the ISCO Detailed Design and Planning process is to prepare detailed quality assurance, health and safety, and performance monitoring plans. Each of these execution plans serves a key function during the ISCO Implementation and Performance Monitoring Process. The scope and level of detail included in these documents is highly dependent upon project-specific conditions and site regulator and owner requirements. Therefore, only general ISCO-specific content is suggested in the subsections that follow.

DD.4.2.1 Quality Assurance Project Plan

A Quality Assurance Project Plan (QAPP) should provide a platform for presenting quality assurance / quality control procedures, policies, and requirements so data are scientifically valid and defensible. QAPPs should be prepared on a project-specific basis to meet the project's unique data quality objectives. The Department of Defense requires a QAPP for any project with environmental sampling plans, under the Uniform Federal Policy (UFP-QAPP). Additional information on the UFP-QAPP can be found on the U.S. Environmental Protection Agency's website at http://www.epa.gov/fedfac/documents/qualityassurance.htm. A summary of typical elements per UFP-QAPP is provided in A25. Elements of a Quality Assurance Project Plan.

The primary purpose of the QAPP is to specify the functional requirements necessary to ensure that data collected according to the Performance Monitoring Plan is analyzed and integrated into the decision logic specified in the Contingency Plan. The Performance Monitoring Plan states what data is to be collected, the QAPP prescribes the data analysis procedures, and the Contingency Plan uses the results of the data analysis to refine the course of ISCO treatment program. Data analysis methods are described in ISCO Implementation and Performance Monitoring Decision C and Decision E.

ISCO-specific quality assurance procedures should include oversight and analysis of delivery and treatment processes to ensure that design parameters are met. From a quality control perspective, often times multiple lines of data evidence are necessary to ascertain effectiveness. For example, during delivery, hydraulic head, oxidant and activator concentration, and redox state are measured in monitoring wells within the expected influence of the delivery process. If all three lines of evidence indicate oxidant contact, then the contractor is allowed to proceed to the next injection location, for example. Quality assurance for ISCO treatment effectiveness determinations can also involve using multiple lines of evidence. For example, the project must make sure that injection dilution effects have dissipated and hydraulic and contaminant partitioning re-equilibrium has been re-established prior to assessing contaminant treatment effectiveness. Discussion of treatment effectiveness monitoring is addressed in ISCO Detailed Design and Planning Process 2 (Treatment Cessation Criteria).

DD.4.2.2 Health and Safety Plan

A site-specific Health and Safety Plan should be prepared to comply with the Occupational Safety & Health Administration (OSHA) Hazardous Waste Operations and Emergency Response Standard (HAZWOPER) 29 Code of Federal Regulations (CFR) 1910.120 (Occupational Safety and Health Standards) and 29 CFR 1926.65 for Safety and Health Regulations for Construction. The Health and Safety Plan should be reviewed and endorsed by all members of the project team and by contractors working on-site. A copy of the Health and Safety Plan should be kept on-site, and amended as project activities or conditions change or when supplemental information becomes available.

Typical Health and Safety Plan components include (but are not limited to):

- Project information
- Site map and site plans
- Tasks to be performed during project
- Field team and health and safety communication plan
- Employee and contractor sign-off sheet
- Training requirements
- Required personal protective equipment (PPE)
- Hazard controls (project specific, general work environment, biological, chemicals of concern)
- Traffic control plan
- Air monitoring plan
- Decontamination procedures
- Site control plan
- Emergency response plan (e.g., emergency supplies and equipment, incident response and reporting, emergency facility contacts, directions to hospital)
- Behavior-based prevention forms (Job Hazard Analysis [JHA], pre-task safety planning, safe-work / loss prevention observations, loss / near-loss investigations)

Many of the aforementioned Health and Safety Plan components are not unique to ISCO. A summary of ISCO-specific hazards is provided in The ITRC document, "*Technical and Regulatory Guidance for In Situ Chemical Oxidation for Contaminated Soil and Groundwater, Second Edition*" (January 2005).

The primary hazards associated with oxidant use are dermal exposure effects, gas and heat generation, high-pressure, and the potential for uncontrolled reaction through improper storage. Engineering controls and appropriate personal protective equipment must be employed in handling and mixing oxidants. The Health and Safety Plan should include safety precautions and appropriate training requirements for the specific oxidant(s) to be used on site, including oxidant activators such as acids or bases. Some important specific considerations include:

- Hazards of dusts of solid phase oxidants (e.g., potassium permanganate and sodium persulfate).
- Electrical hazards associated with oxidant generation on site (e.g., ozone).
- Oxidant surfacing or day-lighting when using pressurized probe injections, where oxidant may travel up the outside of the probe to the surface, or up through adjacent improperly abandoned investigation boreholes or wells. Adding pressure relief valves along the injection pipe / hose, and pressure-tight capping nearby monitoring wells should help mitigate oxidant surfacing during pressurized injections.
- The need to monitor injection pressures real-time and incorporate automated system shutdowns if they exceed safe levels.
- Using pressure-tight caps with pressure gauges for all wells within the TTZ during injection, and the need to wait for the pressure to drop before opening the well.
- Provision of neutralizer such as sugar for spill response and containment in case of day-lighting, short-circuiting.

