Soil Treatability Study

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

# Investigations Recommended for Resolving Uncertainty About Soil Remediation at ETEC

**September 18, 2012, Sandia National Laboratories**

## Purpose

The purpose of this memorandum is to present investigations, also known as "treatability studies," recommended by Sandia National Laboratories (SNL) for resolving uncertainty regarding soil remediation at ETEC. The Administrative Order on Consent for Remedial Action (AOC) requires the "*DOE shall conduct treatability testing to develop data for assessing treatment in place that could achieve the cleanup goals. Treatability testing is required to demonstrate the implementability and effectiveness of such technologies, unless DOE can show DTSC that similar data, documentation or information exists."* (AOC, 2010).

SNL was asked to study the soil contamination issues at ETEC and make recommendations to the DOE about what treatability studies could be performed to help them in their decision making process. SNL was also asked to interact with the public through the auspices of the Soil Treatability Investigations Group (STIG) and give consideration to their concerns to the best extent possible in the recommendations being made. It should be emphasized that the recommendations contained herein are for studies that could be performed to help the DOE determine what options might be available to them for soil remediation at ETEC. No recommendations are being made by SNL about what should be done for soil remediation at ETEC.

## Background

Previously, the STIG was presented with:

1. A series of tables that reflect the study boundaries and objectives (see *Soils Remediation Technology Screening Update* dated July 10, 2012, Sandia National Laboratories)
2. The technologies for soil remediation that have been eliminated and why, and the technologies that are being recommended by SNL for possible remediation of ETEC soils (see *Soils Remediation Technology Screening Update* dated July 10, 2012, Sandia National Laboratories)
3. A series of tables that reflect the technology, contaminant, and clearly contaminated area (CCA) specific uncertainties that have been identified for soil remediation at ETEC (see *Identification of Uncertainties Regarding Soil Remediation at ETEC, Revision 1* dated September 2012, Sandia National Laboratories)
4. A list of potential studies that could be performed to address the uncertainties identified for soil remediation at the ETEC site (see *Identification of Uncertainties Regarding Soil Remediation at ETEC, Revision 1* dated September 2012, Sandia National Laboratories).

Following the STIG meeting on July 19, 2012, the possible studies were prioritized based on a number of considerations, primarily which studies address the most important uncertainties. To identify the most important uncertainties a structured thinking exercise to help the DOE visualize the steps to decision making and which uncertainties most affect those steps was invoked. This exercise is documented in the memorandum entitled *Consideration of Possible Soil Remediation Decisions at ETEC* dated September 2012, Sandia National Laboratories. The following recommendations resulted from discussion during past STIG meetings, the structured thinking exercise, and site specific considerations including the most difficult contaminants to treat and the relative soil volumes estimated to need treatment.

## Determining Priority of Recommended Studies

The ultimate goal of the treatability studies is to give the DOE information about in-situ and/or possibly ex-situ but on-site treatment technologies that can be used to remediate soil at ETEC. When prioritizing the studies being recommended by Sandia, priority was given to those studies that address uncertainties pertaining to technologies that can address the larger contaminated soil volumes at ETEC. These are soils contaminated with mercury, Dioxins, PCBs and/or TPH. In addition, priority was given to the studies that address uncertainties pertaining to technologies that can address the more difficult contaminants for in-situ remediation at ETEC. These are mercury, heavy metals, and radionuclides. Finally, priority was given to the studies that address uncertainties pertaining to technologies that can address soils contaminated with multiple contaminants, especially from different contaminant groups. Having a long, complicated treatment train is not ideal and probably not possible.

## Recommendation 1: Address Contaminant Partitioning/Separation in the Soil

***Justification*:**

Potential volume reduction of soils requiring off-site disposal through treatment is a key reason to perform this study. Potentially the best way to achieve this volume reduction is to separate the soil into particle size fractions that become less and less contaminated as the particle size increases. That is, if the contamination resident in the soil is associated with the smaller particles sizes (frequently called “fines”), then possibly the fines can be separated from the rest of the soil and possibly only the fines will require off-site disposal. Even if the DOE does not wish to dispose of the fines off-site, they can be “washed” or thermally treated separate from the larger particle sizes.

Particle size separation can potentially be performed with or without adding any fluids (e.g. water) to the system to facilitate the separation process. This is different from soil washing, which is designed to remove contaminants from the particles rather than separate particle sizes. This uncertainty can be resolved by performing particle size analyses on soil samples from ETEC.

