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## **Forest Irrigation of Tritiated Water: A proven tritiated water management tool – 13357**

Phil Prater\*, Gerald Blount\*\*, Thomas Kmetz\*\*\*, Karen Vangelas\*\*\*\*

\* DOE (SRS, P.O. Box A, Aiken SC, 29802, [m.prater@srs.gov](mailto:m.prater@srs.gov))

\*\* SRS (Savannah River Nuclear Solutions LLC, Bldg. 730-4B, Aiken, SC 29808,  
[Gerald.blount@srs.gov](mailto:Gerald.blount@srs.gov))

\*\*\* SRS (Savannah River Nuclear Solutions LLC, Bldg. 730-4B, Aiken, SC 29808,  
[Thomas.kmetz@srs.gov](mailto:Thomas.kmetz@srs.gov))

\*\*\*\* SRS (Savannah River National Laboratory, Bldg. 773-42A, Aiken, SC 29808,  
[karen.vangelas@srnl.doe.gov](mailto:karen.vangelas@srnl.doe.gov))

### **ABSTRACT**

Tritium releases from the Old Radioactive Waste Burial Ground (ORWBG) at the SRS in South Carolina has impacted groundwater and surface water. Tritiated groundwater plumes discharge into Fourmile Branch which is a small tributary of the Savannah River, a regional water resource. Taking advantage of the groundwater flow paths and the local topography a water collection and irrigation system was constructed and has been used at the SRS for over a decade to reduce these tritiated water releases to Fourmile Branch. The tritiated water is transferred to the atmosphere by evaporation from the pond surface, and after irrigation, wetted surface evaporation and evapotranspiration through the forest vegetation. Over the last decade SRS has irrigated over 120,000,000 gallons of tritiated water, which diverted over 6000 curies away from Fourmile Branch and the Savannah River. The system has been effective in reducing the flux of tritiated groundwater by approximately 70%. Mass balance studies of tritium in the forest soils before operations and over the last decade indicate that approximately 90% of the tritiated water that is irrigated is transferred to the atmosphere. Dose studies indicate that exposure to site workers and offsite maximally exposed individual is very low, approximately 6 mrem/year and 0.004 mrem/year, respectively.

To consistently meet the flux reduction goal of tritium into Fourmile Branch optimization activities are proposed. These efforts will increase irrigation capacity and area. An additional 17 acres are proposed for an expansion of the area to be irrigated and a planting of approximately 40 acres of pine forest plantations is underway to expand irrigation capacity.

Co-mingled with the tritiated groundwater are low concentrations of chlorinated volatile organic compounds (cVOCs), and 1,4-dioxane. Research studies and SRS field data indicate the forest irrigation system may have an added benefit of reducing the mass of these co-contaminants via degradation.

This semi-passive system makes use of natural processes of hydrology and evapotranspiration to manage tritium-contaminated water by reducing its entrance into site streams and the Savannah River, as well as treating low levels of co-mingled VOCs. SRS expects to operate the system until

the tritium decays to levels that represent a minimal impact to Fourmile Branch and the Savannah River, and meets the stakeholder expectations.

## INTRODUCTION

Operation of nuclear facilities worldwide has generated wastewater, groundwater and surface water contaminated with tritium. Treatment of environmental tritium contamination is challenging because the properties of the contaminant are similar to those of bulk water. Tritium is not destroyed through treatment; thus, a successful strategy balances lowering the tritium flux with the level of exposure associated with its release. Such an approach was taken by SRS in developing a forest irrigation system to address the impact of tritiated groundwater emanating from the ORWBG into the surface waters of Fourmile Branch.

## BACKGROUND

The Old Radioactive Waste Burial Ground (ORWBG) occupies approximately 76 acres and is located in the central portion of SRS, approximately 5 miles from the nearest site boundary, as shown in Figure 1. The ORWBG is part of the central disposal area for solid radioactive waste at SRS known as the Burial Ground Complex (BGC). Waste was disposed of at the ORWBG from 1952 until 1974.