DD.4.2.3 Performance Monitoring Plan

The Performance Monitoring Plan should be designed to:

- Collect the necessary data to measure achievement of the operational objectives and treatment milestones,
- Monitor the ISCO process to continually confirm that the design is performing as designed and is being optimized as prescribed by the Contingency Plan, and
- To document whether the implementation was a success or failure with respect to the ISCO treatment goals as prescribed by the Treatment Cessation Plan.

Achieving these objectives requires an adequately designed delivery and treatment performance monitoring program that provides data that are consistent with operation and performance metrics endorsed by the project stakeholders during the Preliminary Design phase. The Performance Monitoring Plan should be reviewed and endorsed by all members of the project team. A copy of the Performance Monitoring Plan should be kept on-site and readily available to project team members, and amended as project activities or conditions change or when supplemental information becomes available that justifies plan modification.

The Performance Monitoring Plan should cover the three primary stages of ISCO implementation: baseline monitoring, delivery performance monitoring, and treatment performance monitoring. Typical Performance Monitoring Plan components include (but are not limited to):

- Clearly defined data needs and objectives (including measurements for contingency assessment)
- Baseline monitoring program
- Delivery performance monitoring program
- Treatment performance monitoring program
- Number and location of monitoring points
- Frequency of monitoring
- Field and laboratory analytical methods
- Data quality objectives
- Quality assurance / quality control sampling procedures
- General data analysis plan and reference to Contingency Plan for decision logic

Detailed ideas and recommendations for A26. Elements of a Performance Monitoring Plan are attached.

IMPLEMENTATION & PERFORMANCE MONITORING

IM.1 INTRODUCTION

The primary purposes of the ISCO Implementation and Performance Monitoring component are (1) to construct and initiate implementation of the ISCO design, (2) implement the Performance Monitoring Plan (see A26. Elements of a Performance Monitoring Plan) to evaluate if the ISCO design is meeting delivery and treatment performance criteria, and (3) execute the Operation and Contingency Plan (ISCO Detailed Design and Planning Process 2) to adapt and optimize the ISCO remedy in response to new site data obtained and/or efficiently address performance deficiencies encountered during ISCO implementation. The objective of this process is to achieve the ISCO treatment goals. This process is the last component in the ISCO Technology Practices Manual and completes implementation of the ISCO remedy.

This narrative guidance explains the process to be followed to implement, monitor, and evaluate performance of ISCO at a site. The instructions below correspond to the decisions and processes depicted on the ISCO Implementation and Performance Monitoring Flow Diagram (Figure IM-1), and are divided into three phases: the implementation phase, the delivery performance monitoring phase, and the treatment performance monitoring phase. The numbers and letters of the subsequent sections correspond with the numbered process steps and lettered decision steps in the flow chart protocol.

Many steps of the ISCO Implementation and Performance Monitoring component included herein are remediation industry best practices and are not necessarily unique to an ISCO remedy. The prescribed procedure was written to apply to a wide variety of ISCO remedial applications. While it is expected that most components of this process are necessary and prudent for most ISCO projects, some aspects of this process may or may not be applicable and depend significantly upon project-specific needs / goals and contracting approaches. The user is advised to carefully consider the content of this process prior to execution and tailor it as needed to meet their needs.

The process prescribed herein focuses on best practices for the technical aspects of ISCO implementation and does not specifically address regulatory documentation required for implementation, optimization, and cessation. Since regulatory requirements vary significantly, no attempt has been made to tailor the process. However, in many cases, the data derived from this process can be used to obtain regulatory approval for the remedial action.

For the purposes of this ISCO Implementation and Performance Monitoring component, the following terminology is used:

- Owner – Site owner responsible for site remediation and regulatory compliance.
- Engineer – Consultant responsible for design of the ISCO treatment system.
- Contractor – ISCO contractor responsible for physical implementation of the ISCO treatments.

