# Environmental Stewardship at the Savannah River Site: Generations of Success – 13212

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## ABSTRACT

Approximately sixty years ago, the Savannah River Site (SRS) was built to produce nuclear materials. SRS production operations impacted air, soil, groundwater, ecology, and the local environment. Throughout its history, SRS has addressed these contamination issues directly and has maintained a commitment to environmental stewardship. The Site boasts many environmental firsts. Notably, SRS was the first major Department of Energy (DOE) facility to perform a baseline ecological assessment. This pioneering effort, by Ruth Patrick and the Philadelphia Academy of Sciences, was performed during SRS planning and construction in the early 1950s. This unique early generation of work set the stage for subsequent efforts. Since that time, the scientists and engineers at SRS proactively identified environmental problems and developed and implemented effective and efficient environmental management and remediation solutions. This second generation, spanning the 1980s through the 2000s, is exemplified by numerous large and small cleanup actions to address metals and radionuclides, solvents and hydrocarbons, facility and area decommissioning, and ecological restoration. Recently, a third generation of environmental management was initiated as part of Enterprise SRS. This initiative to "*Develop and Deploy Next Generation Cleanup Technologies*" formalizes and organizes the major technology matching, development, and implementation processes associated with historical SRS cleanup success as a resource to support future environmental management missions throughout DOE. The four elements of the current, third generation, effort relate to: 1) transition from active to passive cleanup, 2) in situ decommissioning of large nuclear facilities, 3) new long term monitoring paradigms, and 4) a major case study related to support for recovery and restoration of the Japanese Fukushima-Daiichi nuclear power plant and surrounding environment.

## INTRODUCTION

The Savannah River Site (SRS) commitment to environmental stewardship has spanned several generations over more than 60 years. These include: a) an early period of baseline activities and monitoring, b) a middle period of active environmental cleanup and facility decommissioning, and c) a current focus on next generation cleanup technologies to support successful a high level of environmental stewardship, practical facility closure, and effective end state achievement. Each of these generations is discussed in more detail below with exemplars of the work.

## FIRST GENERATION: EARLY WORK

The first generation began in 1951 with development of baseline environmental assessments prior to facility operations and the establishment of a detailed environmental monitoring program to study the impacts of operations on the environment over time. These earliest activities were supported by the Atomic Energy Commission and DuPont and were performed by the Savannah River Laboratory (now Savannah River National Laboratory, SRNL), the Philadelphia Academy of Sciences, the University of Georgia (now the Savannah River Ecology Laboratory, SREL), the US Forest Service (USFS), and others [see 1].

As noted above, an important early action was a preoperational baseline assessment that was performed between 1951 and 1953. This survey (e.g., Figure 1) was coordinated by SRNL and performed in collaboration with the Philadelphia Academy of Sciences, a technical organization that had provided similar services to DuPont who had formulated and implemented a corporate policy of performing preoperational surveys at all major new facilities. The preoperational survey included 6600 samples collected from an area of 6000 sq miles over an 18 month period of time. The Philadelphia Academy of Sciences was then contracted to monitor the ongoing health of the Savannah River and other water bodies. This early focus was expanded by the Atomic Energy Commission (AEC, now the US Department of Energy, DOE) to include local Universities (the University of Georgia (UGA) and the University of South Carolina) and the ecological monitoring has continued through the present.

