Tool 4.5: Considerations for Selecting a Method of Soil Treatment

LIMITATION: The following table represents the state of technologies as of January 2022. EPA, DoD, and other agencies are leading ongoing research and technology evaluation, and users of this guidebook should refer to those agencies for the most up-to-date information on technologies and their applicability to the remediation project in question.

In Situ Treatment

Soil Treatment Technologies
In Situ Thermal Treatment *Cost: Very High; Screening Status: Do not Retain*
Description: ✓ Heat is used to volatilize PFAS from the soil matrix for off-gas treatment and disposal. Thermal conduction heating can achieve temperatures needed to volatilize PFAS. The off-gas is condensed and adsorbed onto activated carbon or treated at very high temperature to break down the PFAS. Combustion byproducts include hydrogen fluoride, which requires treatment in an air pollution control device (such as a scrubber) (CRCCARE, 2018). SERDP/ESTCP studies are currently underway assessing in situ thermal technologies (ER20-5250). **Implementability:** ✓ Technically and administratively difficult to implement. Requires extensive engineering to treat byproducts such as condensed water and highly acidic thermal oxidation byproducts. Requires air and water pretreatment permitting. Air monitoring and off-gas treatment methods are currently being evaluated by EPA (EPA 2020) and SERDP/ESTCP (ER-1408). **Effectiveness:** ✓ In situ thermal treatment is effective for removal of SVOCs like PFAS. Additional research is needed to design effective off-gas treatment equipment due to acid gases being formed during thermal oxidation and coating of PFAS on off gas condensation equipment. Not effective for shallow soil treatment.

Soil Treatment Technologies
Availability / Maturity: ✓ Thermal conduction heating equipment is available but has not been used commercially for PFAS treatment. Off-gas treatment in development stage.
In Situ Stabalization *Cost: Moderate - High; Screening Status: Retain*
Description: ✓ Sorbents are added to and mixed with the soil to stabilize and immobilize the PFAS compounds within the soil. Minerals such as organoclays, silica, iron oxides, and zeolites are used to remove contaminants from soil and water (ITRC, 2018b). Clay-based material (modified clay adsorbent) and carbon enhanced material have been used to stabilize PFAS in soil mass reducing leachability (Mahinroosta and Senevirathna, 2020). **Implementability:** ✓ Technically and administratively easy to implement. Requires bench tests to determine additive to soil ratios. ✓ In situ mixing requires backhoes, auger attachments to excavation equipment, large diameter augers, etc. Appropriate equipment would be selected following predesign. ✓ Leachability testing may be performed to gauge effectiveness. **Effectiveness:** ✓ PFAS is not destroyed and left on-site. Long-term efficiency and stability have not been evaluated. May require a large volume of the adsorbent, which increases the cost. Proven leachability reduction of 99%. ✓ Longer chain PFAS generally have increased sorption, but other soil properties (mineralogy, pH, organic content, co-contaminants) appear to have different impacts on effectiveness (ITRC, 2021). **Availability / Maturity:** ✓ Commercially available.

Excavation

Soil Treatment Technologies
Excavation *Cost: Low to Medium; Screening Status: Retain*
Description: ✓ Source area soil or sediment is excavated and relocated on-site. Clean soil or sediment is used to backfill the excavated area. **Implementability:** ✓ Implementable where high-concentration source mass has been identified; equipment is available to remove soil or sediment in various scenarios. Once excavated, soil may need to be stockpiled prior to being treated or disposed off-site. ✓ Soil or sediment may require dewatering prior to treatment or disposal; dewatering liquids may require containment and treatment. **Effectiveness:** ✓ PFAS is not destroyed but removed from source area and relocated to designated location on-site with approved containment. **Availability / Maturity:** ✓ Commercially available.

Ex Situ Treatment

Soil Treatment Technologies
Ex Situ Thermal Desorption *Cost: Very High; Screening Status: Do not Retain*
Description: ✓ Excavated soil is placed in piles or insulated boxes with heating elements and heat is applied to volatilize PFAS. The off gas is condensed and adsorbed onto activated carbon or treated at very high temperature to break down the PFAS. Combustion byproducts include hydrogen fluoride, which requires treatment in an air pollution control device (such as a scrubber) (CRCCARE, 2018). SERDP/ESTCP studies are currently underway assessing ex situ thermal technologies (ER20-5198). **Implementability:** ✓ Technically and administratively difficult to implement. Requires extensive engineering to manage incomplete combustion byproducts, and to treat byproducts such as condensed water and highly acidic thermal oxidation byproducts. Requires air and water pretreatment permitting. Air monitoring and off-gas treatment methods are currently being evaluated by EPA (EPA 2020) and SERDP/ESTCP (ER-1408). **Effectiveness:** ✓ Ex situ thermal desorption has been shown to be effective for removing >99% SVOCs but limited data exists for PFAS treatment at full scale. Additional research is needed to design effective off-gas treatment equipment due to acid gases being formed during thermal oxidation and coating of PFAS on off gas condensation equipment. **Availability / Maturity:** ✓ Thermal desorption equipment is available but has not been used commercially for a PFAS treatment application. Off gas treatment is in the development stage.