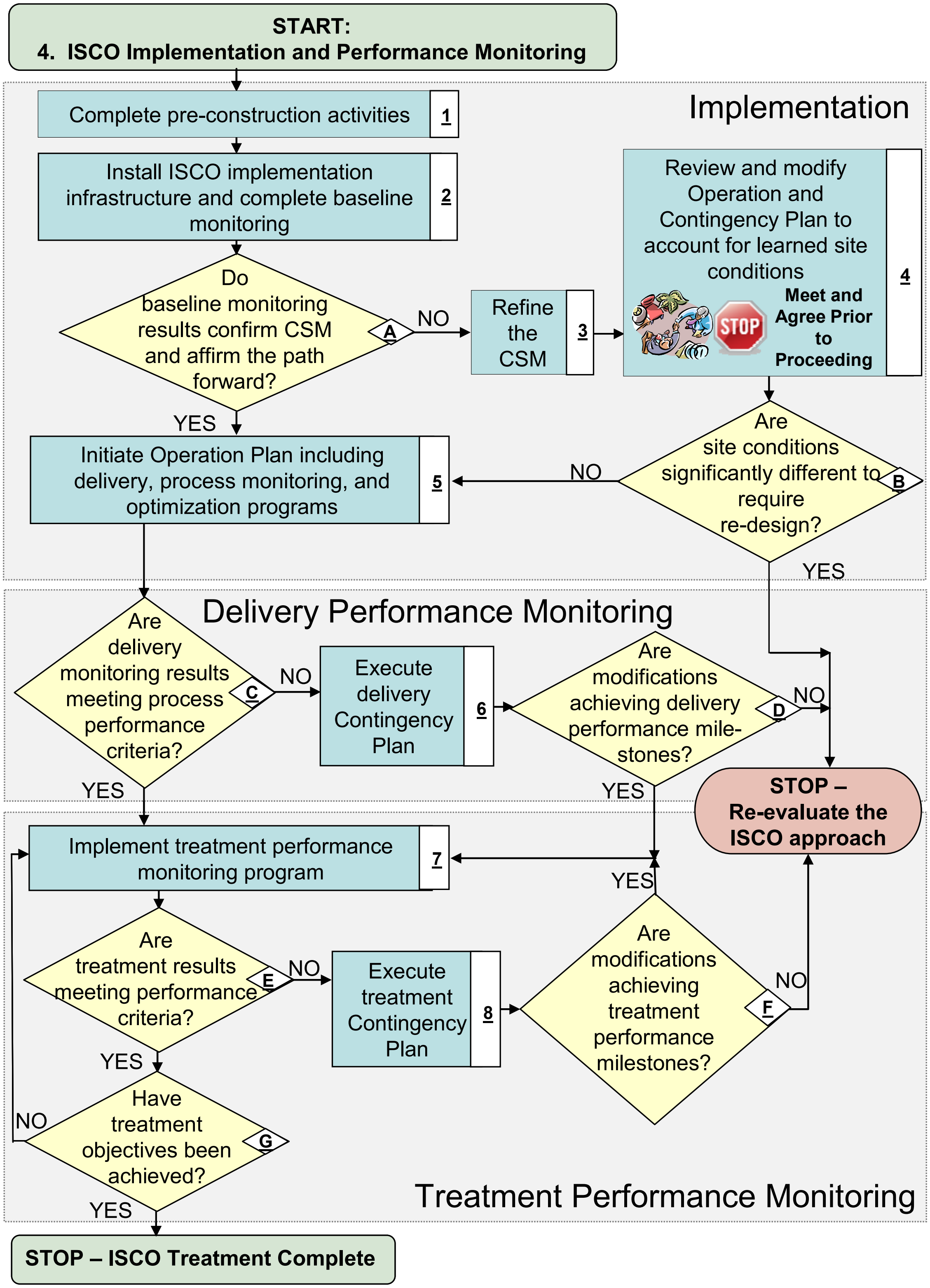


Figure IM-1: ISCO Implementation and Performance Monitoring Flow Diagram.
[To navigate the electronic version of this tool, click on the Process (blue rectangle) or Decision (yellow diamond) on which you would like more information and you will be directed to that location.]

Care should be taken during the permitting process to clarify that monitoring will be used to demonstrate geochemical changes to the aquifer (e.g., an increase in dissolved metals) are temporary and of low-magnitude if expected (Crimi and Siegrist, 2003 and Moore, 2008). This is a typical phenomenon at many sites with a natural capacity (i.e., natural organic matter or reduced metals) to re-equilibrate to pre-existing conditions. For sites with a low natural capacity to re-equilibrate after a large ISCO injection program, a contingency plan may be prescribed which will quench detrimental oxidation by-products using direction injection of oxidant neutralizing or consuming agents such as sodium thiosulfate, sugar water, or lactate. Quenching agents may also be used to stimulate post-ISCO coupled treatment approaches such as enhanced reductive dechlorination. More discussion on the geochemical effects of the various oxidants is provided in the ISCO volume of the SERDP / ESTCP Remediation Technology Monograph Series (Springer Science+Business Media, LLC, 2011).

