Active-to-Passive Environmental Cleanup Transition Strategies – 13220

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ABSTRACT

The Savannah River Site uses a graded approach to environmental cleanup. The selection of groundwater and vadose zone remediation technologies for a specific contamination area is based on the size, contaminant type, contaminant concentration, and configuration of the plume. These attributes are the result of the nature and mass of the source of contamination and the subsurface characteristics in the area of the plume. Many large plumes consist of several zones that are most efficiently addressed with separate complementary corrective action/remedial technologies. The highest concentrations of contaminants are found in the source zone. The most robust, high mass removal technologies are often best suited for remediation of the source zone. In the primary plume zone, active remedies, such as pump-and-treat, may be necessary to remove contaminants and exert hydraulic control of the plume. In the dilute fringe zone, contaminants are generally lower in concentration and can often be treated with passive techniques. A key determination in achieving an acceptable and cost-effective end state for a given waste unit is when to transition from an active treatment system to a more passive or natural approach (e.g., monitored natural attenuation or enhanced attenuation). This paper will discuss the considerations for such a transition as well as provide examples of successful transitions at the Savannah River Site.

INTRODUCTION

The Savannah River Site has an established, successful history of developing implementable risk reduction strategies, deploying innovative technological solutions, and collaboratively achieving realistic and protective environmental end states. Our success embodies management, technical, regulatory, legal and stakeholder involvement aspects in the cradle-to-grave process of achieving consensus end states. These activities are supported by a variety of services that include: knowledge transfer endeavors (training, symposia, internships, etc.), technical services (remedy selection and design, applied research tests, peer reviews), technology verification and testing, access to well-characterized field research sites, as well as public and regulatory interaction/negotiation.

This paper focuses on SRS's approach in employing active-to-passive environmental cleanup transition strategies; from diagnosing the site problem, to the matching of remedies to site specific conditions, to the transition from active treatments systems to passive or enhanced passive approaches.

Figure 1 provides a simplified conceptual diagram of a facility that has impacted the surrounding environment. The three ovals – the source zone, the primary groundwater/vadose zone, and the dilute plume/fringe – represent different portions of the affected environment. Each of these zones has a different character. The source zone (depicted as red in Figure 1) received relatively high levels of contamination. As a general guideline, more aggressive remediation technologies or approaches (e.g., excavation, heating, chemical oxidation) are appropriate in the source zone where the highest levels of contamination are observed and where the maximum benefit can be obtained through large volume reductions. The primary groundwater/vadose zone (depicted as green below), often manifests as a contaminant plume that contains lower levels of groundwater pollutants than the source zone but still represents a potentially significant present or future hazard. In this less contaminated but more expansive zone, traditional approaches typically include technologies such as pump & treat with air stripping, recirculation wells, and funnel & gate approaches where removal success is measured in dollars per gallon or cubic foot. The dilute plume/fringe zone (depicted as blue below) contains contamination at relatively low concentrations but impacts relatively large volumes of water where more passive or natural remedies are most efficient (e.g., pytoremediation, passive soil vapor extraction, monitored natural attenuation).