***Key uncertainties to resolve:*** The key uncertainties that need to be resolved are:

- What are the particle size distributions for ETEC soils?
- Do contaminants known to be present at ETEC reside preferentially with the soil fines or are they uniformly/randomly distributed throughout the soil with the various particle sizes?
- Which contaminant groups are preferentially associated, with the fines and which are not?
- Can multiple contaminants be remediated at the same time utilizing this technique, and if so, which contaminant groups?

***Specific Recommendations:*** The following specific studies are recommended. The analyses are listed in order of importance. The DOE may want to terminate this Treatability Study after the second (Large Volume) analysis.

- Small Volume Analyses
    - o Collect soil samples from a number of CCAs that have contaminants from each of the contaminant groups. The researcher may want to collect soil samples from a few CCAs that have single contaminants; however, the options will be limited as very few of the CCAs are identified as having single contaminants. The number of CCAs that need to be sampled depends on the variability found in the results. The researcher can determine when to

discontinue sampling based on the convergence of the results. Soil samples should also be collected from uncontaminated areas with the same suite of geotechnical analyses performed to provide some background information that will help with the other treatability studies. For example, an analysis of the thermal conductivity of the soils will benefit Recommendation 5 made below.

  - Analyze soils for geotechnical properties including particle size distribution, chemical properties, and thermal properties (the researcher should use uncontaminated soil for this exercise)
  - Analyze the contaminated soil samples (small volume samples) to determine the contaminants present. This will help identify which CCAs to target for the Large Volume Analyses. If chemical analyses are available for soil close to where the Large Volume Sample will be taken, this step may not be necessary.

- Large Volume Analyses

  - Excavate required volumes from selected CCA's. These will be contaminated soil samples. This exercise is not recommended for CCAs containing mercury due to its toxicity and volatility.
  - Perform dry soil partitioning/sieving to separate the soil into particle size fractions.
  - Collect and submit laboratory samples from the partitioned soil, both the fines and larger particles, to assess the contaminant levels in each of the fractions.
  - Develop a mass balance for soil contaminants before and after partitioning utilizing the laboratory analyses.

- Enhanced Separations Analyses

  - Excavate required volumes from selected CCA's. These will be contaminated soil samples. This exercise is not recommended for CCAs containing mercury due to its toxicity and volatility.
  - Perform wet soil partitioning/sieving to separate the soil into particle size fractions.
  - Collect and submit laboratory samples from the partitioned soil, both the fines and larger particles, to assess the contaminant levels in each of the fractions.
  - Develop a mass balance for soil contaminants before and after partitioning utilizing the laboratory analyses.

- Soil Washing/Thermal Analyses. The DOE may want to perform these analyses if they discover that contaminants only partially separate with particle size. For example, suppose the heavy metal contamination resides with the fines but the PCBs do not. The next question to answer is: "Is the fraction containing PCBs easier to treat with soil washing or thermal treatment than it was when the metals were present?"

  - Excavate required volumes from selected CCA's. These will be contaminated soil samples. This exercise is not recommended for CCAs containing mercury due to its toxicity and volatility.
  - Perform wet soil partitioning/sieving to separate the soil into particle size fractions.
  - Perform soil washing/thermal treatment on isolated fractions of the soil.
  - Collect and submit laboratory samples from the partitioned soil, both the fines and larger particles, to assess the contaminant levels in each of the fractions.
  - Develop a mass balance for soil contaminants before and after partitioning utilizing the laboratory analyses.

***Additional Benefits:***

The tasks defined under the Small Volume Analyses not only provide preliminary information that will be used in the Large Volume Analyses but also provide information that is useful to the treatability studies described below. The tasks defined in the Large Volume Analyses may remediate the soils on which it is performed.

## Recommendation 2: Addressing Mercury Contamination at ETEC

***Justification***: The investigation that SNL has performed over the last year indicates that mercury in contaminated soil at ETEC presents the DOE with its biggest soil remediation challenge. This conclusion is based both on the volume of soil at ETEC that is contaminated with mercury in amounts above the interim screening levels and on the difficulties potentially associated with in-situ treatment of mercury contaminated soil. Given this understanding, the uncertainty around in-situ treatment of mercury contaminated soil is, from the SNL perspective, one of the most important uncertainties for DOE to resolve prior to development of the *Soils Remediation Action and Implementation Plan*.

SNL sees only one feasible option for in-situ treatment of mercury contaminated soils within the study boundaries and AOC, which is in-situ thermal treatment utilizing the application of high heat. SNL investigations over the last year have not identified any other viable technologies for in-situ treatment of mercury contaminated soils. Further, SNL sees thermal treatment itself as only marginally viable depending on the outcome of the investigations recommended here and in Recommendation 4.