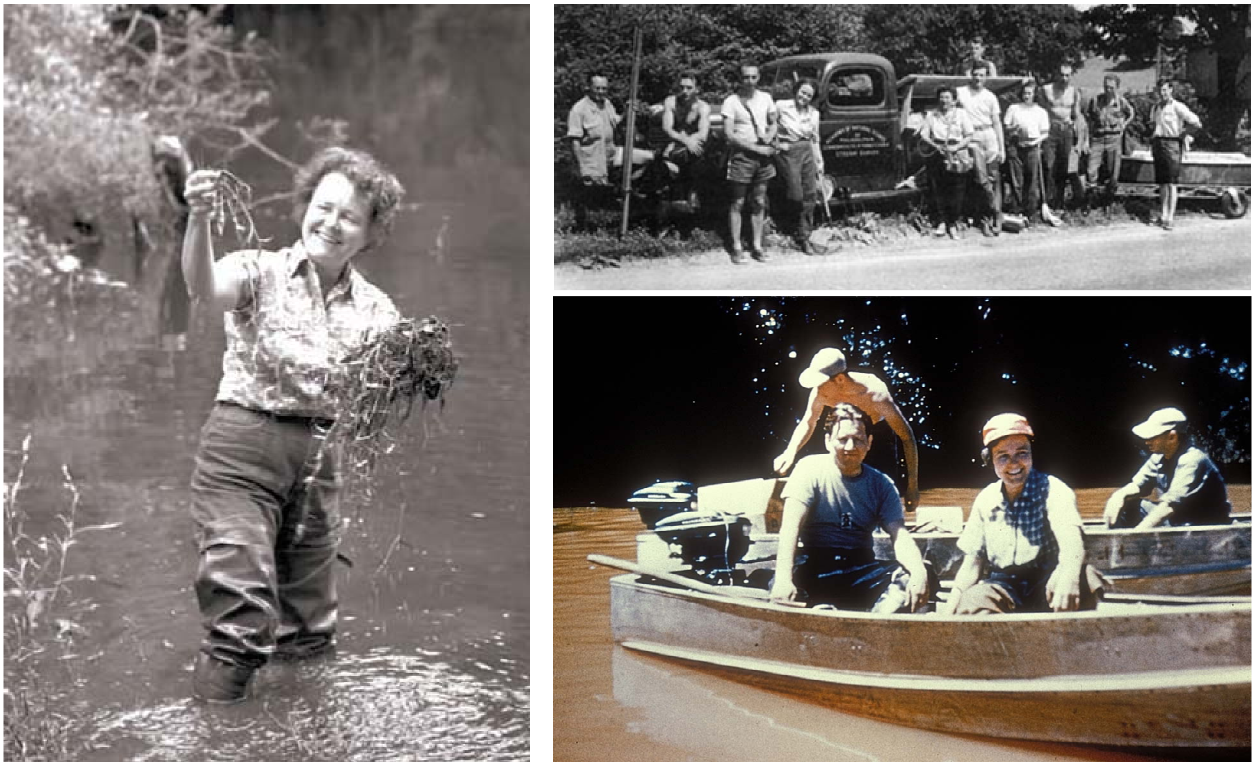


Figure 1. Dr Ruth Patrick (left) and crews from the Philadelphia Academy of Sciences (right) performed preoperational surveys and ongoing monitoring of the Savannah River Site

From its inception, environmental research on the SRS was multi-disciplinary, involving collaboration with many universities and institutions. DOE has strongly supported this collaboration with the support and oversight of SRNL. A notable achievement in the first generation, formation of the Savannah River Ecology Laboratory (SREL), grew out of the vision of Eugene Odum. Early beginnings were modest in funding: $10,000 per year for UGA in Odum's first Atomic Energy Commission grant with a similar amount for South Carolina to conduct biotic inventories. In 1961, UGA formed SREL as the premier international center for applied- and radio- ecology. Odum and his colleagues (Figure 2) advocated a new systems approach that emphasized ecological interactions and relationships and a ground-breaking emphasis on the interaction of human activities with natural systems. The efforts at SREL have generated more than 3000 scientific publications, 60 books and hundreds of popular science articles. In commitment to students, SREL has supported the work of over 650 undergraduate students (from all 50 states and throughout the world), 450 Master's theses and doctoral dissertations. In commitment to the community, SREL has provided active outreach – in recent years this has included more than 300 talks per year to local schools and civic organizations, and the Ecologist-for-a-Day program (twice a week).