IM.2.1.2 Utility Clearance

All drilling and underground work will also require utility clearance, at a minimum, by marking out the work area and calling the local underground service alert network (e.g., Call before you dig, Digger's Hotline, One-call, and Miss Utility). Utility clearance via the local underground service alert is required by law, and notifies all utility companies owning underground lines (water, wastewater, storm, natural gas, electrical, telephone, cable, and fiber optic) in the proposed work area. Once notified, the utility owners will then denote the line locations with color-coded markings. It is also recommended that a private utility locator be subcontracted to provide a more thorough utility survey of the site, especially on privately-owned property where some public utilities will not be marked through the underground service alert network, or where the location and alignments of utilities and other underground structures are not well documented.

In all cases, when utilities are located within or immediately adjacent to the target treatment zone (TTZ), the chemical compatibility of underground utilities with the oxidant to be used should be evaluated. Engineering controls will be needed if the material is chemically incompatible. Engineering controls are discussed further below.

The location of utilities is important not only for health and safety reasons, but for understanding potential effects on delivery uniformity as well. Utility bedding / trenches often represent a potential short-circuit at shallow ISCO injection sites since they can be more permeable than the native formation. If injection locations are cited too close to a utility corridor, then oxidant may be lost or wasted. In the worst case, the oxidant may react with the incompatible material of construction of the utility and cause damage. Best case, oxidant is lost and new injection locations will be needed to distribute oxidant into the adjacent targeted native formation. It should be noted that in some cases, ISCO treatment of utility corridors is acceptable for treatment of contaminants that may have migrated into them. Extreme care should be taken to ensure that the oxidant will not harm the utility (e.g., concrete storm sewer line with no immediate discharge point) and that the oxidant will indeed follow a similar flow path as the contaminant. If this approach is taken, extreme care should be taken to monitor all potential exposure pathways including vapors in manholes / vaults.

IM.2.1.3 Potential Receptor Survey

Another important pre-construction activity is a site walk and survey of the TTZ and surrounding area (above- and below-grade) for potential exposure pathways that may lead to human health and environment risk during the ISCO treatment process. The pathways and potential receptors are site-specific. For example, a high-pressure direct injection approach may lead to a higher risk for breach of utility manholes than a hydraulically-controlled oxidant recirculation system. Potential receptors include human and ecological flora and fauna. Example exposure pathways include:

- Utility vault or manhole
- Wetlands
- Ground surface ponding via short-circuiting from lithologic fractures or old boreholes
- Surface water (e.g., stream or pond)
- Drainage swale / ditch or culvert
- Indoor air

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- Utility vault or manhole
- Wetlands
- Ground surface ponding via short-circuiting from lithologic fractures or old boreholes
- Surface water (e.g., stream or pond)
- Drainage swale / ditch or culvert
- Indoor air

The site should be carefully surveyed and ISCO injection result scenarios reviewed to assess potential for exposure. Each of these potential exposures should then be considered for engineering controls and/or contingency response actions. The mitigation measures should be included in the Operation and Contingency Plan prepared as part of Detailed Design and Planning Process 2.

IM.2.1.4 Engineering Controls for ISCO Implementation

In some extreme cases where ISCO treatment adjacent to sensitive utilities or receptors like wetlands is necessary, engineering controls can be used to protect them from oxidant contact. For example:

- Temporary sheet piling can be driven to protect fiber-optic cables.
- Manhole / vaults can be vented (passive or mechanical) to prevent the build-up of vapors.
- Hydraulic controls (i.e., groundwater circulation) can be used to control extent of oxidation.
- Sentinel monitoring program to ensure that ISCO injection is controlled and results in no exposures.

The nature and extent of engineering controls should be carefully evaluated, designed, installed, and monitored by experienced project team personnel.

IM.2.1.5 Administrative Activities

Administrative activities that are conducted after contract procurement and prior to mobilization should include the following activities:

- Obtain site access and personnel clearance (as appropriate) for all site workers.
- Perform a pre-construction meeting with field contractor(s) to identify underground and overhead utilities, review general work plan, review general health & safety hazards, and other existing site activities that could interfere with the ISCO implementation over the duration of the project.
- Ensure contractor(s) will have the specified equipment and materials and additional equipment identified during the pre-construction meeting, and ensure chemical compatibility of all equipment to be used.
- Verify availability of and access to water source and electrical supply.
- Confirm field schedule and identify / resolve any technical issues prior to mobilization.