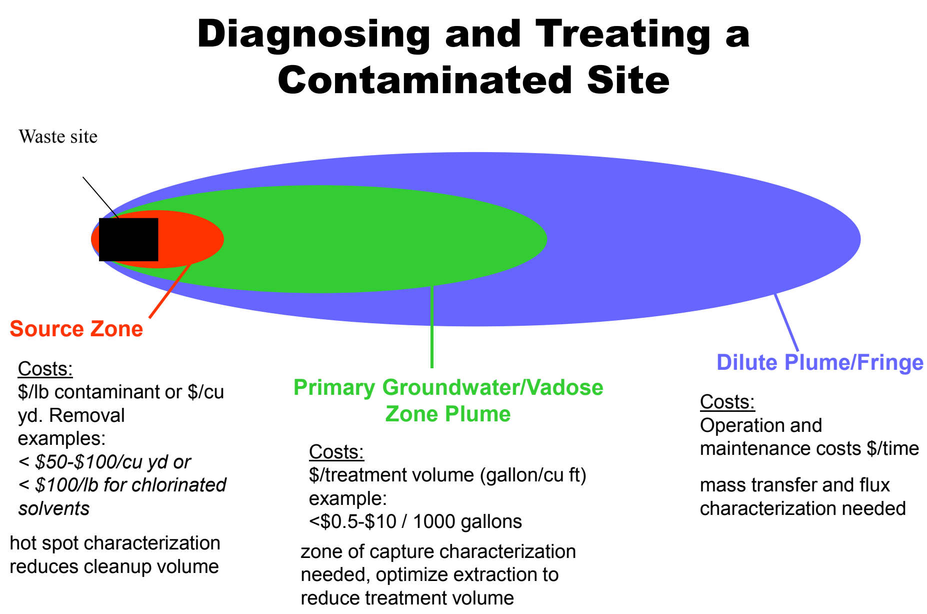

Figure 1 Plume Conceptual Diagram

Aggressive active remediation technologies deplete sources and lower contaminant concentrations in plumes. As remediation projects mature and the bulk of contaminants are removed, transitioning from robust active systems to passive, low-energy-consumption, low-carbon-emission technologies becomes more efficient and cost-effective. The active systems are phased out and replaced with passive and enhanced-passive technologies. Ultimately, when final remedial goals have been met, the groundwater remediation systems are no longer necessary. SRS has groundwater remediation projects in every phase of remediation [1].

In determining whether remediation is complete, shutdown criteria are used, which are typically established in regulatory documents. For groundwater, maximum contaminant levels (MCLs) are the regulatory standards most often used. For vadose zone soils, soil remedial goals are typically established based on protection of groundwater. Once it is demonstrated that these criteria have been achieved, the remediation is considered complete.

Experience has shown that soil remedial goals are often difficult to achieve. The remedial goals are typically concentrations back-calculated using simple fate and transport models and conservative input assumptions. The physical processes responsible for contaminant retention in fine-grained soils are often not considered. The following alternative closure criteria (list not all-inclusive) should be considered to support a remedial strategy for closure that is not based strictly on a soil remedial goal:

- Site characterization data
- Remedial system design
- Performance monitoring results
- Mass flux to and from groundwater and evaluation of rate-limited vapor transport

Defining the transition points for conversion of active remediation systems to enhanced-passive or entirely passive systems can use some of the same lines of evidence described above. For groundwater systems, if land use controls are effective and surface water is not impacted, the transition point can be identified in a cost/benefit analysis. The active and passive systems can be compared considering the following:

- Cost
- Contaminant concentration and removal rates
- Time to reach MCLs and/or remedial goals
- Carbon emission
- Overall energy use
- Waste generation

- Natural resource protection

For vadose zone remediation, controlling the flux to groundwater is an important criterion to consider. Any combination of these parameters can be used in a technical justification of a proposal to transition a project from an active to a passive remedy.

MATCHING OF REMEDIES TO SITE-SPECIFIC CONDITIONS

In reality, the contaminated areas are not simple ovals. Instead, dissolved contamination occupies a complex three-dimensional geometry and encounters multiple geochemical conditions and geological materials at it travels through surface water (e.g., wetlands and streams), the vadose zone, and groundwater. The site-specific technology assessment process considers these multiple levels of complexity to identify areas of opportunity. [2]

Careful matching of remedies to site-specific conditions is critical to long-term success in environmental cleanup and restoration. The matching process facilitates selection of technologies with particular strengths that align with real-world needs and constraints, encourages strategic use of multiple or combined technologies to address major plume subdomains, and supports transitioning technologies in space and time as remediation progresses.