***Key Uncertainties to Resolve***: The key question regarding in-situ thermal treatment of mercury contaminated soil is the chemical form of the mercury in the soil. Mercury is a naturally-occurring metal, traces of which occur in rocks of the earth's crust. Mercury has three possible "valence states", or conditions of electrical charge. The uncharged metallic or elemental mercury (Hg0), which is the form commonly used in thermometers and readily vaporizes from its liquid state, is the most common form of mercury in the atmosphere.

Historical records at ETEC indicate that the mercury was originally deposited in its elemental state. If the mercury still exists in its elemental form in the soil, it is possible that in-situ thermal treatment could be used to drive the mercury from the soil. A typical thermal desorption unit for mercury removal operates at temperatures ranging from 320 to 700 °C. Heating ETEC soils to these temperatures is a highly uncertain prospect, however. Moreover, if the soils can be heated and the mercury driven off, the mercury vapors will have to be collected and contained for transport and disposal at an off-site disposal facility.

In soils and surface waters, mercury predominantly exists in the mercuric (Hg++, with a double positive electrical charge), and mercurous (Hg+, with a single positive charge) states, as ions with varying solubility. Mercuric chloride, a simple salt, is the predominant form in many surface waters. Mercury can form many stable complexes with organic (carbon-containing) compounds. Methyl mercury is a toxic, organic mercury compound that is fairly soluble in water. Dimethyl mercury, another organic mercury compound, is much less soluble. Inorganic mercury can be methylated by microorganisms indigenous to soils, sediments, fresh water, and salt water, to form organic mercury. The analyses performed under Recommendation 1 that determine the prevailing chemical conditions in the soils can provide information relevant to the determination of the current form of mercury in the soils.

If the mercury exists in a reacted form (any form other than elemental mercury), it cannot be driven from the soil by heat and cannot be treated with any other in-situ process that is acceptable according to the study boundary conditions that have been established with the possible exception of phytoremediation. However, in some studies investigated by SNL, mercury ions have been converted to elemental mercury by bacteria and nanoparticles. Thus, SNL recommends that the mercury investigation include an analysis of this possibility if mercury is not found in its elemental form in the ETEC soils.

Phytoremediation should also be evaluated for its effectiveness in removal of mercury from ETEC soils. This is covered under Recommendation 3 below.

***Specific Recommendations***: The following specific studies are recommended. Only Small Volume Analyses are recommended because of the volatility and toxicity of mercury. The DOE may want to terminate this Treatability Study after the first (Small Volume) analysis.

SNL does not recommend an in-situ thermal test on mercury contaminated soils at the ETEC site at this time. The information that is needed regarding the possible benefits of in-situ heating of ETEC soils can be obtained via Recommendation 4 below without the potential consequences of a heater test involving mercury.

- Small Volume Analyses
  - Collect soil samples from a number of CCAs that have mercury contamination. The number of CCAs that need to be sampled depends on the variability found in the results. The soil chemistry data collected under Recommendation 1 can also help to determine if enough sampling has been performed. The researcher needs to be aware that the nature of the soil, the terrain, the water the soil has come in contact with, and the co-contaminants present vary for each CCA. This means that the chemical reactions that lead to conversion of elemental mercury to ionic mercury may vary in each CCA. It may be necessary to sample each CCA that has mercury contamination.
  - Analyze the soils for the chemical form of the mercury as well as its potential bioavailability.
- Biological Conversion to Elemental Mercury
  - If chemical analyses indicate that the mercury largely does not exist in its elemental form at ETEC for some or all of the CCAs, a study of utilizing bacteria to convert mercury ions to elemental mercury is advised.
  - This study should be performed in a laboratory, not in the field.
  - Clean soil samples should be collected from ETEC to use in the study.
  - Bacteria resident in the soil should be identified. Nutrients required for the bacteria to thrive should be identified. The soil chemistry analysis is also included in Recommendation 1 and a survey of existing soil biota is also included in Recommendation 4.
  - Mercury in the form identified as predominant at ETEC should be introduced to bacterial cultures to determine the efficacy of the thesis that ionic mercury can be converted to elemental mercury by bacteria present at the ETEC site.
  - If the natural biota do not effectively convert ionic mercury to elemental mercury, the DOE may want to consider non-native biota or zero-valent iron nano-particles in this study. However, the use of nanoparticles at ETEC was not whole-heartedly embraced by all members of the STIG.

***Additional Benefits:***

Identification of the biota species in the soils at ETEC will benefit Recommendation 4.