IM.2.1.6 Health and Safety Preparations

Ensure that the site will be equipped with all appropriate health & safety facilities and equipment as documented in the Health and Safety Plan. Some examples include:

- Personal protective equipment
- Chemical storage and handling facilities
- Oxidant neutralization and spill containment and control kit
- Eye wash and shower stations
- Fire extinguishers

Detailed safety checklists, as typically specified in the Health and Safety Plan, should be completed and reviewed by the entire project field team. The contractor should complete these checklists and include information on specific methods of the operation and measures that should be employed to correct deficiencies. Safety checklists should be developed based on project-specific health and safety requirements, and the field team should verify that all high-risk site activities are addressed during pre-construction. High-risk project activities may include (but not be limited to) the following:

- Drilling
- Electrical
- Forklifts
- Hand and power tools
- Hazardous materials
- Respiratory protection
- Traffic control
- Waste characterization, sampling, and analysis

Additional information on ISCO health and safety is provided in ISCO Detailed Design and Planning Process 9.

IM.2.2 IMPLEMENTATION AND PERFORMANCE MONITORING PROCESS 2: Install ISCO Implementation Infrastructure and Complete Baseline Monitoring

In this process the fundamental activities that should be performed when installing ISCO injection infrastructure (e.g., injection wells, monitoring wells, manifold piping, injection equipment) and performing the baseline soil and groundwater sampling are described. Fewer or additional activities will be required depending on the actual injection design and methodologies employed, and site-specific requirements imposed by the owner and/or regulatory oversight agencies. For example, if oxidant injection is to be via direct-push technology only, then the ISCO infrastructure may be simpler than prescribed herein.

With all elements of this process, the Operation and Contingency Plan (ISCO Detailed Design and Planning Process 2) should be referred to for identifying all potential future project contingency requirements, so that all health & safety, subcontracting, site access, material, and equipment needs can be met, to the extent practical, without significant project delays.

IM.2.2.1 ISCO Infrastructure

Installation of ISCO infrastructure includes injection and monitoring wells, and setup of oxidant staging, mixing, and delivery equipment. Equipment may include the following: water supply, storage tanks, chemical hoppers and mixers, chemical feed systems, pumps, injection pipe / hose, injection well manifold assemblies, and instrumentation (pressure gauges, flow meters, etc.). The equipment used will vary depending on the method selected for mixing and delivering the oxidant. Irrespective of the oxidant injected or delivery method selected, the following field practices should be employed during infrastructure installation activities:

- Proper oversight of contractors is necessary to ensure that ISCO infrastructure is installed as designed. Quality control staff familiar with the final design (ISCO Detailed Design and Planning Process Final Design Phase) and the project work planning documents (ISCO Detailed Design and Planning Process Planning Phase) should be required to be on site during delivery and key treatment performance monitoring phases of field work.
- Frequent communication with the designated quality control staff, contractor, engineer, and owner should be maintained so project decisions in response to changed field conditions and design basis can be made in an efficient manner.
- Thorough and detailed field documentation in field book, field data sheets and well construction logs should be maintained.

A27. Infrastructure Construction and Delivery Effectiveness QA / QC Guidelines for the various oxidant delivery techniques are attached. It lists the major delivery techniques, their primary construction elements, and the associated quality assurance / quality control (QA / QC) inspections / tests that should be conducted to verify their integrity and effectiveness.

IM.2.2.2 Baseline Sampling

Baseline soil and groundwater samples should be collected and analyzed in accordance with the Performance Monitoring Plan (see A26. Elements of a Performance Monitoring Plan).

IM.2.3 IMPLEMENTATION AND PERFORMANCE MONITORING DECISION A: Do Baseline Monitoring Results Confirm the CSM and Affirm the Path Forward?

Soil and groundwater baseline data should be used to verify that the current understanding of the conceptual site model (CSM) is correct and whether the current ISCO design should be refined. The objective is to review all new information learned, and to determine if any changes to the CSM will have significant affect on the effectiveness, implementability, or cost of the current ISCO design. If baseline monitoring results are significantly different than expected, then the user proceeds to update the CSM. If not, then the user proceeds with delivery operation. Assessment of the significance of data difference between what is expected and what is encountered is similar to the method presented in ISCO Screening Decision B.

IM.2.4 IMPLEMENTATION AND PERFORMANCE MONITORING PROCESS 3: Refine the CSM

If it is determined that the nature of soil and groundwater baseline data is such that the ISCO design may need refinements, the CSM should first be revisited to make sure that input parameters used for subsequent design refinements are conducted with the most updated site information. If baseline monitoring results are significantly different than expected, then the user proceeds to update the CSM. If not, then the user proceeds with delivery operation. The A3. CSM Certainty Evaluation Tool should be re-visited to update the level of certainty in the CSM in light of the baseline monitoring results. During the implementation and performance monitoring process, a high overall degree of certainty (greater than 80 percent) should increase the chances of success.

IM.2.5 IMPLEMENTATION AND PERFORMANCE MONITORING DECISION B: Are Site Conditions Significantly Different to Require Re-design?

