Soil Treatability Study

Energy Technology Engineering Center • U.S. Department of Energy

Consideration of Possible Soil Remediation Decisions at ETEC

September 17, 2012, Sandia National Laboratories

Purpose

The purpose of this memorandum is to discuss a structured approach to possible soil remediation decisions at ETEC. This analysis is being performed to apply due diligence to the identification of uncertainties that may affect the decision-making process for soil remediation at ETEC. A number of uncertainties have been identified through other techniques (see *Identification of Uncertainties Regarding Selection of Soil Remediation Technologies at ETEC, July 19, 2012, Sandia National Laboratories*). In this analysis, those uncertainties are mapped into a high-level, generic decision tree. Following this approach allows for an examination of the importance of those uncertainties in the decision-making process and highlights, to the decision-maker, any other uncertainties that have not yet been identified. Ultimately, a list of potential studies to address the identified uncertainties (compiled and documented in the memorandum *Identification of Uncertainties Regarding Selection of Soil Remediation Technologies at ETEC Revision 1, September 17, 2012, Sandia National Laboratories*) can be prioritized based on the impact each uncertainty has on the decision-making process.

Background

Appendix A provides a summary of the process Sandia National Laboratories (hereafter referred to as Sandia) has undertaken to identify possible studies that the DOE might consider as part of the Soil Treatability Study. The information in Appendix A has been previously presented to the members of the Soil Treatability Investigations Group (STIG) over the course of several public meetings. The appendix contains: the Soil Treatability Study boundaries and objectives; possible treatment strategies; listings of technologies considered for possible remediation of specific contaminants; listings of uncertainties relating to specific treatment technologies, specific contaminants and individual clearly contaminated areas (CCAs); and listings of possible studies that could be performed to address specific uncertainties.

Structured Thinking Regarding Soil Remediation at ETEC

The structured approach described here considers the key uncertainties that impact the choices to be made regarding remediation of soils at ETEC. These key uncertainties are excavation, ex-situ treatment, and in-situ treatment. As shown in Figure 1, resolution of these uncertainties will allow the decision-maker to choose between alternatives for meeting the requirements of the Administrative Order on Consent for Remedial Action (AOC). Figure 1 shows this approach as it applies to an individual CCA. The structured thinking process can be applied to each individual CCA because it is high-level and generic, and can be utilized to determine which pathways are viable for soil remediation for that CCA.

In Figure 1, a CCA is shown at the top. The three key uncertainties are shown in the green oval and resolution of those uncertainties leads to decisions: excavate the entire CCA, excavate a portion of the CCA with in-situ treatment of the remaining portion of the CCA, or treat the entire CCA in-situ. Decisions are shown in rectangles at the bottom of Figure 1.

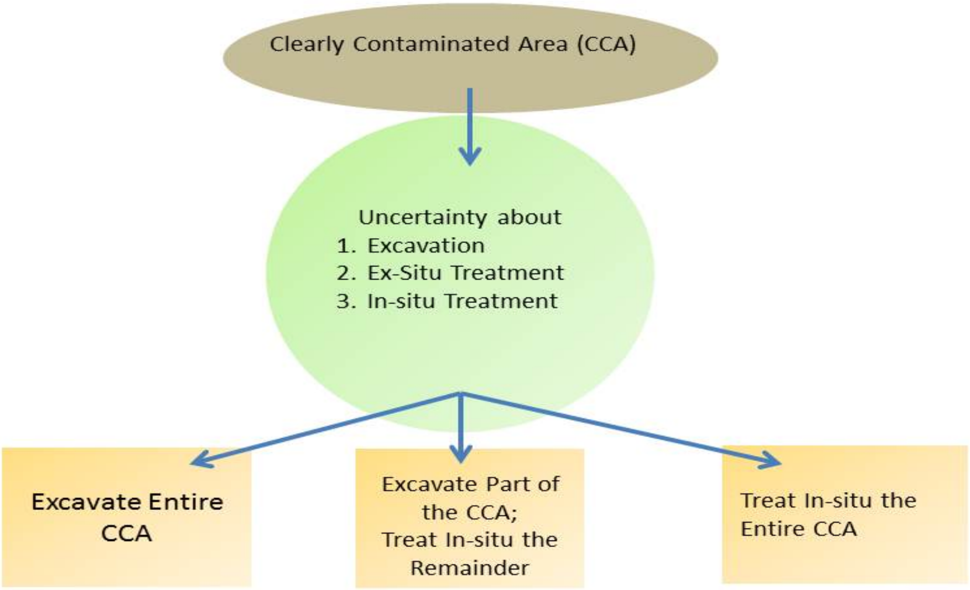

Figure 1. Resolution of Uncertainties Allows the Decision-Maker to Choose Between Alternatives for Meeting the Requirements of the AOC

Though Figure 1 can be likened to a decision tree, it is different in that it is generic and high-level. Additionally, clear pathways to meeting the AOC are not shown and no performance measures are indicated. Pathways for meeting the AOC and performance measures will be explored in the *Soils Remedial Action and Implementation Plan* to be developed by DOE. Examples of performance measures include, but are not limited to cost, duration, or number of truckloads of soil transported away from the ETEC site. Many possible performance measures can be identified; however, attaining the “clean-up” value (that will be set in the look-up tables) is not a performance measure. The assumption is that every branch in the tree leads to the desired outcome of satisfying the AOC. To this end, the two-step treatment strategies (active followed by passive treatment shown in Table A-3 of Appendix A), when the choice is to remediate the soil, are recommended by Sandia.

The uncertainties (green oval) in Figure 1 are accumulated uncertainties associated with the decision to excavate some and/or all of the soil and the ancillary decisions to treat in-situ or ex-situ some and/or all of the soil. It is called an accumulated uncertainty because it represents a group of uncertainties that, when fully resolved, allows the decision-maker to choose a branch. The next sections discuss each of these accumulated uncertainties.

Excavation Uncertainty for a CCA

The excavation uncertainty for a CCA is shown in Figure 2. Resolution of this uncertainty allows the decision-maker to determine whether to:

1. Excavate all soil from the CCA,
2. Excavate some of the soil from the CCA and treat the remainder of the CCA soils in-situ, or
3. Treat the entire CCA with in-situ technologies.