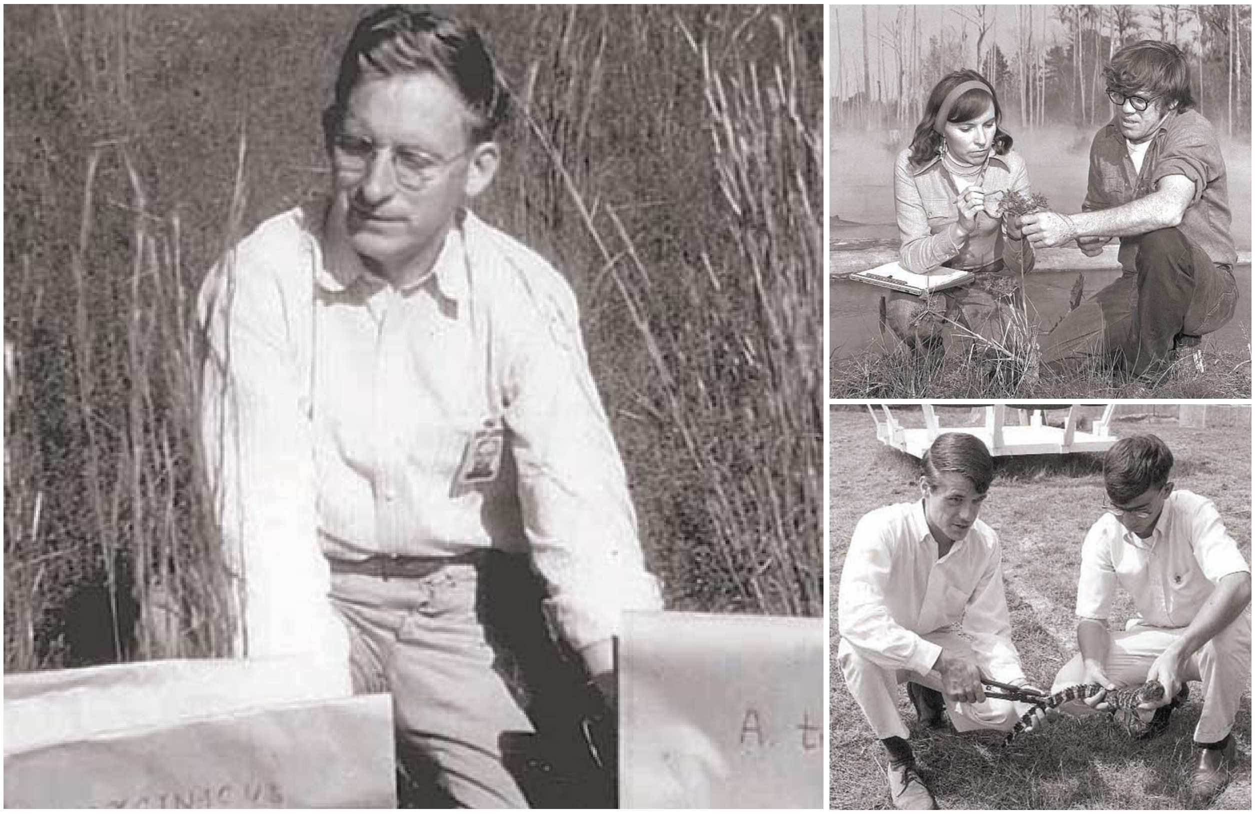


Figure 2. Dr Eugene Odum (left) some of his colleagues at the Savannah River Ecology Laboratory -- Sharitz and Gibbons (upper right) and Brisbin and a student (lower right)

During this same period (beginning in 1952), DOE created a partnership with the USFS to restore the forests and manage the land resources (much of the land was initially farmland, cut-over forest, or abandoned fields). By the 1960s, the USFS developed a land management plan for SRS, conducted a forest inventory, began timber harvesting, and initiated a research-based wildlife program that includes controlled deer hunts. In 1980, the USFS began prescribed burns to reduce wildfire hazards and to enhance habitat for the endangered Red-cockaded woodpecker and other wildlife species. The interagency partnership of DOE and the USFS has proven to be an effective and efficient land management model.