## Recommendation 3: Phytoremediation of ETEC Soils for Metals and other Contaminants

***Justification***: Based on the investigation that SNL has performed over the last year, it appears that phytoremediation is the only potential option for in-situ remediation of soils at ETEC that contain heavy metals (for example, lead, silver cadmium etc.) within the study boundaries and the AOC. Thus, SNL recommends that the DOE investigate possible phytoremediation strategies for removing heavy metals from the CCA soils. Without phytoremediation as an option, the DOE has no other in-situ treatment alternative available to them. This is the primary driver for a phytoremediation study.

While the need to find an in-situ remediation alternative for soils contaminated with heavy metals is the primary driver for a phytoremediation study, a secondary driver for this recommendation is the interest of the STIG in phytoremediation as a remediation alternative for contaminated soils at ETEC. Another driver for studying phytoremediation is that SNL's investigation indicates that applying an active treatment technology followed by a passive treatment technology is an advantageous approach for soil remediation at ETEC. In all cases, phytoremediation is recommended as a passive treatment technology if it is shown to be viable at the ETEC site. Therefore, the recommended suite of studies discussed below includes all contaminants, not just heavy metals.

***Key Uncertainties to Resolve*:**

SNL has identified plant species that are known to remove specific contaminants from soil. Table 1 summarizes these findings. Most of these plant species are not currently growing at the ETEC site. Table 1 also provides on-site alternatives to the plants known to take up contaminants that may be used for remediation at ETEC if proven to be viable.

*Table 1. Plants Known to Exist at ETEC and Their Possible Use to Phytoremediate Specific Contaminants*

| *Contaminant Group* | *Remediation Method* | *Plants shown to Demonstrate Remediation Potential* | *Suggested On-Site Alternative* |
|---|---|---|---|
| Dioxins | Phytovolatilization, Phytoextraction, Rhizodegradation | Poplar (Populus sp.) | Black Cottonwood [1,2] |
| Metals | Phytoextraction | Indian Mustard (Brassica juncea) | Black Mustard[3], Mediterranean Mustard[1,3] |
| | | Sunflower (Helianthus annuus) | Canyon sunflower[1,2], Common Sunflower[2], California Sunflower[2], Slender Sunflower[2], Bush Sunflower[2] |
| | | Barley (Hordeum vulgare) | Little Barley[2] |
| PAHs | Phytovolatilization, Phytoextraction, Rhizodegradation | Clover/Alfalfa (Trifolium sp.) | Small-headed Clover[2], Creek Clover[2], White-Tipped[2], Tomcat Clover[2], White Clover[2] |
| | | Fescue (Festuca sp.) | Red Fescue[2], Small Fescue[2], Rat-Tail Fescue[2] |
| | | Ryegrass (Lolium multiflorum) | Giant Ryegrass[2], Beardless Wildrye[2] |
| | Rhizodegradation | Bermuda Grass (Cynodon dactylon) | Bermuda Grass |
| PCBs/PCTs | Phytoextraction, Phytovolatilization | Pumpkin/Zucchini (C. pepo) | Buffalo Gourd (native), Pumpkin/Zucchini Gourd (naturalized), Gourd[2] |
| | Phytovolatilization, Phytoextraction, Rhizodegradation | Clover/Alfalfa (Trifolium sp.) | Small-headed Clover[2], Creek Clover[2], White-Tipped Clover[2], Tomcat Clover[2], White Clover[2] |
| | | Fescue (Festuca sp.) | Red Fescue[2], Small Fescue[2], Rat-Tail Fescue[2] |
| | | Ryegrass (Lolium multiflorum) | Giant Ryegrass[2], Beardless Wildrye[2] |
| | | Willows (Salix spp.) | Red Willow[1,2], Arroyo Willow[1,2] |
| | Rhizodegradation | Bermuda Grass (Cynodon dactylon) | Bermuda Grass (naturalized in wet areas) |
| Perchlorate | Phytovolatilization, Phytoextraction, Rhizodegradation | Poplar (Populus sp.) | Black Cottonwood[1,2] |
| Pesticides | Phytovolatilization, Phytoextraction, Rhizodegradation | Willows (Salix spp.) | Red Willow[1,2], Arroyo Willow[1,2] |
| | Phytoextraction, Phytovolatilization | Pumpkin/Zucchini (C. pepo) | Buffalo Gourd (native), Pumpkin/Zucchini Gourd (naturalized), Gourd[2] |
| Radionuclides | Phytoextraction | Sunflower (Helianthus annuus) | Canyon sunflower[1,2], Common Sunflower[2], California Sunflower[2], Slender Sunflower[2], Bush Sunflower[2] |