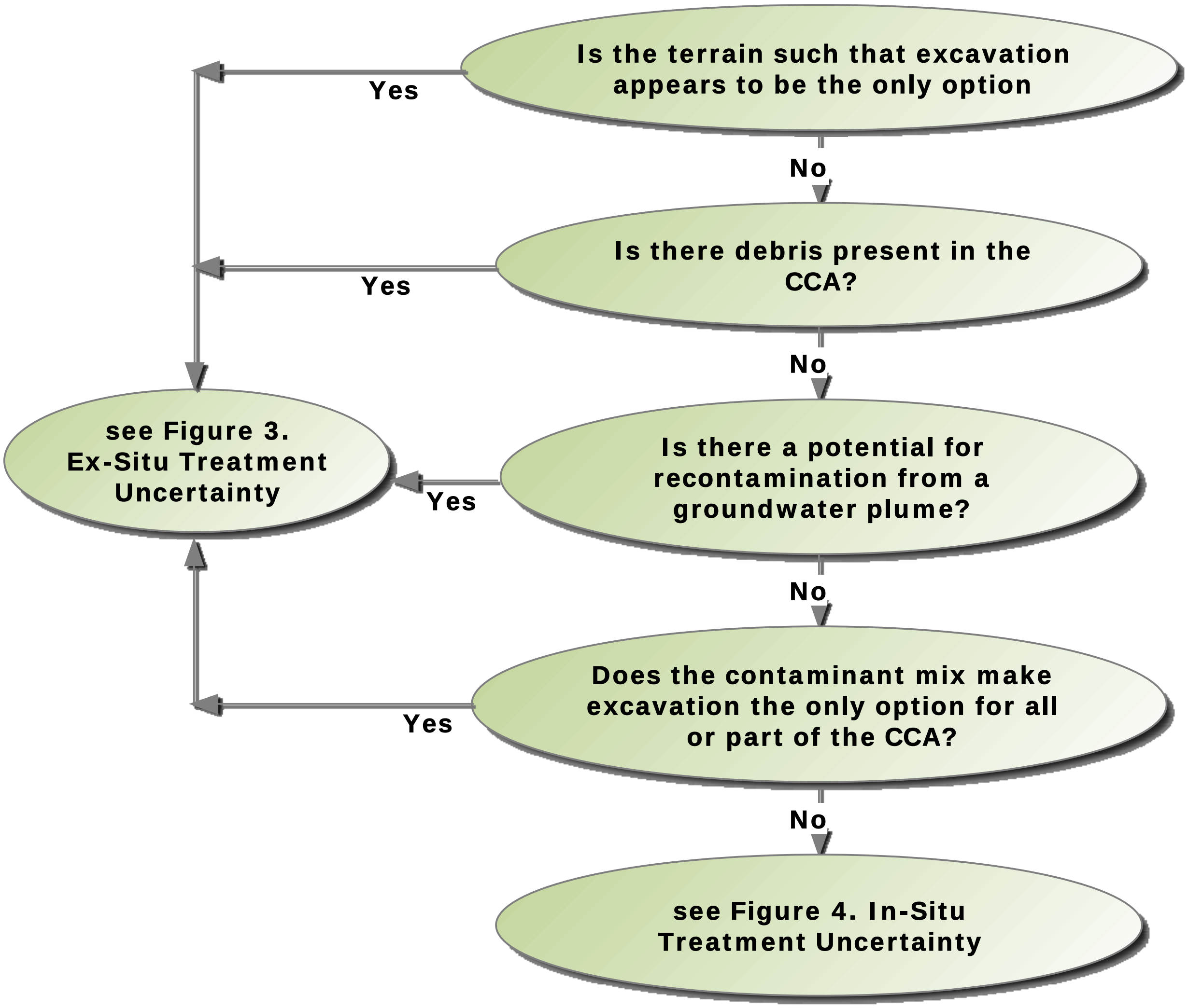

Figure 2. Excavation Uncertainty for a Clearly Contaminated Area

The following questions are asked as part of this decision making process:

1. Is the terrain such that excavation appears to be the only option?
2. Is there debris present in the CCA?
3. Is there a potential for recontamination from a groundwater plume?
4. Does the contaminant mix make excavation the only option for all of part of the CCA?

A “yes” answer to one of the first three questions indicates that the entire CCA will require excavation. In the first case, the terrain severely limits any possibility of in-situ treatment. In the second case, the presence of debris indicates that in order to clear out the debris, the entire CCA must be excavated. In the third case, if recontamination from a below ground source is possible, Sandia has suggested that the entire CCA be excavated and a barrier to recontamination be installed prior to returning the clean soil to the CCA. A “yes” answer to the fourth question does not necessarily mean the entire CCA must be excavated although it could mean that. It could also mean that a part of the CCA, what one might call a “hot spot”, would require excavation while the remainder of the CCA could be remediated utilizing in-situ strategies.

Once excavated the question then becomes whether the excavated soil is treated on-site to clean it up to the requirements of the AOC or whether the excavated soil should be transported to an off-site disposal facility. The uncertainty about that decision is embodied generally in the ex-situ treatment uncertainty shown on the left hand side of Figure 2, and in detail in Figure 3.

Ex-Situ Treatment Uncertainty for a CCA

The ex-situ treatment uncertainty for a CCA is shown in Figure 3. Resolution of this uncertainty allows the decision-maker to determine whether to:

1. Transport and dispose of the soil off-site,
2. Employ an on-site soil washing facility to clean the soil so that it meets the look-up table values, or
3. Employ an on-site thermal treatment facility to clean the soil so that it meets the look-up table values.

The following questions are asked as part of this decision making process:

1. Is the soil volume large enough to justify ex-situ treatment rather than hauling off-site?
2. Can significant soil volume reduction be accomplished by ex-situ treatment?
3. Is the contaminant mix so complicated that ex-situ treatment requires several treatment trains?
4. Were there items/issues encountered during excavation that make off-site disposal the only option?

A “no” answer to the first two questions and a “yes” answer to the latter two questions indicate that the excavated soil should be transported off-site for disposal. A “yes” answer to the first two questions and a “no” answer to the latter two questions indicate that the decision-maker could consider ex-situ treatment. Deciding between soil-washing versus thermal treatment is facilitated by asking:

1. Does the excavated soil contain radionuclides and/or metals other than mercury?

Because these contaminants cannot be destroyed through a thermal process, a “yes” answer to this question implies that soil washing is the only option for ex-situ treatment of this soil. Finally by asking if building a thermal treatment system makes sense, the decision-maker can choose between the two ex-situ treatment possibilities.

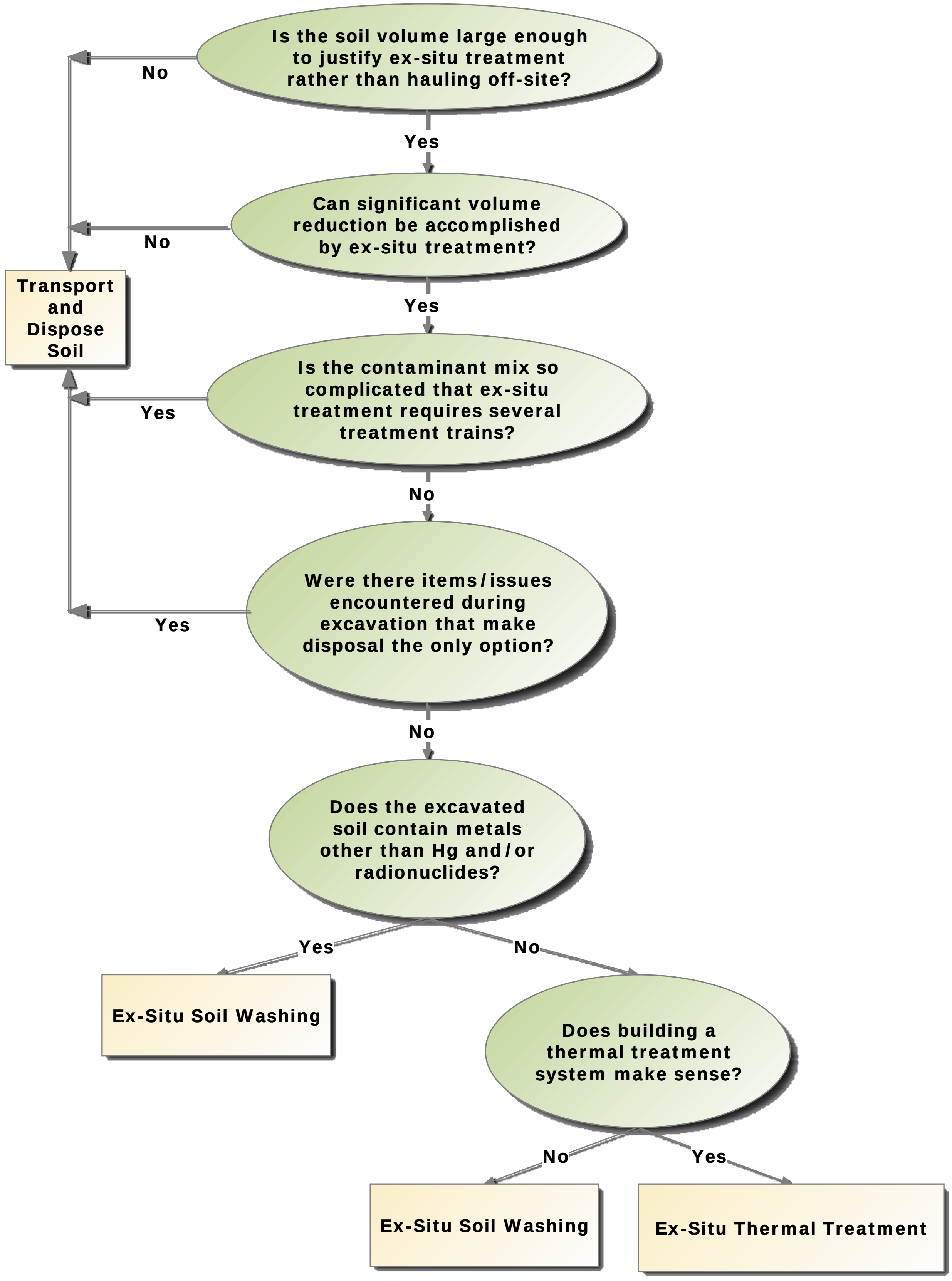

Figure 3. Ex-Situ Treatment Uncertainty

In-Situ Treatment Uncertainty for a CCA

The in-situ treatment uncertainty for a CCA is shown in Figure 4. Resolution of this uncertainty allows the decision-maker to determine whether to:

1. Use an in-situ thermal treatment technology,
2. Use a phytoremediation treatment technology,
3. Use bioremediation with either native or non-native biota, or
4. Use an in-situ nanotechnology.