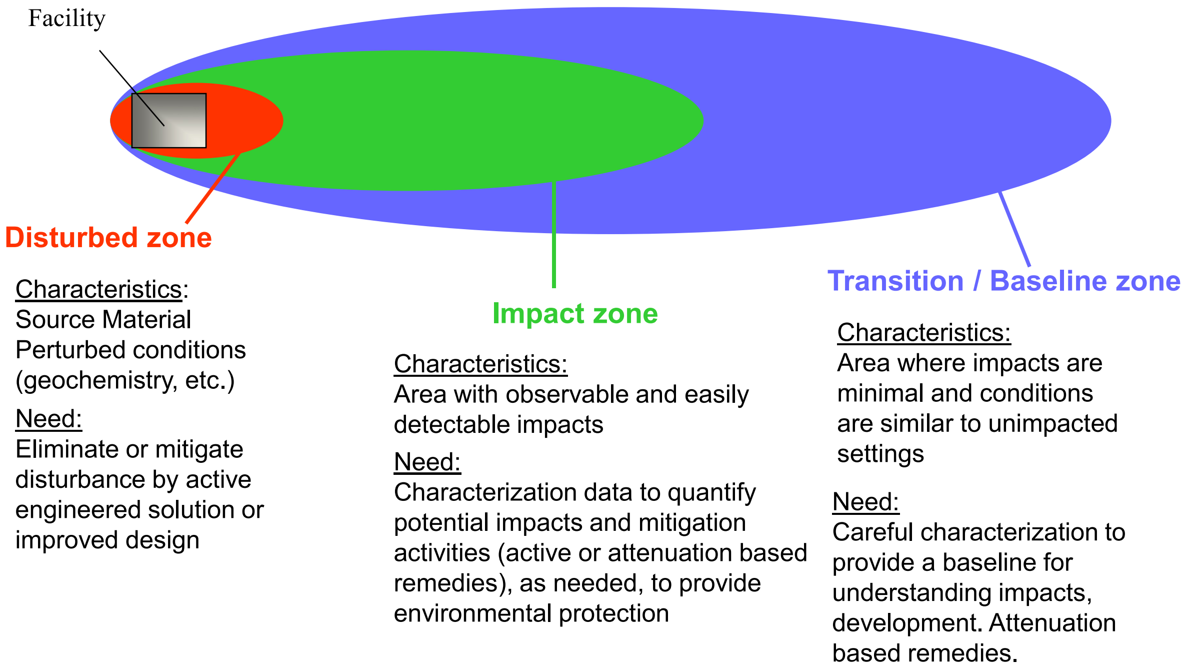
In 1954, concurrent with facility startup, SRS initiated the development of an annual environmental report that provided detailed multimedia data that documented the impacts of SRS operations on the surrounding environment. Publication of this annual report has continued uninterrupted through the present day. These early efforts were groundbreaking for a major federal facility in the mid-20th century and created a culture of vigilance and technical creativity at SRS. In recognition for these pioneering efforts, SRS was the first DOE facility formally recognized as a National Environmental Research Park in 1972 [2].

## SECOND GENERATION: ACTIVE CLEANUP AND FACILITY DECOMISSIONING

The second generation of SRS environmental stewardship, beginning in about 1980, focused on active environmental cleanup of facilities, soil and groundwater impacted by contamination. This generation is exemplified successful closure of waste sites, a collaborative and open environmental management program operating in partnership with regulatory agencies and stakeholders, and the development and use of innovative technologies. The types of waste units to be addressed included: landfills (e.g., large radioactive waste burial grounds and early construction operational disposal pits (< ¼ acre)), chemical and radioactive seepage basins & associated process sewer lines, decommissioned facilities and area operable units, contaminated groundwater operable units, and contaminated stream ("integrator") operable units. Environmental contaminants associated with these facilities included radionuclides, organic solvents and metals.

A cooperative regulatory relationship was established through a Federal Facilities Agreement (signed in 1993). Through 2012, remediation of 380 of 515 FFA Waste Sites is complete with a 75% footprint reduction. Key to the success was disciplined engineering and safe operations combined with a science based process to identify the characteristics that control contaminant behavior and associated risk and then to carefully match technology solutions to those site specific conditions. 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.

Figure 3 provides a simplified conceptual plan view diagram of a facility that has impacted the surrounding environment. The three ovals – the disturbed zone, the impact zone, and the transition/baseline zone – represent different portions of the affected environment. Each of these zones has a different character. The disturbed zone received relatively high levels of contaminant. The impact zone often manifests as a primary contaminant plume that contains lower levels of pollutants than the disturbed zone but still represents a potentially significant present or future hazard. The transition/baseline zone contains contamination at relatively low concentrations but impacts relatively large volumes of water (or air or soil). For a real-world target problem, the contaminated areas are not simple ovals. Instead, contamination occupies a complex three-dimensional geometry and encounters multiple geochemical conditions and geological materials as it travels through subsurface (vadose zone and groundwater), surface water (e.g., wetlands and streams), and/or the atmosphere. The site-specific technology assessment process considers these multiple levels of complexity to identify areas of opportunity.