If changes in site conditions encountered during the installation of ISCO infrastructure or baseline sampling are significantly different such that the current ISCO design is not expected to perform adequately, be implementable, be cost-effective, or be safe with only minor design refinements, a complete re-design may be required. The need for a complete re-design, and the degree to which the re-design is performed, will need to be evaluated and decided upon by the project team, taking into consideration the updated CSM data, regulatory drivers, schedule, and budget. Considerations during this decision process should include the following:

- Is ISCO still applicable to site geology, remediation goals, and/or contaminant mass and architecture? (ISCO Screening Process 1).
- Should coupled ISCO treatment approaches be reconsidered? (ISCO Screening Process 2).
- Do the original conceptual ISCO design alternatives (oxidant and delivery approaches developed during the ISCO Conceptual Design Process) need to be revisited and re-ranked based on the changes in the predicted delivery effectiveness, treatment performance certainty, cost, cost certainty, implementability, and/or safety of the current ISCO design? (ISCO Conceptual Design Process 4).
- Are the TTZ or data collected from the site for hydrogeology, soil / natural oxidant demand characteristics, and/or contaminant concentrations significantly different such that the A11. ISCO Spreadsheet Design Tool needs to be re-run? (ISCO Conceptual Design Process 1, Process 2, and Process 3)

IM.2.6 IMPLEMENTATION AND PERFORMANCE MONITORING PROCESS 4: Review and Modify Operation and Contingency Plan to Account for Learned Site Conditions

At this point, the Operation and Contingency Plan (see ISCO Detailed Design and Planning Process 2) should be refined in order to optimize performance and cost of future ISCO efforts. At the implementation phase of an ISCO design, design optimization / refinements may include:

- Revising the TTZ lateral extent and depth.
- Refining oxidant dosage (total mass and injected concentration) based on soil and groundwater analytical data for contaminants of concern, soil and groundwater geochemistry (i.e., pH, alkalinity, metals, oxidation / reduction potential, dissolved oxygen, and temperature), natural oxidant demand, and/or additional laboratory oxidant persistence testing performed.
- Refining injection spacing or injection depth interval to optimize oxidant distribution / radius of influence, based on the soil lithology and heterogeneities identified during drilling.
- Adding additional monitoring wells within and/or around the TTZ, if the TTZ was revised, to adequately monitor oxidant deliver and treatment performance.
- Refining the Performance Monitoring Plan (A26. Elements of a Performance Monitoring Plan) and Operation and Contingency Plan (ISCO Detailed Design and Planning Process 2) based on ISCO design refinements, and also to address monitoring and management of previously unidentified redox sensitive metals.

IM.2.7 IMPLEMENTATION AND PERFORMANCE MONITORING PROCESS 5: Initiate Operation Plan Including Delivery and Treatment Performance Monitoring

Initial ISCO system operations and process monitoring should be conducted in accordance with the Operation and Contingency Plan (ISCO Detailed Design and Planning Process 2) and Performance Monitoring Plan (A26. Elements of a Performance Monitoring Plan). To maximize chances for success and improve efficiency, the Observational Method should be used during ISCO treatment operation.

The ISCO work planning documents provide detailed guidance for performing the first oxidant injection event and specifying performance monitoring requirements needed to verify if the ISCO system meets basis of design and performance specifications. However, the design should also be optimized in real-time by applying the Observational Method throughout the implementation and monitoring programs. The goal of the Observational Method is to integrate performance monitoring results and decision logic real-time, allowing for design modification “as you go”. The Observational Method relies on understanding the uncertainties associated with the CSM, on planning ahead for reasonable bounds of conditions that may occur at the site, and developing specific contingency plans that will be implemented in the event that the actual conditions differ from those assumed. The use of techniques such as direct push technologies and in situ sensors with data loggers have dramatically improved the ability to apply the Observational Method, and the improve outcomes associated with applying it.

As part of the Observational Method, monitoring field indicators during ISCO delivery is important to assess the distribution of oxidant and injection fluid, and oxidant reaction. Tracking field indicators will allow real-time assessment of the ISCO design delivery approach, and identify modifications to the delivery approach if needed (e.g., tighter injection spacing, changes to the injection volume / rate, and changes to the oxidant concentration dosage).

IM.3 DELIVERY PERFORMANCE MONITORING PHASE

The following sections describe the process and decision steps for the delivery performance monitoring phase of the ISCO Implementation and Performance Monitoring Flow Diagram. These process and decision steps are independent of those conducted for the treatment performance monitoring (i.e., contaminant treatment efficiency) phase and are intended to ensure that the oxidant is delivered into the TTZ as designed.

IM.3.1 IMPLEMENTATION AND PERFORMANCE MONITORING DECISION C: Are Delivery Monitoring Results Meeting Performance Criteria?