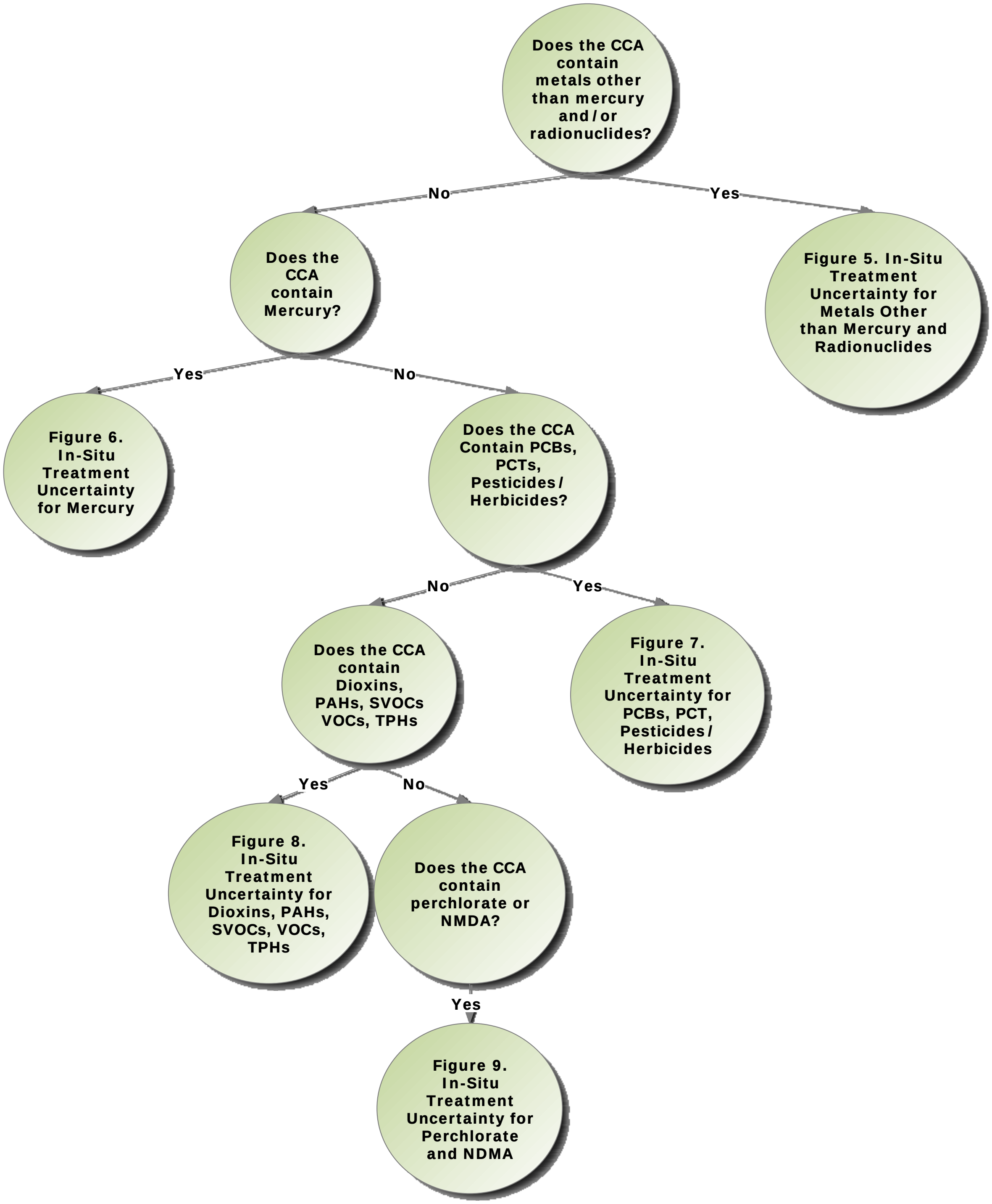

Figure 4. In-Situ Treatment Uncertainty

The choice of which in-situ treatment option to use is primarily based on the contaminants within the CCA. Some of the primary questions that will lead the decision-maker to choose the appropriate in-situ treatment technology for the noted contaminant groups include the following:

1. Does the CCA contain radionuclides and/or metals other than mercury?
2. Does the CCA contain mercury?
3. Does the CCA contain polychlorinated biphenyls (PCBs), poly-chlorinated triphenyls (PCTs), Pesticides/Herbicides?
4. Does the CCA contain dioxins, poly-aromatic hydrocarbons (PAHs), semi-volatile organic compounds (SVOCs), volatile organic compounds (VOCs), total petroleum hydrocarbons (TPHs)?
5. Does the CCA contain perchlorate or n-nitrosodimethylamine (NDMA)?

These groupings are based largely on the applicable treatment technologies from Table A-3 in Appendix A. A secondary consideration for the groupings is that they share contaminant specific uncertainties as shown in Table A-6 in Appendix A.

For CCAs that contain radionuclides and metals other than mercury, one is directed to the uncertainty delineated in Figure 5 of this memorandum. For CCAs that contain mercury, one is directed to the uncertainty delineated in Figure 6 of this document. For CCAs containing PCBs, PCTs, Pesticides/Herbicides, one is directed to the uncertainty delineated in Figure 7. For CCAs that contain Dioxins, PAHs, SVOCs, VOCs, TPHs, one is directed to the uncertainty delineated in Figure 8, and the in-situ treatment uncertainty associated with soils containing perchlorate and NDMA is shown in Figure 9.

In-Situ Treatment Uncertainty for Metals Other than Mercury and Radionuclides

Figure 5 presents the uncertainties associated with remediating soils contaminated with radionuclides and/or metals other than mercury. For these contaminants, the primary questions that need to be answered to determine the appropriate in-situ treatment method include the following:

1. Is the chemical form of the radionuclides and/or metals such that transport in water is possible?
2. Have any plants growing at the ETEC site shown a propensity to hyperaccumulate these contaminants when analyzed?
3. Do laboratory and/or field studies indicate that these plants can clean soil to look-up table values?
4. Are any plants growing at the ETEC site related to plants that have been shown in the literature to hyperaccumulate radionuclides and/or metals (other than mercury)?
5. Do laboratory and/or field studies indicate that these plants can clean soil to look-up table values?

If the answer is “no” to question 1, then phytoremediation is not considered viable for this CCA and these constituents, and if the answer is “yes”, then the decision-maker will go to question 2. A “yes” answer to question 2 leads the decision-maker to question 3 and a “no” answer leads the decision-maker to question 4. A “yes” answer to question 4 leads the decision-maker to question 5 and a ““no”” answer indicates that phytoremediation is not a viable remediation alternative for this CCA. A “yes” answer to question 5 leads to the decision that phytoremediation is a viable remediation alternative and a “no” answer leads to the decision that phytoremediation is not a viable remediation alternative for this CCA and its contaminants.