| *Contaminant Group* | *Remediation Method* | *Plants shown to Demonstrate Remediation Potential* | *Suggested On-Site Alternative* |
|---|---|---|---|
| SVOCs | Phytovolatilization, Phytoextraction, Rhizodegradation | Poplar (Populus sp.) | Black Cottonwood[1,2] |
| | | Clover/Alfalfa (Trifolium sp.) | Small-headed Clover[2], Creek Clover[2], White-Tipped Clover[2], Tomcat Clover[2], White Clover[2] |
| | | Fescue (Festuca sp.) | Red Fescue[2], Small Fescue[2], Rat-Tail Fescue[2] |
| TPHs | Phytovolatilization, Phytoextraction, Rhizodegradation | Clover/Alfalfa (Trifolium sp.) | Small-headed Clover[2], Creek Clover[2], White-Tipped Clover[2], Tomcat Clover[2], White Clover[2] |
| | | Fescue (Festuca sp.) | Red Fescue[2], Small Fescue[2], Rat-Tail Fescue[2] |
| | | Ryegrass (Lolium multiflorum) | Giant Ryegrass[2], Beardless Wildrye[2] |
| | Rhizodegradation | Bermuda Grass (Cynodon dactylon) | Bermuda Grass (naturalized in wet areas) |
| VOCs | Phytovolatilization, Phytoextraction, Rhizodegradation | Clover/Alfalfa (Trifolium sp.) | Small-headed Clover[2], Creek Clover[2], White-Tipped Clover[2], Tomcat Clover[2], White Clover[2] |
| | | Fescue (Festuca sp.) | Red Fescue[2], Small Fescue[2], Rat-Tail Fescue[2] |
| | | Poplar (Populus sp.) | Black Cottonwood[1,2] |

[1]On ETEC site as of Fall Biological Survey Report for Santa Susana Field Laboratory Area IV and Northern Undeveloped Areas conducted in November 13, 2009
[2]Native according to Santa Monica Mountains National Recreation Area Vascular Plant Species List, National Parks Service. http://www.nps.gov/samo/naturescience/plants.htm
[3]Common according to Santa Monica Mountains National Recreation Area Vascular Plant Species List, National Parks Service. http://www.nps.gov/samo/naturescience/plants.htm

**Acronyms**:
PAHs = Polyaromatic hydrocarbons
PCBs = Polychlorinated biphenyls
PCTs = Polychlorinated triphenyls
SVOCs = Semivolatile organic compounds
TPHs = Total petroleum hydrocarbons
VOCs = Volatile organic compounds

The primary uncertainty regarding phytoremediation at ETEC is if the plants that are currently growing on the site have the ability to remove contaminants from the soil. More specifically:

- What plant species currently growing at ETEC can remove contaminants from the soil?
- Which contaminants specifically can be removed by these plants?
- How efficient is this plant uptake? How clean will the soil be? How long will it take?
- What is the mechanism utilized by the plant for removal of the contaminant? Is it hyperaccumulation, rhizoshpere stimulation or phytotranspiration?
- Can the uptake by plants be improved by compost, fertilization, irrigation, and/or the addition of microbes?

***Specific Recommendations*:** The following specific studies are recommended.

- Site Plant Species Inventory
  - o Perform an inventory of plant species growing on the CCAs. This inventory will be used to identify the most promising places to look for ongoing examples of phytoremedation at ETEC. A preliminary and first cut at a CCA plant inventory, completed by Thomas Mulroy of SAIC, is provided below. He examined CCAs 11, 13, 14, 17, 21, 41, 42, 43, 46 and 48.

1. Native species that have come in subsequent to recent (< 5 years) disturbance. These are generally non-woody (herbaceous) species, mostly annuals or short-lived perennials, have fair to good colonizing ability, and reproduce mainly by seed.

a. Telegraph weed (*Heterotheca grandiflora*)
b. Doveweed (*Croton* (*Eremocarpus*) *setigerus*)
c. Needlegrass (*Stipa* (*Nassella*) spp.)
d. Spanish-clover (*Akmispon americanus* [*Lotus purshianus*])
e. Cudweed-aster (*Lessingia* [*Corthrogyne*] *filaginifolia*)
f. California everlasting (*Gnaphalium californicum*)
g. Horseweed (*Erigeron* [*Conyza*] *canadensis*)
h. Narrow-leaved milkweed (*Asclepias fascicularis*)
i. Vinegar weed (*Trichostema lanceolatum*)
j. Palmer's goldenbush (*Ericameria palmeri*)
k. Cattail (*Typha latifolia*) (wetland only)
l. Tall umbrella-sedge (*Cyperus eragrostis*) (wetland only)