Oxidant delivery monitoring should be conducted in accordance with the Performance Monitoring Plan (A26. Elements of a Performance Monitoring Plan). Oxidant monitoring results should be evaluated to determine if the specific oxidant delivery objectives (i.e., operational metrics) and milestones established in the ISCO Detailed Design and Planning Process 2 are being met. Each ISCO design will have its own project-specific objectives and milestones. However the fundamental metric on which the delivery performance of a design should be evaluated is the extent and uniformity of oxidant distribution (at concentrations equal to or exceeding the target oxidant concentration) within the TTZ. If the delivery performance objectives are met, then the user proceeds with implementation of the treatment performance monitoring program. If the delivery performance is deficient, then the user proceeds with execution of the delivery optimization components of the Contingency Plan (ISCO Detailed Design and Planning Process 2).

IM.3.2 IMPLEMENTATION AND PERFORMANCE MONITORING PROCESS 6: Execute Delivery Contingency Plan

Contingency response actions for deficient delivery performance were identified, evaluated, and defined as part of ISCO Detailed Design and Planning Process 2. Based on the outcome of the initial phase of ISCO delivery progress monitoring, procedures pre-defined in the Operation and Contingency Plan should be followed to determine if any contingency response actions should be implemented to address deficiencies in delivery performance. The prescribed decision logic should be followed to define the optimization approach to address the delivery deficiencies. Optimization approaches that address delivery deficiencies typically include additional injections, different injection approach (e.g., bottom-up instead of top-down direct injection sequence), and installation of new injection wells.

IM.3.3 IMPLEMENTATION AND PERFORMANCE MONITORING DECISION D: Are Modifications Achieving Delivery Performance Milestones?

The procedures performed for ISCO Implementation and Performance Monitoring Decision C are repeated to assess the delivery performance of the optimized ISCO delivery design and to determine if the objectives and milestones for oxidant delivery are being met. If the optimized ISCO delivery design is meeting delivery performance criteria, then the treatment performance monitoring program should commence (ISCO Implementation and Performance Monitoring Process 7). If delivery performance criteria are not being met, then the project team should stop and re-evaluate the selected ISCO delivery approach to determine what failure modes (i.e., field conditions, delivery techniques, oxidant dosage, etc.) are limiting delivery effectiveness, or if ISCO is not appropriate for the site.

IM.4 TREATMENT PERFORMANCE MONITORING PHASE

The following sections describe the process and decision steps for the treatment performance monitoring phase of the ISCO Implementation and Performance Monitoring Flow Diagram. These process and decision steps are the final phase of the ISCO Implementation and Performance Monitoring component.

IM.4.1 IMPLEMENTATION AND PERFORMANCE MONITORING PROCESS 7: Implement Treatment Performance Monitoring Program

ISCO system treatment performance monitoring should be conducted in accordance with the Performance Monitoring Plan (A26. Elements of a Performance Monitoring Plan). Any modifications made to the performance monitoring program during execution of the Operation and Contingency Plan during ISCO Implementation and Performance Monitoring Process 6 should also be carried out during this process.

IM.4.2 IMPLEMENTATION AND PERFORMANCE MONITORING DECISION E: Are Treatment Monitoring Results Meeting Performance Criteria?

Treatment performance monitoring results should be evaluated to determine if the specific treatment milestones established in the Operation and Contingency Plan or modified during execution of the Operation and Contingency Plan during ISCO Implementation and Performance Monitoring Process 6 are being met. As discussed in the ISCO Detailed Design and Planning Process 2, each ISCO design will have its own project-specific treatment milestones, respectively. However the fundamental metrics on which the treatment performance of a design should be evaluated are: (1) the extent of contaminant of concern treatment within the TTZ; (2) the degree of source removal or source mass flux reduction, and (3) progress towards achieving ISCO treatment goals. If the ISCO treatment approach is meeting treatment performance criteria and making remediation progress, then the treatment continues and the user progresses to ISCO Implementation and Performance Monitoring Decision G. If treatment performance criteria and milestones are not being met as expected, then the user proceeds with execution of the treatment optimization components of the Contingency Plan.

IM.4.3 IMPLEMENTATION AND PERFORMANCE MONITORING PROCESS 8: Execute Treatment Contingency Plan

Contingency response actions for treatment delivery performance were identified, evaluated, and defined as part of ISCO Detailed Design and Planning Process 2. Based on the outcome of the initial phase of ISCO treatment progress monitoring, procedures pre-defined in the Operation and Contingency Plan should be followed to determine if any contingency response actions should be implemented to address deficiencies in treatment performance. The prescribed decision logic should be followed to define the optimization approach to address the treatment deficiencies. Optimization approached that address treatment deficiencies may include additional injections, modification of the activation approach, installation of new injection wells, refinement of the TTZ to be targeted for follow-on injections, and an extended ISCO treatment period.