**Disturbed zone**

Characteristics:
Source Material
Perturbed conditions (geochemistry, etc.)

Need:
Eliminate or mitigate disturbance by active engineered solution or improved design

**Impact zone**

Characteristics:
Area with observable and easily detectable impacts

Need:
Characterization data to quantify potential impacts and mitigation activities (active or attenuation based remedies), as needed, to provide environmental protection

**Transition / Baseline zone**

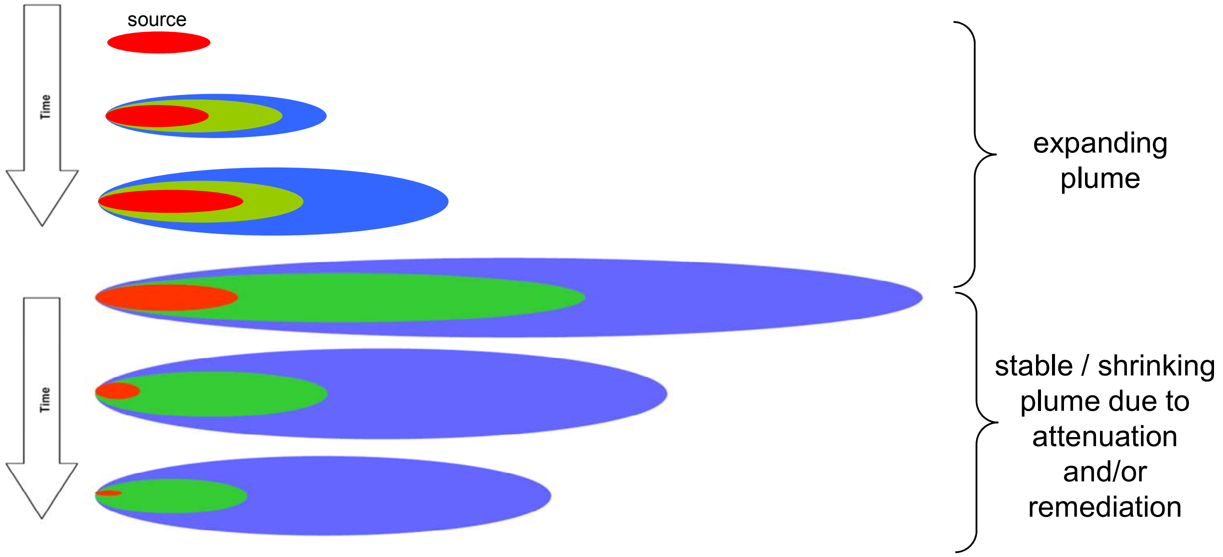
Characteristics:
Area where impacts are minimal and conditions are similar to unimpacted settings

Need:
Careful characterization to provide a baseline for understanding impacts, development. Attenuation based remedies.

Figure 3. Simplified conceptualization of facility impacts on the surrounding environment and technology matching principles developed by SRNL

In the case of groundwater contamination, the changing size and structure of a contaminant plume is a dynamic process with conditions that change in both space and time. Figure 4 schematically depicts the general trends of plume expansion stabilization and shrinkage and overlays the examples of potential matches of remedial technologies for application – this approach is used to help apply appropriate technologies and to transition technologies (e.g., from active to passive) at appropriate times.