2. Native species that have survived on site (generally > 5yrs). These are generally woody perennials. Species below that have relatively good colonizing capability (given suitable habitat conditions) and reproduce mainly by seed are identified by an asterisk (*)

a. Laurel sumac (*Malosma laurina*)
b. Coyote brush (*Baccharis pilularis*)*
c. Mule fat (*Baccharis salicifolia*)*
d. Coast live oak (*Quercus agrifolia*)
e. Hairy ceanothus (*Ceanothus oliganthus*)
f. Poison oak (*Toxicodendron diversilobum*)
g. Arroyo willow (*Salix lasiolepis*)*
h. Red willow (*Salix laevigata*)*
*i.* Branching phacelia (*Phacelia ramosissima*)*
*j.* Thick-leaved yerba santa (*Eriodictyon crassifolium*)
*k.* Coastal sagebrush (*Artemisia californica*)*
*l.* Bush monkeyflower (*Mimulus aurantiacus*)*
m. Yucca (*Hesperoyucca* [*Yucca*] *whipplei*)
n. Mexican elderberry (*Sambucus nigra*)

3. Non-native species. Non-native species comprise the majority of species at most of the CCA sites we investigated. Although the STIG made it clear that they wanted the phytoremediation investigation to focus on native species, some non-native species may be worthy of <u>further investigation and possible consideration for testing of their phytoremediation abilities</u>. These would be species that abundantly establish on disturbed sites (such as most of the CCA sites) without human assistance and that are thoroughly naturalized in the area and as such present little threat of spreading into surrounding native vegetation. Additional measures may be required to further discourage their spread. Special management considerations may apply (such as mowing and harvesting the biomass prior to seed set).

a. Summer mustard (*Hirschfeldia incana*)
b. Horehound (*Marrubium vulgare*)
c. Curly dock (*Rumex crispus*)
d. Annual grasses (species of *Bromus, Vulpia, Avena*)

4. Many of the non-native species observed on the sites have qualities that make them <u>unsuitable for any consideration for use in phytoremediation</u>. These qualities include invasiveness (fountain grass, fennel, tamarisk), spinyness (thistles, Russian-thistle), or a combination.

a. Italian thistle (*Carduus pycnocephalus*)
b. Tocalote (*Centaurea melitensis*)
c. Milk thistle (*Silybum marianum)*
d. Fennel (*Foeniculum vulgare*)
e. Tamarisk (*Tamarix ramosissima*)
f. Tumbleweed (*Amaranthus albus*)
g. Russian-thistle (*Salsola tragus*)
h. Tree tobacco (*Nicotiana glauca*)
i. Fountain grass (*Pennisetum setaceum*)

- Develop a crosswalk of CCAs, contaminants, and plant species on those CCAs that may contain contaminants.
- Identify plant species that are like the species shown to demonstrate remediation potential identified in Table 1. This will be the first set of plant species to be tested on site.

- Site-wide Plant Species Sampling
  - Collect plant species samples from a number of CCAs listed in the crosswalk developed in the plant species inventory. The number of plant species that need to be sampled depends on the variability found in the results. Any plants that are known to only phytotranspire contaminants cannot be included in this study. The highest priority sampling should be plants that may hyperaccumulate metals. For example, indian mustard which is prevalent on the site could serve this function and should be tested where metals are known to reside.
- Laboratory Phytoremediation Studies
  - For plants that are shown under the site-wide plant species sampling study to have removed contaminants from the soil, initiate a controlled laboratory study to determine the efficiency of the plant uptake.
  - Determine how long the plants will take to clean the soil, the efficiency and duration of the process, and what the mechanism is for uptake of contaminants.
  - For plants thought to phytotranspire contaminants (like VOCs), initiate a controlled laboratory study to determine if indeed they do phytotranspire (this cannot be tested in the

field). Determine how long the plants will take to clean the soil, the efficiency and duration of the process.

- o Determine if phytotranspiration, hyperaccumulation, or rhizosphere stimulation by the plants can be improved by composting, fertilization, irrigation, and/or the addition of microbes.

***Additional Benefits*:**

In-situ remediation utilizing phytoremediation is a minimally destructive and "green" manner in which to clean up the contaminated sites.