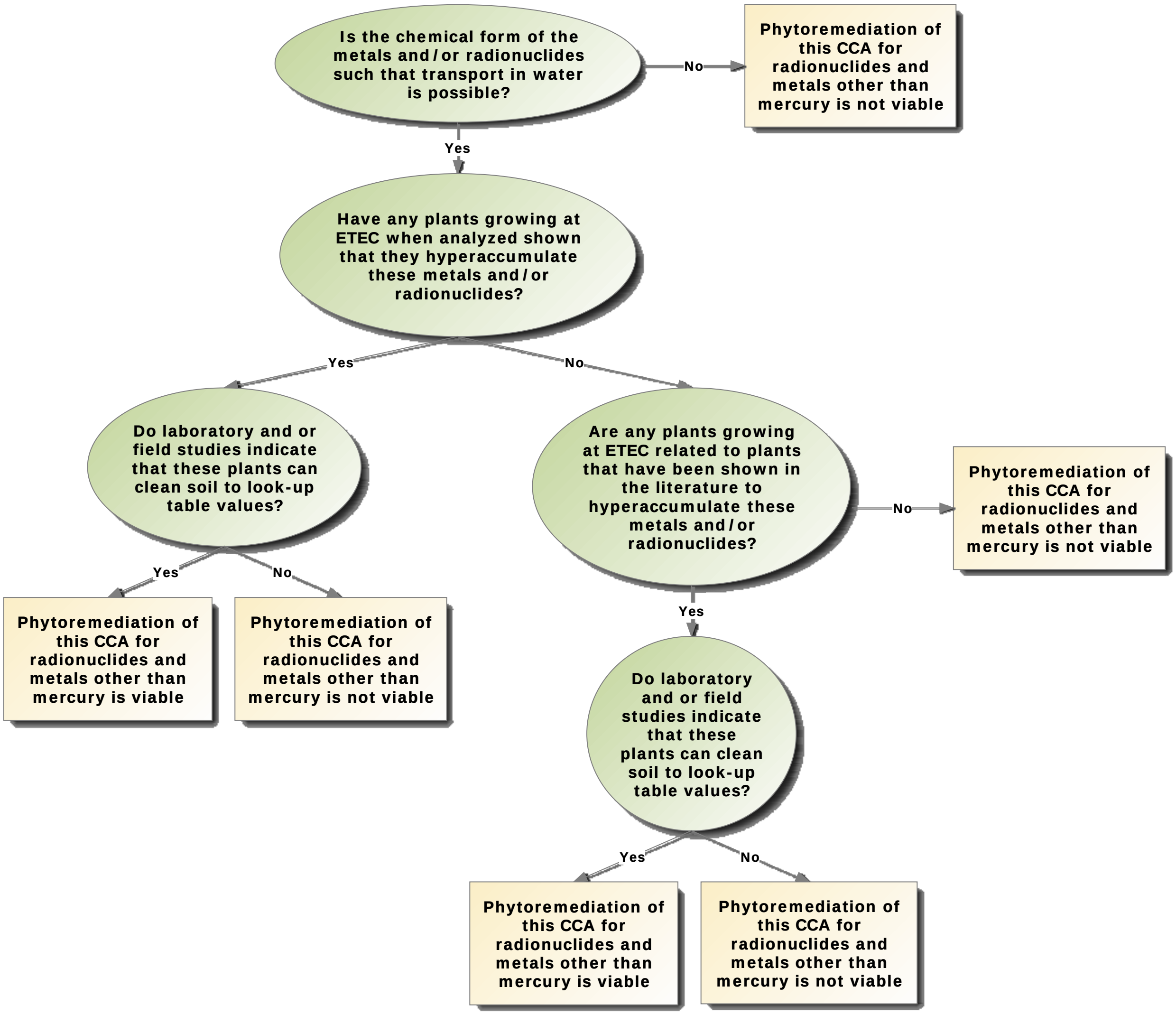

Figure 5. In-Situ Treatment Uncertainty for Radionuclides and/or Metals Other than Mercury

In-Situ Treatment Uncertainty for Mercury

Mercury remediation and clean up present a challenge due to the chemical nature of the contaminant and the extent of the contaminant on site, and are therefore assessed separately from the other metals. Figure 6 presents the uncertainties associated with remediating soils contaminated with mercury. Some of the primary questions that will lead the decision-maker to choose the appropriate in-situ treatment technology for the noted contaminant groups include the following:

1. Is the mercury in its elemental form?
2. Can an in-situ thermal system be designed to heat the soil to temperatures required to release mercury?
3. Can an overhead collection system be designed to capture the mercury released?
4. Do laboratory and/or field studies indicate that heating the soil can clean soil to look-up table values without vitrifying the soil?
5. Can in-situ thermal treatment for mercury lower the concentration enough to make phytoremediation possible?

6. Can mercury ions be converted to elemental mercury by bacteria or nanoparticles?
7. Is the chemical form of the mercury such that transport in water is possible? Or can the chemical form be altered by application of bacteria or nanoparticles so that it is transportable in water?
8. Have any plants growing at ETEC when analyzed shown a propensity to hyperaccumulate mercury?
9. Do laboratory and/or field studies indicate that these plants can clean soil to look-up table values?
10. Are any plants growing at ETEC related to plants that have been shown in the literature to hyperaccumulate mercury?

The answer to question 1, “Is the mercury in its elemental form”, leads the decision-maker to a thermal treatment route on the left-hand side of the figure, or further assessment of the potential for transforming the existing chemical form of mercury, utilizing bacteria or nanoparticles, to the elemental form for potential treatment using thermal (on the left-hand side of the figure) or phytoremediation (on the right-hand side of the figure).

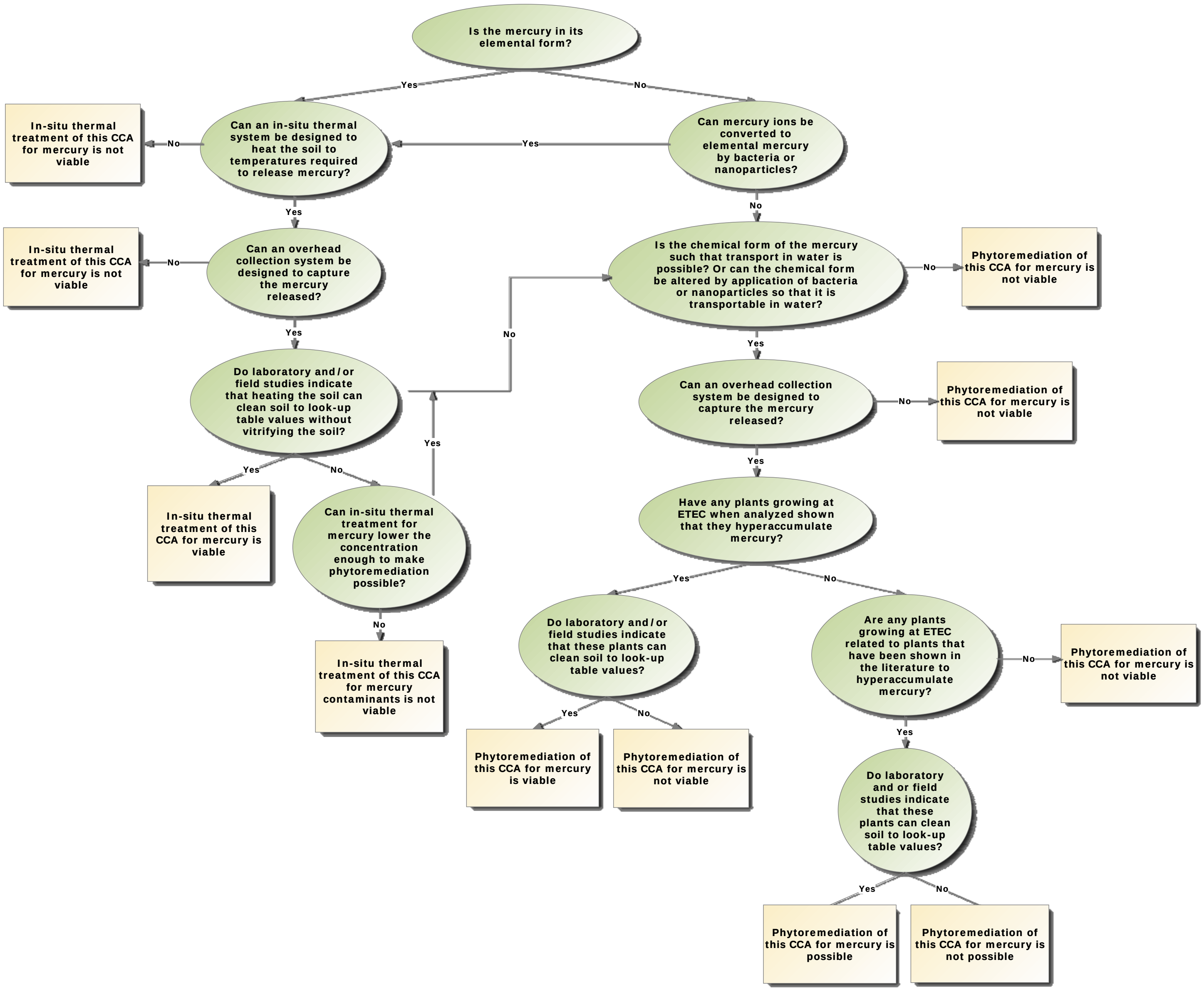

Figure 6. In-Situ Treatment Uncertainty for Mercury

In-Situ Treatment Uncertainty for PCBs, PCTs, Pesticides, Herbicides

Based on their chemical form and the applicability of remediation alternatives, the uncertainty associated with in-situ treatment of PCBs, PCTs, and pesticides/herbicides is presented in Figure 7. Some of the primary questions that will lead the decision-maker to choose the appropriate in-situ treatment technology for the noted contaminant groups include the following:

1. Can an in-situ thermal system be designed to heat the soil as necessary?
2. Can an in-situ thermal treatment system be designed to capture the released contaminants?
3. Do laboratory and/or field studies indicate that heating the soil can clean the soil to look-up table values without vitrifying the soil?
4. Can in-situ thermal treatment for these contaminants lower the concentrations enough to make phytoremediation possible?
5. Can an in-situ treatment system to dechlorinate these contaminants (with bacteria or nanoparticles) be designed?
6. Do laboratory and/or field studies indicate that dechlorination can clean soil to look-up table values?
7. Can in-situ dechlorination of these contaminants lower the concentration enough to make phytoremediation possible?
8. Have any plants growing at ETEC when analyzed shown that they hyperaccumulate these contaminants or their dechlorinated by-products?
9. Do laboratory and/or field studies indicate that these plants can clean soil to look-up table values?
10. Are any plants growing at ETEC related to plants that have been shown in the literature to hyperaccumulate or phytotranspire these contaminants or their dechlorinated by products?
11. Do laboratory and/or field studies indicate that these plants can clean soil to look-up table values?

The answers to these primary questions lead the decision-maker to determine if in-situ treatment of these constituents via thermal, bacterial, and phytoremediation are viable or not viable alternatives for remediation to established look-up table values. The decision-maker will determine whether to either utilize a thermal treatment system that includes a capture system (on the left-hand side of the figure) or to degrade and/or treat of the contaminants with bacteria or phytoremediation (on the right-hand side of the figure).

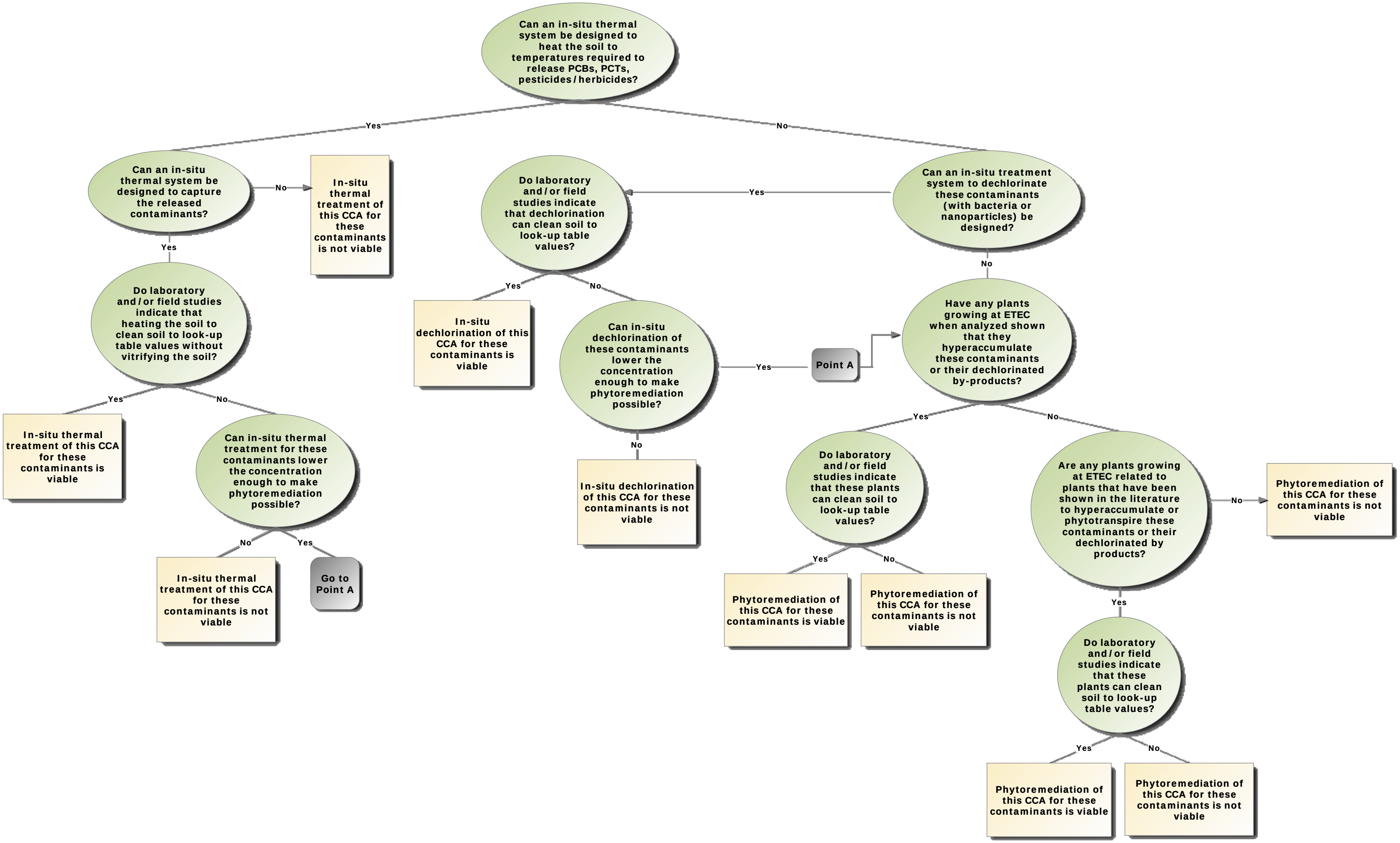

Figure 7. In-Situ Treatment Uncertainty for PCBs, PCTs, Pesticides, Herbicides

In-Situ Treatment Uncertainty for Dioxins, PAHs, SVOCs, VOCs and TPHs

Based on their chemical make-up and the applicability of remediation alternatives, the uncertainty associated with in-situ treatment of dioxins, SVOCs, VOCs, and TPHs is presented in Figure 8. Some of the primary questions that will lead the decision-maker to choose the appropriate in-situ treatment technology for the noted contaminant groups include the following:

1. Is the rate of natural attenuation (with or without added biota) for these contaminants fast enough to degrade them to look-up table values in five years?
2. Is the rate of natural attenuation rate (with or without biota) for these contaminants fast enough to lower their concentrations so phytoremediation in 5 years is possible? Or are concentrations already low enough for phytoremediation?
3. Can an in-situ thermal system be designed to heat the soil to temperatures required to release dioxins, PAHs, SVOCs, VOCs and TPHs?
4. Do laboratory and/or field studies indicate that heating the soil can clean soil to look-up table values without vitrifying the soil?
5. Can an in-situ treatment system to dechlorinate these contaminants (with bacteria or nanoparticles) be designed?
6. Do laboratory and/or field studies indicate that dechlorination can clean soil to look-up table values?
7. Can in-situ dechlorination of these contaminants lower the concentration enough to make phytoremediation possible?
8. Can in-situ thermal treatment for these contaminants lower the concentration enough to make phytoremediation possible?
9. Have any plants growing at ETEC when analyzed shown that they hyperaccumulate these contaminants or their dechlorinated by-products?
10. Do laboratory and/or field studies indicate that these plants can clean soil to look-up table values?
11. Are any plants growing at ETEC related to plants that have been shown in the literature to hyperaccumulate or phytotranspire these contaminants or their dechlorinated by products?

In general, the answers to the above questions lead the decision-maker to determine if natural attenuation is or is not occurring, and if the remediation alternatives including thermal, bacterial or nanoparticles, or phytoremediation are going to be viable or not viable.