**a) simplified representations of a groundwater plume in space and time**



**b) potential remedial technologies**

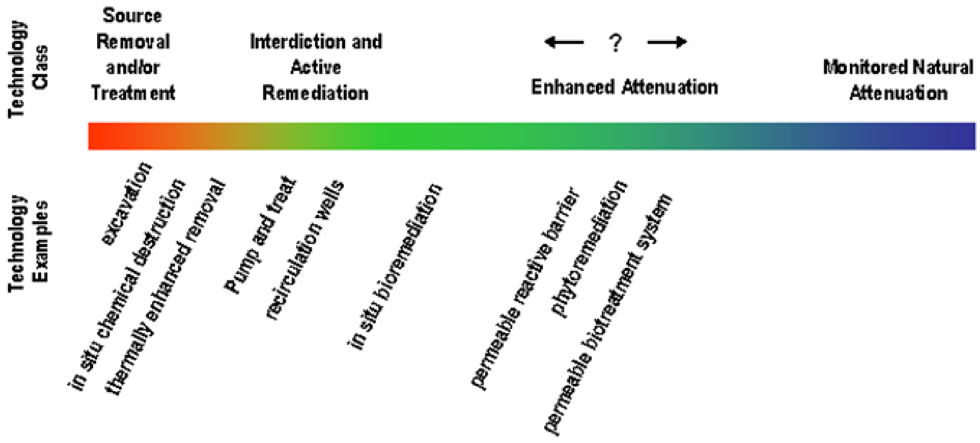


Figure 4. Simplified depiction of plume structure over time and the matching of potential remediation technologies

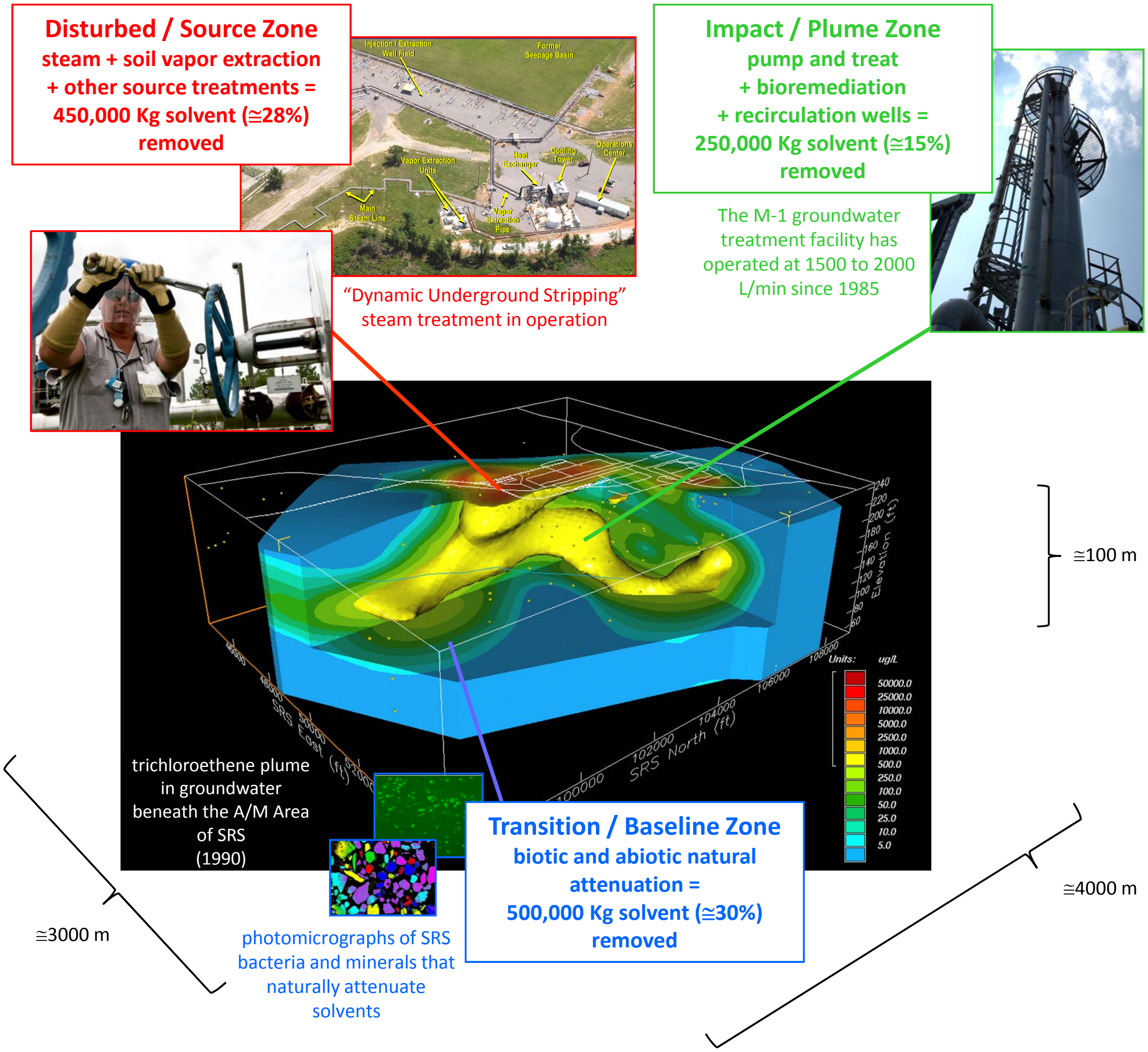
The result of this approach has led to numerous innovative technology successes. For example:

- Use of aggressive technologies like dynamic underground steam stripping of industrial solvents from the soil in highly contaminated disturbed zone associate with the M-Area Settling Basin (resulting in removal of chlorinated solvents and depletion of a future groundwater source),
- In Situ geochemical and biological treatments in M Area, F Area, and T Area to treat target plumes of moderate contamination in the impact zone.
- Enhanced and Natural Attenuation in areas with low levels of contamination such as T Area and M Area.

Figure 5 summarizes the technology matching and application approach for an example problem, M-Area groundwater, at SRS. As emphasized in this figure, the various target zones (red, green and blue) and the subsurface plume in a real world site is not simple ovals (the 1992 trichloroethene, TCE, plume is depicted). Instead, this contaminant plume occupies a complex three dimensional geometry determined by geologic heterogeneity and hydrologic boundaries (i.e., locations where water enters and exits the subsurface). In M Area, approximately 1.6 million Kg of industrial solvents were released to the subsurface beginning in the early 1950s [3].

Key remedial actions in the disturbed/source zone, the red zone, notably include full scale soil vapor extraction (SVE) and dynamic underground stripping (DUS, a thermal-steam cleaning of contaminated soil and shallow groundwater), as well as pilot scale chemical oxidation and other technologies. To date, these red zone activities removed approximately 450,000 Kg of solvents (circa 28% of the original releases). Notably, treatments in the red zone were initiated in the 1980s after 30 years historical discharges. Releases from the source during this lag time allowed a large groundwater plume to develop, necessitating active groundwater treatment. A number of technologies were applied in the green zone, including groundwater pump and treat, bioremediation, and groundwater recirculation wells. The green zone actions removed approximately 250,000 Kg of solvents (circa 15% of the original release). Additionally, as source areas approach cleanup, technology transitioning from active-expensive methods to more passive methods was implemented. For example, active SVE was shifted to passive SVE (solar and barometric pressure powered SVE) throughout M Area. A current focus of work is elucidating and documenting natural attenuation mechanisms and rates. In M Area, the primary attenuation mechanisms are biotic (aerobic cometabolism) and abiotic (reactions of solvents with minerals that contain Fe(II)). A rough (order of magnitude) estimate for natural attenuation based on a conservative 40 year half-life, suggests that 500,000 Kg of solvents (circa 30% of the original releases) may have been degraded by natural attenuation. This relatively large percentage results from the large plume size (natural attenuation "operates" in the entire plume footprint) and the long timeframe (natural attenuation has "operated" for over 60 years while the active treatment activities were performed over significantly shorter timeframes).

Note that the contaminant removal performance of the active treatments (SVE, DUS, groundwater pump and treat, etc.) is relatively certain and based on measured data, while the original mass released and the natural attenuation impacts are less certain. Nonetheless, the current data indicate that the active and passive treatment activities have removed over 70% of the original releases and contributed to substantial reductions in contaminant concentrations in groundwater, plume stabilization, and a path to closure for this complex and challenging site. Applied research is underway to definitively quantify natural attenuation processes and rates. This work will support transitioning the site into a passive monitored natural attenuation status.