## Recommendation 4: Bioremediation Treatment of Contaminated Soils at ETEC

***Justification*:** Bioremediation is already mentioned in Recommendations 2, 3, and 6 because of its ability to act synergistically with other technologies to aid in soil remediation. Bioremediation technology on its own is very effective for remediating soils contaminated with petroleum hydrocarbons and organics, and is already occurring in the on-site soils in conjunction with phytoremediation and natural attenuation.

***Key Uncertainties to Resolve*:**

- What biota and "bugs" currently exist in the soils and are they present in enough of a concentration to remediate soils?
- Will the existing biota need to be enhanced through introduction of food or additional biota?
- Will introduced biota be successful and not interfere with existing biota?

***Specific Recommendations*:**

- Site Biota Inventory
  - o Sample the soils and have laboratory analyses completed to determine what native biota exist at the site and the biological properties of the soil to sustain biota life (also suggested in Recommendation 2).
  - o The soil samples should come from both contaminated and uncontaminated areas of the site.
- Laboratory Analyses
  - o Through laboratory studies, determine if bioremediation can be enhanced through the addition of food for the biota or the introduction of non-native biota.
  - o Add contaminants to the biota in the laboratory setting to assess the efficiency and effectiveness of the remediation cycle. The highest priority contaminant for this recommendation is TPH.

***Additional Benefits:***

Bioremediation is considered a "green" technology and assessment and inventory of the biota will benefit Recommendations 2, 3, and 6.

## Recommendation 5: Thermal Treatment of Contaminated Soils at ETEC

***Justification*:** The primary driver for recommending thermal treatment of contaminated soils is that it can be used to treat several contaminants, in fact almost all of the contaminants, together. In addition, this may be the only in-situ method available to effectively remediate the most difficult contaminants including mercury, dioxins, and PCBs.

***Key Uncertainties to Resolve*:** The key uncertainties that need to be resolved as part of this recommendation are the following.

- Can the soil be heated enough in-situ to drive off the contaminants? For example, boiling points were researched for specific PCBs, and the following data were available.

***Table 2. Boiling Points for Select PCBs***

| PCBs | Boiling Point (°C) |
|---|---|
| 156-HxCB | 417.1 |
| Aroclor 1242 | 347.7 |
| Aroclor 1254 | 365.0 – 390.0 |
| Aroclor 1260 | 385.0 - 420.0 |
| Aroclor 5460 | 553.5 |

- What is the thermal conductivity of ETEC soils (also addressed in Recommendation 1)?
- What will the condition of the soil be after in-situ thermal treatment?
- Will all of the contaminants be remediated, or will there be remaining chemicals/contaminants after treatment?

***Specific Recommendations*****:** This study has to be a field test at ETEC. A laboratory study will not suffice. Because it must be a field study, SNL has given consideration to the requirements for a field study and determined that targeting CCAs containing only PCBs is their recommended approach for demonstrating the viability of in-situ thermal treatment at ETEC. The temperatures (in Table 2) required to drive off PCBs are considered high and will be sufficient to drive off the other contaminants that can be remediated utilizing thermal technologies. The specifications for remediation that can be derived from a thermal test are independent of the contaminant. Finally, the fate of volatilized PCBs during a test is less of a concern than it would be for other contaminants like mercury.

Two types of in-situ thermal tests are being recommended by SNL. They are listed in order of priority. The in-situ thermal remediation for shallow soils test is recommended first because it is likely to provide sufficient information to decide if in-situ thermal remediation is a viable option while probably being the less expensive test. However, there is insufficient information at this time to rule out the needs for the second test. If after the extent of contamination is characterized more completely and the depth of contamination proves unimportant overall (for example, most of the CCAs that are candidates for in-situ thermal treatment for other reasons also turn out to be "shallow" CCAs), the need for a test with deeper soils may not exist. The shallow and deep soil determination is based on the effective depth of thermal blankets in typical soils, which may differ slightly for the ETEC soils depending on the thermal properties.

- In-situ Thermal Remediation for Shallow Soils
  - Thermal technologies known to work for shallow soils (typically less than three-foot depth) include thermal blankets and thermal probes. The researcher should select a system that will allow heating the soil to values greater than 300 degrees Celsius. The test should heat the soils to temperatures comparable to the temperatures presented in Table 2.
  - Several of the PCB CCAs are ideal candidates for an in-situ thermal test. The researcher should choose a CCA with high concentrations of PCBs as well as one that is shallow for this test. For example, CCAs #10, #15, #24, #25 can be considered for this type of test.
  - The researcher should investigate the requirements for containment and emissions for the study processes, and subsequently implement a containment system for the resulting volatiles as required and necessary.