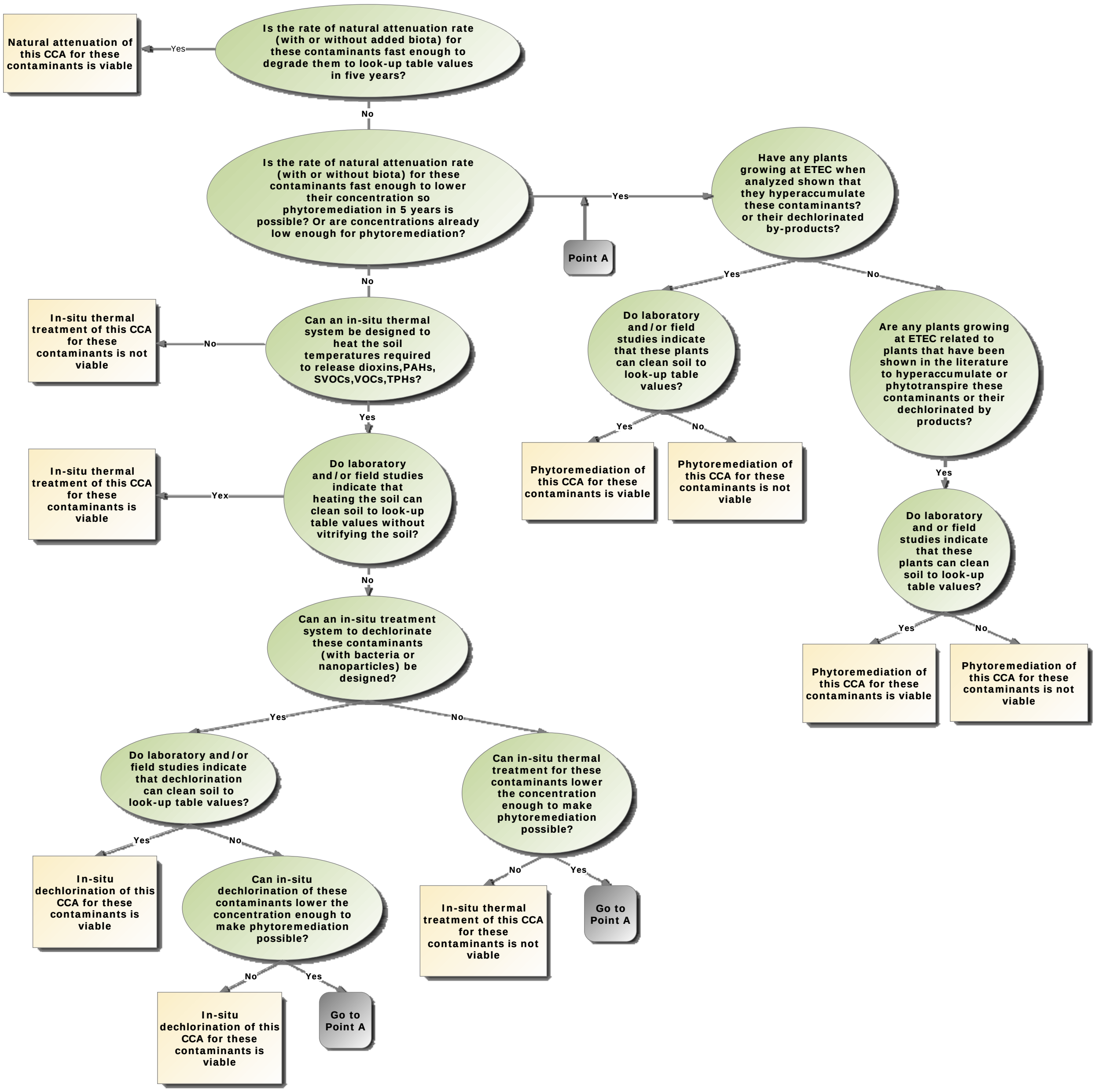

Figure 8. In-Situ Treatment Uncertainty for Dioxins, PAHs, SVOCs, VOCs and TPHs

In-Situ Treatment Uncertainty for Perchlorate and NDMA

Based on their chemical form and the applicability of remediation alternatives, the uncertainty associated with in-situ treatment of perchlorate and N-nitrosodimethylamine (NDMA) is presented in Figure 9. Some of the primary questions that will lead the decision-maker to choose the appropriate in-situ treatment technology for the noted contaminant groups include the following:

1. Is the rate of natural attenuation (with or without added biota) for these contaminants fast enough to degrade them to look-up table values in five years?
2. Is the rate of natural attenuation rate (with or without biota) for these contaminants fast enough to lower their concentrations so phytoremediation in 5 years is possible? Or are concentrations already low enough for phytoremediation?
3. Can an in-situ thermal system be designed to heat the soil to the temperatures required to release perchlorates and/or NDMA?
4. Do laboratory and/or field studies indicate that heating the soil can clean soil to look-up table values without vitrifying the soil?
5. Can an in-situ treatment system to degrade these contaminants (with bacteria or nanoparticles) be designed?
6. Do laboratory and/or field studies indicate that degradation can clean soil to look-up table values?
7. Can in-situ degradation of these contaminants lower the concentration enough to make phytoremediation possible?
8. Can in-situ thermal treatment for these contaminants lower the concentration enough to make phytoremediation possible?
9. Have any plants growing at ETEC when analyzed shown that they hyperaccumulate or phytotranspire these contaminants or their dechlorinated by-products?
10. Do laboratory and/or field studies indicate that these plants can clean soil to look-up table values?
11. Are any plants growing at ETEC related to plants that have been shown in the literature to hyperaccumulate or phytotranspire these contaminants or their dechlorinated by products?
12. Do laboratory and/or field studies indicate that these plants can clean soil to look-up table values?

In general, the answers to the above questions lead the decision-maker to determine if natural attenuation is or is not occurring, and if the remediation alternatives including thermal, bacterial or nanoparticles, or phytoremediation are going to be viable or not viable.

Next Steps – final steps

The next step is the recommendations memorandum. It will be developed after this structured thinking process is vetted with DOE.