The ultimate approach for a specific contaminated site may include a sequence of technologies. Remedy selection must consider factors such as implementability, expected performance, uncertainties/risks, and costs for actions as they apply to the various target zones. In addition to the traditional factors, emphasis is increasingly placed on sustainability and metrics for evaluating remedial actions and balancing benefits against the associated environmental burdens and collateral damages. A key metric that has proven valuable is the concept of "plume status" (whether the plume is expanding, stable or shrinking), particularly for sites with dilute contaminants. [3]

"Plume status" is a form of a mass balance. When the mass release rate (discharge or flux) from the source is greater than the natural attenuation occurring in the footprint of the plume, the plume will expand. When the plume reaches a size such that the attenuation occurring within the plume footprint is equal to (or greater than) the mass release rate from the source, then the plume will stabilize (shrink). This is a dynamic process with conditions that change in both space and time (Figure 2). Depletion of the source or implementation of remediation technologies, such as source treatment, can alter conditions during specific time period(s), changing the total mass entering the plume and the future plume structure. Plume status is often combined with local issues (e.g., crossing property boundaries or impacting a water supply) and the expected performance characteristics of a selected remediation technology in order to generate appropriate metrics to monitor and/or track progress at a particular site.

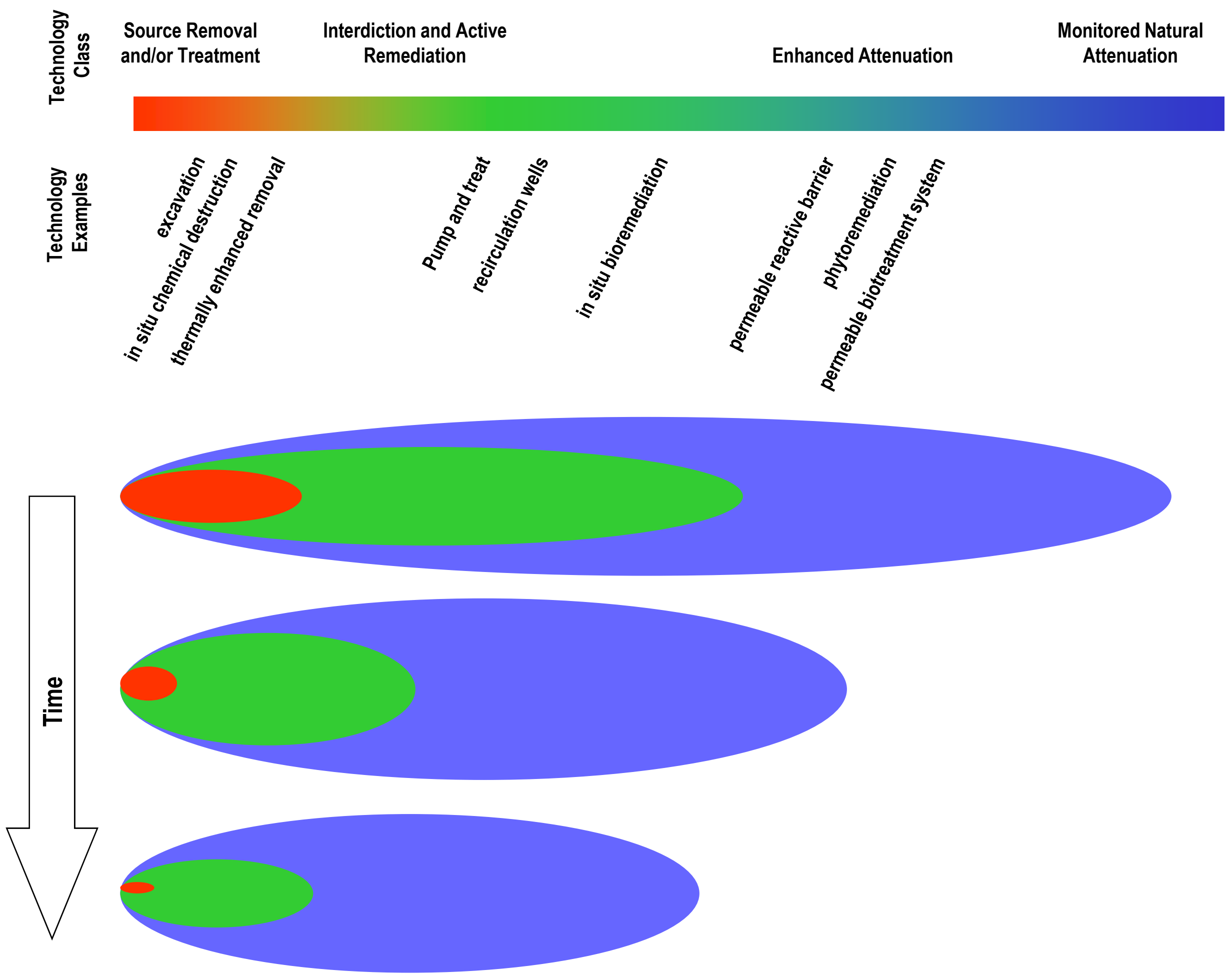

Figure 2 Plume Conditions over Time

The mass balance approach is powerful because it allows site representatives to make technology decisions in a succinct and intuitive manner, and it provides the opportunity to develop simple tools to predict the temporal impacts of alternative remedial actions. Moreover, a mass balance approach can be implemented based on relatively few parameters. Several of these parameters (e.g., groundwater flow velocity and direction and contaminant discharge from the source) can be estimated from standard monitoring data. Other key parameters, such as attenuation rates in plumes, can be estimated based on mechanism-specific studies (e.g., laboratory microcosms);