- In-situ Thermal Remediation for Deeper Soils
  - Thermal technologies known to work for deeper soils (typically greater than three-foot depth) include thermal probes and thermal wells. The researcher should select a system that will allow heating the soil to values greater than 300 degrees C. The test should heat the soils to temperatures comparable to the temperatures presented in Table 2.

  - Several of the PCB CCAs are ideal candidates for an in-situ thermal test. The researcher should choose a CCA with high concentrations of PCBs as well as one that is greater than three foot in depth. For example, CCA #31 can be considered for this type of test.
  - The researcher should also investigate the use of a containment system for the resulting volatiles. Containing the volatile compounds that are driven off during the test is not necessarily required but for application to some of the contaminants as a remediation technology, the thermal treatment system will have to have a containment system as well. Therefore, the efficacy of containment must also be demonstrated in the test.

***Additional Benefits:***

As stated under the justification for this recommendation, thermal treatment may be the only in-situ option for some of the most difficult contaminants on site to treat, including mercury, dioxins, and PCBs, and it can treat several contaminants at one time. In addition, performing tests on the CCAs containing PCBs may serve the dual function of testing and remediation of the CCA.

## Recommendation 6: Natural Attenuation of Contaminated Soils at ETEC

***Justification*****:** Natural attenuation is a passive remediation technique that takes advantage of the existing degradation capabilities of the soils to remediate contamination. Natural attenuation is likely already occurring at the ETEC site for numerous contaminants. The contaminant groups most likely to benefit from natural attenuation processes in a reasonable amount of time include the following:

- Dioxins
- PAHs
- SVOCs
- VOCs
- TPH
- Perchlorate
- NDMA

It is important for DOE and its regulators to know and understand the extent to which natural attenuation is occurring at ETEC. With quantitative information about the extent of natural attenuation, more informed decisions about soil remediation can be made.

***Key Uncertainties to Resolve*****:** The key uncertainties that need to be resolved as part of this recommendation are following:

- Is natural attenuation of the above-mentioned contaminants occurring and at what rates?
- Could the natural attenuation rates of existing processes be enhanced so that remediation of contaminants is complete within a five-year timeframe, or as otherwise dictated? Per the AOC, the remedy is only required to be in place by 2017 and not completed at that time.
- Can an effective monitoring program be implemented to demonstrate the efficacy of the natural attenuation remedy?

***Specific Recommendations*****:** The specific recommendations for natural attenuation studies are following and include examination of historical sampling data and field and laboratory demonstrations.

- Examination of historical sampling data
  - It is not clear if historical records contain enough information to demonstrate analytically that natural attenuation at ETEC is occurring. This study involves the examination of historical sampling data to determine if enough information exists. The historical contaminant data need to be for consistent locations and chemical analyses.
  - If it is determined that enough information exists, an analysis of the data may provide evidence that natural attenuation is occurring. The likelihood that quantitative evidence can

be derived is small. Therefore this study would lead to a second study to determine the rate of natural attenuation of certain contaminants at ETEC.
    - Small volume samples should be collected in contaminated areas and laboratory analyses should be completed to ascertain whether natural attenuation is occurring at the site for the above-mentioned contaminants, and if so, at what rate.
    - Based on the results of Recommendation 4, more specific laboratory analysis should be completed to assess if natural attenuation processes can be enhanced through biota or fuel/food additions to speed the natural attenuation processes to remediate contaminants within the desired five-year timeframe.
    - This type of data may not be available and may need to be replicated in the lab by artificially “aging” the soils utilizing known biota.
- Field Demonstration at ETEC Site
    - SNL recommends performing this type of study on one of the CCAs that contains dioxins. In addition, a CCA should be chosen that has recently been sampled for dioxins. The recommendation is to continue sampling in the chosen location(s) at regular intervals. This would be a baseline study for specific contaminants in specific CCAs, so a database of occurring natural attenuation processes can be developed. This baseline study should include soil sampling in CCAs with known contaminants, preferably individual contaminants to start with, and comparison of the results of current analyses to historical analyses to assess if the levels are reducing due to natural processes.
    - In the areas where natural attenuation is occurring, routine monitoring will be required to understand the attenuation rates and to ensure that the processes are still occurring through time.
- Laboratory Demonstration of Natural Attenuation
    - Laboratory studies should also be performed that include adding biota and/or fuel and food to the existing biota to see if processes can be enhanced or sped up, also suggested in Recommendation 4.

***Additional Benefits:***

The natural attenuation remediation strategy is the least destructive method of remediation that may be utilized at the ETEC site. It can be particularly helpful for areas that must be protected and not disturbed.