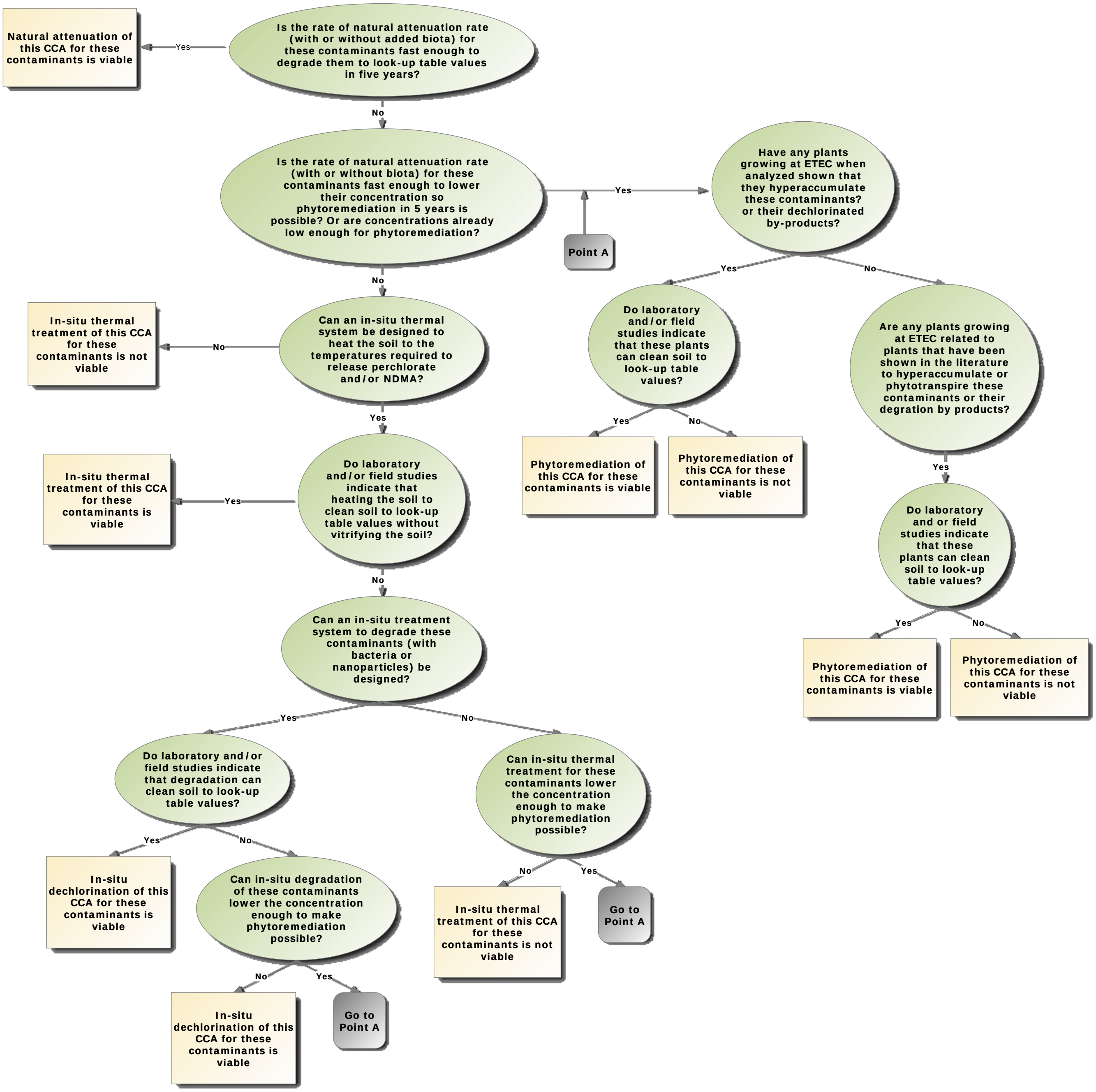

Figure 9. In-Situ Treatment Uncertainty for Perchlorate and NDMA

Appendix A: Background

Previously, the Soil Treatability Investigations Group (STIG) was presented with a series of tables that reflect the study boundaries (Table A-1) and objectives (Table A-2), the technologies that are being considered for possible remediation of ETEC soils (Table A-3), and the remediation strategies and applicable contaminant groups as shown in Table A-4 (see *Soils Remediation Technology Screening Update, July 10, 2012, Sandia National Laboratories*). The study boundaries have been crafted for general consistency with the requirements of the Administrative Order of Consent for Remedial Action (AOC, 2010). The study objectives reflect input received from the STIG as well as reflecting general consistency with the requirements of the AOC. The treatment technologies that are being considered for possible remediation of ETEC soils embody the recommendations from Sandia National Laboratories (Sandia) regarding what treatment technologies should be considered.

Table A-1. Study Boundaries

	Study Boundary
1	The goal of the chosen soil remediation alternatives will be to meet the established cleanup levels or reduce the contaminant concentrations/volume of soil to be excavated.
2	There will be no "leave in place" or on site burial/landfilling of contaminated soils.
3	Remediation alternatives will be in place by 2017.
4	Incineration (burning that forms an ash) will not be used as a remediation alternative.
5	Remediation alternatives will not exacerbate existing contamination issues or create new contamination problems.
6	Treatability studies being conducted for groundwater and unweathered bedrock are ongoing and will not be duplicated.
7	Plants that are not native or not naturalized to SSFL will not be considered as part of phytoremediation technologies. (native plants will be considered first as applicable)

Table A-2. Study Objectives

	Study Objectives
1	Dig and haul/excavation will be minimized as much as possible.
2	Remediation alternatives will be designed to consider the wild fires, native vegetation, and natural environment as much as possible.
3	Land and site disturbance will be minimized as much as possible.
4	Green and innovative/cutting edge technologies will be assessed as much as possible.

Table A-3. Treatment Strategies

Active Treatment Technology (Step 1)	In-Situ Thermal (Less than 200°C)	Ex-Situ** Thermal (Greater than 200°C)	In-Situ Bio-remediation	Phyto-remediation	In-Situ Nano	Ex-Situ** Soil Washing
Potential Passive Treatment Technology (Potential Step 2)	Phyto-remediation	Engineered Barrier*	Phyto-remediation	Phyto-remediation	Phyto/Bio-remediation	Engineered Barrier*

*Only in cases where recontamination is possible

**On-site with no off-site haulage

Table A-4. Remediation Strategies and Applicable Contaminant Groups

		Summary of Strategies					
Contaminant Types	**Contaminants**	**In-Situ Heat (0°C-200°C)[1]**	**Ex-Situ Heat (200°C-500°C)**	**Biostimulation/ Bioaugmentation**	**Phytoremediation/ Phytodegradation**	**In-Situ Nanotechnology**	**Ex-Situ Soil Washing[2]**
Dioxins	Dioxins	< 200°C	> 400°C	Dechlorinating Biota	Native or Naturalized Species - To Be Determined	nZVI; BNPs	Solvent Solution
Metals	As	▨	▨	▨		▨	Solvent Solution
	Cd						Solvent Solution
	Cr						Solvent Solution
	Cu						Solvent Solution
	Hg	Dependent on chemical form	> 400°C	Dependent on chemical form	Dependent on chemical form	Dependent on chemical form	Solvent Solution
	Pb	▨	▨	▨	Native or Naturalized Species - To Be Determined		Solvent Solution
NDMA	NDMA	< 200°C	> 200°C	Dechlorinating Biota		nZVI; BNPs	Solvent Solution
PAHs	PAHs	< 200°C	> 300°C	Dechlorinating Biota		nZVI; BNPs	Solvent Solution
PCBs	PCBs	Partial remediation < 200°C	> 300°C	Dechlorinating Biota		nZVI; BNPs	Solvent Solution
PCTs	PCTs	Partial remediation < 200°C	> 400°C	Dechlorinating Biota		nZVI; BNPs	Solvent Solution
Perchlorate	Perchlorate	▨	> 200°C	Dechlorinating Biota		nZVI; BNPs	Solvent Solution
Pesticides/ Herbicides	Pesticides/ Herbicides	< 200°C - Type Dependent	> 200°C - Type dependent	Dechlorinating Biota - Type Dependent		nZVI; BNPs	Type dependent
Rads	Co-60	▨	▨	▨		▨	Solvent Solution
	Cs-137						Solvent Solution
	Sr-90						Solvent Solution
	U-238						Solvent Solution
SVOCs	SVOCs	< 200°C	> 400°C	Dechlorinating Biota		nZVI; BNPs	Solvent Solution
TPHs	TPHs	< 200°C	> 400°C	Dechlorinating Biota		nZVI; Fenton Oxidation	Type dependent
VOCs	PCE	< 200°C	> 200°C	Dechlorinating Biota		nZVI; BNPs	Solvent Solution
	TCE	< 200°C	> 200°C	Dechlorinating Biota		nZVI; BNPs	Solvent Solution

▨ Not Applicable

[1] - Provided temperatures for In-Situ Heat are high to account for efficiency and expediency of the remediation cycle; the strategy could be applied at lower temperatures

[2] - Soil washing applicability is highly dependent on the soil characteristics, which have not been considered for this summary

The STIG was also presented with a table of uncertainties (Table A-5) that are specific to the treatment technologies for soil remediation, which are classified as feasibility, applicability, or optimum operation uncertainties. Similarly, a table of contaminant specific uncertainties (Table A-6), in the categories of chemical form, physical form, and natural attenuation potential, was presented to the STIG. Finally, uncertainties related to individual Clearly Contaminated Areas (CCAs) were identified and are shown in Table A-7. These three tables have been revised based on input received from the STIG at the July 19, 2012 meeting and are included in the Appendix in their revised form. Documentation of the revisions is given in *Identification of Uncertainties Regarding Selection of Soil Remediation Technologies at ETEC Revision 1, September XX, 2012, Sandia National Laboratories.*

Table A-5. Technology Specific Uncertainties

Technology	Feasibility	Applicability	Optimum Operation
Phytoremediation	Are plants on-site taking up contaminants?	Will the plant grow in this particular soil?	What are the ideal growing conditions for the plant?
	Will the plant remove the contaminant(s)? If “yes”, how much?	Will the plant grow with a particular contaminant mix?	
		Where does the contaminant reside in the plant?	
In-Situ Thermal	How hot does it have to get for PCBs, pesticides, herbicides, and dioxins to volatilize?	What is the thermal conductivity and heat capacity of the soil?	Should we use a thermal blanket or heat probes?
		How long will it take to cool the soil?	How close should we place the heat probes?
In-Situ Nanotechnology	Will the nanotechnology degrade the contaminant(s) and what are the by-products of the degradation process?	Can the nanoparticles be distributed effectively in the soil?	
		Does soil chemistry limit applicability?	
In-Situ Bioremediation (native)	What biota already exist at the site?		What can enhance the biota's ability to degrade the contaminant(s)?
	Will the biota degrade the contaminant(s) and what are the by-products of the degradation process?		
In-Situ Bioremediation (Non-native)	Will the biota degrade the contaminant? What are the by-products of the degradation process?	Can non-native biota thrive at the site?	What can enhance the biota's ability to degrade the contaminant(s)?
Ex-Situ Thermal		What is the end state of the heated soil?	What is the optimum temperature for treatment?
		What do we have to add to the treated soil before replacing it?	What is the best method for applying the heat?
Ex-Situ Soil Washing		To what extent will clays in the soil limit applicability?	What solvent should be used to treat this contaminant mix?
		To what extent will fines in the soils limit applicability?	What is the best mixing method?
Engineered Barrier	Will an impermeable engineered barrier emplaced horizontally prevent recontamination from seasonal water fluctuations?		What sort of barrier will work best for the contaminants of concern?