IM.4.4 IMPLEMENTATION AND PERFORMANCE MONITORING DECISION F: Are Modifications Achieving Treatment Performance Milestones?

The procedures performed for ISCO Implementation and Performance Monitoring Decision E are repeated to assess the treatment performance of the optimized ISCO treatment design and to determine if the milestones for treatment are being met. If the optimized ISCO treatment design is meeting treatment performance criteria, then treatment performance monitoring should continue. If treatment performance criteria are not being met, then the ISCO treatment approach should be re-evaluated to determine what failure modes (i.e., field conditions, delivery techniques, oxidant dosage, etc.) are limiting treatment effectiveness, or if ISCO is not appropriate for the site.

IM.4.5 IMPLEMENTATION AND PERFORMANCE MONITORING DECISION G: Have Treatment Goals Been Achieved?

After most treatment milestones have been achieved, treatment performance monitoring data should be reviewed by all project stakeholders to determine if ISCO treatment goals have been achieved. As with most of the processes and decisions made during the ISCO Implementation and Performance Monitoring Process, determining if treatment goals have been achieved will need to be based on comparison to the pre-established criteria (ISCO Detailed Design and Planning Process 1) and stakeholder consensus. Potential questions to answer (or revisit if already posed earlier during design planning and implementation) include:

- Are monitoring data sufficient to demonstrate successful implementation of the ISCO remedy and satisfy the ISCO treatment cessation milestone?
- Have source concentrations of contaminants of concern been reduced?
- Is there sufficient data to demonstrate a reduction of mass flux from the treatment area?
- Does the rebound assessment conducted during or after treatment performance monitoring indicate the presence of residual source mass or non-aqueous phase liquid?
- Are planned coupled treatment technologies still appropriate to implement given the ISCO monitoring results?
- If coupled treatment technologies were not considered earlier, should they be reconsidered given the ISCO monitoring data and remediation objectives?

If, after careful analysis and scrutiny of the data and comparison to the treatment goals, the project team consensus is that goals have been achieved, then the ISCO treatment is complete. If not, then treatment continues and the user is directed back to ISCO Implementation and Performance Monitoring Process 7.

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Acronyms and Abbreviations

ARAR	-	applicable or relevant and appropriate requirements
CDISCO	-	Conceptual Design for In Situ Chemical Oxidation spreadsheet design tool
CERCLA	-	Comprehensive Environmental Responsibility, Compensation and Liability Act
CFR	-	Code of Federal Regulations
CHP	-	catalyzed hydrogen peroxide; catalyzed hydrogen peroxide propagations
COC	-	contaminants of concern
CSM	-	conceptual site model
DISCO	-	database for ISCO developed under ESTCP Project ER-0623
DNAPL	-	dense nonaqueous phase liquid
DoD	-	Department of Defense
DPT	-	direct push technology
ER-0623	-	project number for this ESTCP project to develop an ISCO TPM
ERI	-	electrical resistivity imaging
ESTCP	-	Environmental Security Technology Certification Program
FAQ	-	frequently asked questions
FS	-	feasibility study
H_2O_2	-	hydrogen peroxide
HAZWOPER	-	Hazardous Waste Operations and Emergency Response Standard
ISCO	-	in situ chemical oxidation
ITRC	-	Interstate Technology & Regulatory Council
$KMnO_4$	-	potassium permanganate
K_{sat}	-	saturated hydraulic conductivity
MCL	-	maximum contaminant level
MIP	-	membrane interface probe
MNA	-	monitored natural attenuation
MnO_4^-	-	permanganate
MnO_2	-	manganese dioxide
$Na_2S_2O_8$	-	sodium persulfate
NAPL	-	nonaqueous phase liquid
NOD	-	natural oxidant demand
O_3	-	ozone
O&M	-	operation and maintenance
ORP	-	oxidation-reduction potential
OSHA	-	Occupational Safety and Health Administration
ppb	-	parts per billion
PPE	-	personal protective equipment
PV	-	pore volume
QA	-	quality assurance
QAPP	-	Quality Assurance Project Plan
QC	-	quality control
RCRA	-	Resource Conservation and Recovery Act
RI	-	remedial investigation
RIP	-	remedy in place
ROI	-	radius of influence
RPM	-	remedial project manager
SERDP	-	Strategic Environmental Research and Development Program
S_2O_8	-	persulfate
TCE	-	trichloroethene or trichloroethylene
TPM	-	technology practices manual
TTZ	-	target treatment zone
USEPA	-	U.S. Environmental Protection Agency
VE	-	value engineering

Overall ISCO Protocol Flow Diagram