correlations of site characterization data to rates (e.g., relating reactive mineral content and surface area to contaminant transformation); or evaluation of field scale plume structure [4; 5] if a known and accepted degradation mechanism, such as contaminant reduction by interaction with reactive minerals, has been identified [3]. Identification, characterization, and quantification of the processes that control and attenuate contaminants are crucial to effective environmental management decisions for large dilute contaminant plumes. As discussed above, the use of multiple concerted processes, each matched to plume conditions and selected to be robust to site-specific uncertainties, provides "defense in depth" and helps optimize overall performance and efficiency.

ACTIVE-TO-PASSIVE SUCCESS STORIES AT THE SAVANNAH RIVER SITE

The Savannah River Site (SRS) has a variety of examples of transitioning from active remediation systems, both to enhanced-passive and completely passive systems. Completely passive systems utilize the natural capability of the subsurface or media to reduce or stabilize contamination, while enhanced-passive systems rely on a one-time or infrequent addition of an enhancement to jump start or sustain the natural process. Two active-to-passive success stories at SRS follow.

F-Area Barrier Wall with Base Injection and Silver Chloride Injection

At the SRS F/H-Area Seepage Basins Groundwater Operable Unit, groundwater is contaminated with elevated levels of metals, radionuclides and nitrates, including tritium. The constituents of concern (COCs) associated with the F-Area groundwater plume are tritium, uranium-238, iodine-129 (I-129), strontium-90, curium-244, americium-241, technetium-99, cadmium, and aluminum. The COCs in H Area are tritium, strontium-90, and mercury [6].

In 1992, SRS was issued a RCRA Part B Permit that specified ongoing groundwater monitoring requirements and a Corrective Action Plan to remediate the contaminated portions of the uppermost groundwater aquifer. Several of the contaminants exceeded regulatory limits and were targeted for remediation.

In 1997, SRS designed and built two water treatment units (WTUs). The systems were designed to treat metals, radionuclides, and to reduce the migration of tritium to Fourmile Branch, a tributary of the Savannah River, by trapping it in an extraction/re-injection loop until it decayed to regulatory limits. The remediation system extracted groundwater down-gradient of the closed seepage basins, passed it through a WTU to remove metals and radionuclides, and re-injected the treated water up-gradient to maintain the recirculation loop.