**Disturbed / Source Zone**
steam + soil vapor extraction
+ other source treatments =
450,000 Kg solvent (≅28%)
removed

"Dynamic Underground Stripping"
steam treatment in operation

**Impact / Plume Zone**
pump and treat
+ bioremediation
+ recirculation wells =
250,000 Kg solvent (≅15%)
removed

The M-1 groundwater
treatment facility has
operated at 1500 to 2000
L/min since 1985

trichloroethene plume
in groundwater
beneath the A/M Area
of SRS
(1990)

**Transition / Baseline Zone**
biotic and abiotic natural
attenuation =
500,000 Kg solvent (≅30%)
removed

photomicrographs of SRS
bacteria and minerals that
naturally attenuate
solvents

Figure 5. Implementation of remediation technologies in the various target zones of SRS A/M Area

During the second generation, the SRS Environmental Management program focused on active cleanup and transitioning to more efficient methods as conditions on the ground change through time. For example, using innovative geochemical and bioremediation methods, remediation of groundwater in both F Area and T Area was transitioned from expensive pump and treat to low cost passive in situ strategies – an approach that was put into broader use in collaboration with the Interstate Technology and Regulatory Council [4]. During this period, characterization and monitoring technologies have evolved to use lower cost field screening methods and minimally intrusive access and measurement technologies where appropriate. These and many other examples have been described in detail in journal articles, reports and scientific presentations [e.g., 5-11].

## THIRD GENERATION: DEVELOP AND DEPLOY NEXT GENERATION CLEANUP TECHNOLOGIES

Based on a legacy of success in environmental stewardship, SRS is now focused on the Develop and Deploy Next Generation Cleanup Technologies initiative as a part of Enterprise SRS. The overarching goals of this important stage of environmental management activities are to further improve and accelerate "final" cleanup activities at SRS and to export technical information and support to other national and international cleanup programs, encouraging broader use of creative, practical, and implementable solutions to mitigate human health and ecological risk and obtain sustainable end states. Four elements of the Develop and Deploy Next Generation Cleanup Technologies initiative formalize and organize some of the major technology matching and development activities associated with historical SRS cleanup success (items 1-3 below) and an important case study supporting other contaminated sites (item 4): 1) transition from active to passive cleanup, 2) in situ decommissioning of large nuclear facilities, 3) new long term monitoring paradigms, and 4) support for recovery and restoration of the Japanese Fukushima-Daiichi nuclear power plant and surrounding environment.

Specific goals of the various elements are to:

- refine and export active-to-passive environmental cleanup transition strategies to a broad range of customers (e.g., government, academia, industry) dealing with groundwater, surface water and soil (vadose zone) challenges in a variety of geologic settings and for multiple contaminants. Catalyze the acceptance and wide-spread application of innovative passive treatment and enhanced attenuation technologies;
- leverage SRS in situ decommissioning concepts, approaches, research and facilities to broadly assist in national and international government and private industry decommissioning applications. Provide critical services based upon the SRS experience in decommissioning and reactor entombment technology (e.g., grout formulations for varying conditions, structural and material sciences);
- develop technically based Long-Term Monitoring (LTM) strategies to meet regulatory requirements and reduce the life-cycle cost of monitoring and maintaining activities at government and private industry cleanup sites and improve the quality and value of environmental data for decision-making. Advance a LTM paradigm based on integrating traditional point source concentration monitoring with measurements of boundary conditions and controlling geochemistry;
- Support the technical needs in Japan to address critical environmental challenges on/near the Fukushima-Daiichi nuclear facility and to provide deployable technology options for remediation and decommissioning. Facilitate and execute focused mutually beneficial programs for Fukushima remediation and recovery and bring scientific and technical knowledge back to the U.S.

## SUMMARY

Environmental stewardship activities at SRS have evolved through time. Early efforts focused on understanding the baseline environment and the interrelationships between facility operations and the local/regional environment. Middle stage efforts focused on active remediation and mitigation of contaminant impacts. Current efforts focus on efficiently and effectively applying the environmental stewardship concepts and lessons-learned as DOE moves forward. Throughout the "generations", SRS has maintained a commitment to protecting and preserving the environment, remediating and restoring contaminated areas, and developing practical scientific and engineering solutions that are properly matched to complex challenges.

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