Table A-6. Contaminant Specific Uncertainties

Contaminant	Chemical Form	Physical Form	Natural Attenuation Potential
Mercury	What is the current chemical form of mercury at ETEC?	Is this contaminant partitioned to the fines?	
Dioxins		Is this contaminant partitioned to the fines?	What is the rate of natural attenuation for dioxins?
PCBs		Is this contaminant partitioned to the fines?	
PAHs		Is this contaminant partitioned to the fines?	What is the rate of natural attenuation for PAHs?
Perchlorate	What is the speciation of perchlorate at ETEC?	Is this contaminant partitioned to the fines?	What is the rate of natural attenuation for perchlorate?
Metals	What is the speciation of the metals at ETEC site?	Is this contaminant partitioned to the fines?	
Radionuclides	What is the speciation of the radionuclides at ETEC site?	Is this contaminant partitioned to the fines?	
NDMA	What is the speciation of NDMA at ETEC?	Is this contaminant partitioned to the fines?	
PCTs		Is this contaminant partitioned to the fines?	
Pesticides/Herbicides		Is this contaminant partitioned to the fines?	
SVOCs		Is this contaminant partitioned to the fines?	What is the rate of natural attenuation for SVOCs?
SVOCs		What is the fraction of SVOCs that exist in the soil vapor versus SVOCs sorbed to the soil particles?	
VOCs		What is the fraction of VOCs that exist in the soil vapor versus VOCs sorbed to the soil particles?	What is the rate of natural attenuation for VOCs?
TPHs		Is this contaminant partitioned to the fines?	What is the rate of natural attenuation for TPHs?
TPHs		What is the fraction of TPHs that exist in the soil vapor versus TPHs sorbed to the soil particles?	

Table A-7. Clearly Contaminated Areas (CCA) Specific Uncertainties

Uncertainty Name	Nature of Uncertainty
Recontamination	Does this CCA have a potential recontamination issue from either the tritium, TCE, or perchlorate plume at ETEC?
Drainage	Does this CCA have a potential recontamination issue due to drainage from other CCAs?
Terrain	Is this CCA on rocky steep terrain and/or does the terrain preclude in-situ treatment technologies?
Debris	Is there debris in the CCA
Soil Volume	What is the volume of the CCA and what is the anticipated excavated volume?
Co-contaminant	What is the mix of contaminants?
Hot Spot	Does the CCA have "hot spots"?
Surprise Items/Issues	Will excavation reveal surprises?

Tables A-8, A-9, and A-10 present possible studies that could be performed to address the identified uncertainties. Specifically, Table A-8 presents studies that could address technology specific uncertainties. Table A-9 presents studies that could address contaminant specific uncertainties, and Table A-10 presents studies that could address CCA specific uncertainties.

Table A-8. Studies to Address Technology Specific Uncertainties

Technology	Feasibility	Applicability	Optimum Operation
Phytoremediation	Survey of on-site plant materials	Laboratory study of growth in soil types at ETEC	Laboratory study of plant growth enhanced by additives
	Laboratory study of contaminant uptake by on-site plants	Laboratory study of contaminant mix uptake by on-site plants	
		Laboratory study of plant accumulation (necropsies)	
In-Situ Thermal	Laboratory study or literature search of the vaporization point of PCBs, etc.	Survey or laboratory study of thermal conductivity of ETEC Soils	In-Situ thermal treatment using heating probes vs heating blanket of CCAs 10, 15, 24, 25, 31, 32 for PCBs
		Simulation of soil heating/cooling for ETEC soils	In-Situ thermal treatment using heating probes of CCAs 10, 15, 24, 25, 31, 32 for PCBs
In-Situ Nanotechnology	Laboratory study of contaminant degradation by nanoparticles	Field study of in-situ application techniques for nanoparticles at the ETEC Site	
		Survey of geochemistry of ETEC Soils	

Technology	Feasibility	Applicability	Optimum Operation
In-Situ Bioremediation (native)	Survey of naturally occurring biota at the ETEC Site		Laboratory study of biota cultivation enhanced by additives
	Laboratory study of contaminant degradation by native biota		
In-Situ Bioremediation (Non-native)	Laboratory study of contaminant degradation of non-native biota	Laboratory study of non-native biota and soil chemistry	Laboratory study of biota cultivation enhanced by additives
Ex-Situ Thermal		Laboratory study of thermally induced soil remediation with ETEC Soils	Literature search on vaporization temperatures or laboratory study of required temperatures
		Laboratory study of processes to return the soil to normal conditions after thermal treatment	Survey of ex-situ thermal technology suppliers
Ex-Situ Soil Washing		Survey of clay content in ETEC Soils	Laboratory study of solvents and contaminants
		Survey of fines content in ETEC Soils	Survey of soil washing technology suppliers
Engineered Barrier	Literature and site data study with modeling to determine subsurface fluctuations		Study of engineered barrier types for the contaminants of concern

Table A-9. Studies to Address Contaminant Specific Uncertainties

Contaminant	Chemical Form	Physical Form	Other
Mercury	Laboratory study to determine the chemical form of mercury at ETEC	Laboratory study of distribution of mercury between fines and larger particles using soils from ETEC	
Dioxins		Laboratory study of distribution of dioxins between fines and larger particles using soils from ETEC	1. Literature search on dioxin natural attenuation 2.Field study of natural degradation of dioxins at ETEC 3.Analysis of historical information from ETEC to determine degradation rate of dioxins
PCBs		Laboratory study of distribution of PCBs between fines and larger particles using soils from ETEC	
PAHs		Laboratory study of distribution of PAHs between fines and larger particles using soils from ETEC	1. Literature search on PAHs natural attenuation 2. Field study of natural degradation of PAHs at ETEC 3. Analysis of historical information from ETEC to determine degradation rate of PAHs
Perchlorate	Laboratory study to determine the speciation of perchlorate at ETEC	Laboratory study of distribution of perchlorate between fines and larger particles using soils from ETEC	1. Literature search on perchlorate natural attenuation 2. Field study of natural degradation of perchlorate at ETEC 3. Analysis of historical information from ETEC to determine degradation rate of perchlorate
Metals	Laboratory study to determine the speciation of metals at ETEC	Laboratory study of distribution of metals between fines and larger particles using soils from ETEC	
Radionuclides	Laboratory study to determine the speciation of radionuclides at ETEC	Laboratory study of distribution of radionuclides between fines and larger particles using soils from ETEC	
NDMA	Laboratory study to determine the speciation of NDMA at ETEC	Laboratory study of distribution of NDMA between fines and larger particles using soils from ETEC	
PCTs		Laboratory study of distribution of PCTs between fines and larger particles using soils from ETEC	

Table A-9. Studies to Address Contaminant Specific Uncertainties (continued)

Contaminant	Chemical Form	Physical Form	Other
Pesticides/Herbicides		Laboratory study of distribution of pesticides/herbicides between fines and larger particles using soils from ETEC	
SVOCs		Laboratory study of distribution of SVOCs between fines and larger particles using soils from ETEC	1. Literature search on SVOC natural attenuation 2. Field study of natural degradation of SVOCs at ETEC 3. Analysis of historical information from ETEC to determine degradation rate of SVOCs
SVOCs		Historical data research or laboratory study of SVOCs that exist in the soil vapor versus SVOCs sorbed to the soil particles	
VOCs		Historical data research or laboratory study of VOCs that exist in the soil vapor versus VOCs sorbed to the soil particles	1. Literature search on VOC natural attenuation 2. Field study of natural degradation of VOCs at ETEC 3. Analysis of historical information from ETEC to determine degradation rate of VOCs
TPHs		Laboratory study of distribution of TPHs between fines and larger particles using soils from ETEC	1. Literature search on TPH natural attenuation 2. Field study of natural degradation of TPHs at ETEC 3. Analysis of historical information from ETEC to determine degradation rate of TPHs
TPHs		Historical data research or laboratory study of TPHs that exist in the soil vapor versus TPHs sorbed to the soil particles	

Table A-10. Studies to Address Clearly Contaminated Areas (CCA) Specific Uncertainties

CCA	Groundwater	Terrain
For Each CCA	Question can be answered with current information. No study is needed.	Questions can be answered with current information. No study needed.