Additional investigations performed in F-Area revealed the presence of acidic secondary contamination in the subsurface with metals and tritium contributing to the conditions at the seepline of Fourmile Branch. These conditions were key factors in making the decision to research new remediation technologies.

In February 2003, a small-scale pilot study of injecting base (alkaline) solution directly into the F-Area groundwater was completed, successfully raising the pH value of the groundwater. Following the successful deployment of the pilot study, SRS received conditional approval to suspend the six-year running of two WTUs in favor of a new passive system. The passive remediation technologies consist of engineered tritium barriers and base solution injections into the groundwater that will address both creek/seepline and groundwater contamination. The full-scale Barrier Walls with Base Injection System replaced the expensive groundwater pump-and-treat units, which cost $1M a month to operate.

While cationic contaminants in groundwater at the F-Area Seepage Basins are being controlled by base injection, a supplemental treatment is required for I-129, an anionic contaminant. SRS developed an injectable solid silver chloride (AgCl) amendment for treating dissolved ^{129}I. Laboratory and field tests demonstrated the effectiveness and applicability of this amendment. The amendment has recently been deployed at the Savannah River Site in the middle gate of the F-Area funnel-and-gate remediation system.

T-Area Edible Oil Deployment

Enhanced Attenuation (EA) is a recent approach to environmental cleanup, and is the product of a partnership between DOE and the Interstate Technology and Regulatory Council (ITRC). Enhanced Attenuation encourages up-front active engineering solutions that alter the environment in such a way that contamination plumes will passively stabilize and shrink and to document that the results will be effective, timely, and sustainable. This approach often involves innovative combinations of technologies. One of the first Enhanced Attenuation projects was performed at the Savannah River Site T-Area. The enhanced attenuation activities at T-Area included: 1) vegetable oil deployment in the deep soil zone beneath the former source, 2) emulsified vegetable oil deployment within the core of the groundwater plume, and 3) stimulation of aerobic attenuation in the fringes of the plume. This combination of actions reduced the release of chlorinated solvents from the former source and resulted in effective contaminant destruction throughout the groundwater plume.

The T-Area deployment was supported by a unique leveraging approach in which full-scale remediation activities were funded by the SRS operating contractor (Area Completion Projects, ACP) while the applied science development and monitoring of enhanced attenuation was performed by the Savannah River National Laboratory (SRNL) supported by EM Headquarters.

The T-Area implementation of Enhanced Attenuation approach was overseen by a "Core Team," a partnership that includes state and federal regulators, DOE, ACP, SRNL scientists, and others. The Core Team reviewed monitoring data from the site; data that demonstrated that the contamination plume decreased in size and concentration, that contaminants are being destroyed, and that T-Area is now progressing steadily and passively toward remediation goals.

At the T-Area groundwater operable unit, the successful pilot study and subsequent regulatory approval to implement enhanced attenuation (EA) of chlorinated solvents using edible oils and structured geochemical zones resulted in the shutdown of an active pump and treat system. The EA approach eliminated the O&M cost of the pump and treat and air stripper system (estimated at approximately $1M per year) and has stabilized and shrank the contaminated plume in a sustainable manner. The minor intervention to optimize the geochemistry and degradation processes will reduce the time for closure from over 30 years using pump and treat to approximately 10 years under monitored natural attenuation (MNA) and significantly reduce greenhouse gas emissions and energy consumption.

CONCLUSION

Under the umbrella of the Enterprise.SRS initiative, SRS is employing strategies and technologies that efficiently and cost-effectively transition site cleanup from active treatment systems to more passive or enhanced passive remedial approaches. Key factors in achieving this transition include a proper diagnosis of the site problem, the proper matching of a remedy(s) to the site-specific condition, and the demonstration of the transitional approach at an appropriate field scale. These transitional approaches provide a more effective and efficient means to achieve end state objectives and result in significant cost savings/avoidance.

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