Soil Treatment Technologies
Soil Washing *Cost: TBD; Screening Status: Do not Retain*
Description: ✓ Mobilizes PFAS from soil by washing the soil with a liquid (often with a chemical additive), solubilizing the PFAS into the liquid phase, and then separating the clean soils from the liquid rinsate. The liquid rinsate is treated on- or off-site. **Implementability:** ✓ Implementable where high-concentration source mass has been identified. **Effectiveness:** ✓ The effectiveness of soil washing has not been demonstrated in the field; however, a pilot-scale test is being conducted under the DoD ESTCP Program. **Availability / Maturity:** ✓ Not commercially available, developmental stages.

Disposal / Management Options

Soil Treatment Technologies
Disposal at Off-Site Landfill *Cost: Medium to High; Screening Status: Retain*
Description: ✓ Soil is disposed of at approved landfill off-site. Clean soil is used to backfill the excavated area. ✓ EPA's 2020 interim disposal guidance identifies landfilling as a feasible disposal option for managing PFAS wastes and identifies critical parameters to consider when identifying landfill disposal options.

Soil Treatment Technologies
Implementability: ✓ Technically easy to implement. Fewer disposal options may be available if soil is classified as hazardous waste. While hazardous waste regulations are in flux, disposal options may be limited due to: 1) Waste management companies' varying risk tolerance for PFAS-contaminated wastes, unless managed conservatively. 2) Owners' concerns regarding future liabilities. ✓ EPA identifies multiple issues and data gaps regarding PFAS behavior in landfills (including in emission and leachate, and subsequent treatment and management) (EPA 2020). **Effectiveness:** ✓ PFAS is not destroyed but removed from site and disposed at approved landfill. PFAS will persist in the landfill. **Availability / Maturity:** ✓ Commercially available. ✓ The impact of PFAS on landfill regulations and routine O&M is TBD.
Management Using On-Site RCRA Cell *Cost: Medium to High; Screening Status: Retain*
Description: ✓ Source area soil managed at regulatory agency-approved on-site landfill. Clean soil is used to backfill the excavated area. **Implementability:** ✓ Implementable, if compatible with current and future property use. Requires design, construction, maintenance, and LTM to monitor containment cell effectiveness. Must meet current landfill siting and other permit requirements. ✓ New cell must be permitted accordingly. While hazardous waste regulations are in flux, regulatory agencies may be reluctant to approve cell design requirements. ✓ Landfill and associated components would be subject to evolving PFAS regulations (e.g., leachate monitoring). ✓ EPA identifies multiple issues and data gaps regarding PFAS behavior in landfills (including in emission and leachate, and subsequent treatment and management) (EPA 2020).

Soil Treatment Technologies

Effectiveness:

✓ PFAS is not destroyed but removed and disposed at approved on-site landfill. Effective at containing and consolidating PFAS.

Availability / Maturity:

✓ Commercially available.

✓ The impact of PFAS on landfill regulations and routine O&M is TBD.

Off-Site Incineration

Cost: Medium to High; Screening Status: Retain

Description:

✓ Soil is hauled off-site for incineration. Clean soil is used to backfill the excavated area.

✓ EPA identifies hazardous waste combustion technologies (commercial incinerators, cement kilns, and lightweight aggregate kilns) as having the potential for destroying PFAS. 2020 interim guidance identifies critical parameters to consider when selecting an incineration facility (EPA, 2020).

Implementability:

✓ Technically easy to implement. Default approach for high concentration PFAS wastes. Currently, is default approach for minimizing future PFAS liabilities.

✓ EPA identifies multiple uncertainties and data gaps regarding incineration for PFAS management, given potential variability in treatment efficiency and unknowns in off-gas treatment (i.e., optimal temperature, residence time) (EPA, 2020). This technology may be subject to future restrictions or limitations, pending EPA review.

Effectiveness:

✓ EPA's 2019 interim guidance on destruction and disposal of PFAS identifies incineration and thermal treatment as an option, but with significant effectiveness concerns (i.e., is PFAS present in incinerator off-gas). Additional review of this technology is underway (EPA, 2020).

✓ Additional research is needed to demonstrate effective off-gas treatment.

Availability / Maturity:

✓ Commercially available.

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