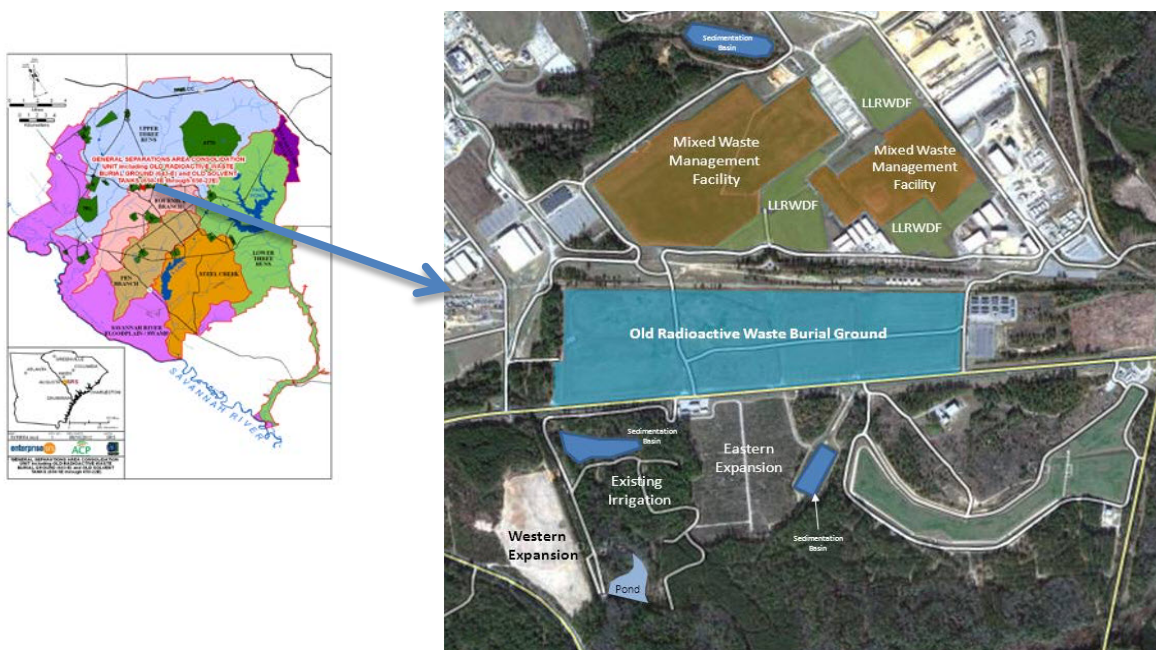


Figure 1. The ORWBG is located near the center of the SRS, Aiken, SC. The ORWBG, a subunit of the General Separations Area Consolidation Unit, is depicted in the aerial photograph in relation to the other subunits.

During its operational history, approximately 7,125,000 ft<sup>3</sup> of radioactive wastes were buried within the ORWBG. Volumetrically, the majority of the disposed materials were low-level incidental waste from laboratory and production operations. Most wastes were placed in drums, cans, cardboard boxes, plastic bags, and metal containers and then buried in earthen trenches approximately 20 ft deep. At the time of burial, approximately 5.1 million curies (Ci) of radioactivity was placed in the ORWBG. Much of the short-lived radioactivity has decayed, but a large inventory of radioactive and hazardous substances remain buried at depth in the ORWBG. In addition, Old Solvent storage Tanks (OSTs) within the ORWBG held spent Plutonium-Uranium Extraction solvent and smaller quantities of tritiated pump oil.

Tritium and trichloroethylene (TCE) are the main contaminants of concern (COCs) impacting the groundwater downgradient of the ORWBG. Groundwater monitoring dates back to 1979 for tritium in the BGC. Monitoring for volatile organic contaminants (VOCs) began in 1988. The tritium and TCE plumes are co-mingled. During the 1994-1995 characterization 1,4-dioxane was not recognized due to poor analytical methods available at that time. In November 2002, as analytical methods improved, 1,4-dioxane was added to the groundwater monitoring program as it would be a likely contaminant due to use as a stabilizer in chlorinated solvents, paint strippers, greases, and waxes [1]. It was detected in several wells during the first round of sampling in 2003. The 1,4-dioxane plume is co-mingled with the TCE plume. Each of these contaminants presents unique challenges. Both TCE and 1,4-dioxane are recalcitrant organics, while tritium in the form of tritiated water (HTO) is similar in properties to water. Thus, tritium at concentrations found in groundwater environments is difficult to treat in a cost effective manner because of the challenges in separating the HTO from water (H<sub>2</sub>O). [2]

## **Regulatory History**

The ORWBG, a sub-unit of the General Separations Area Consolidation Unit (GSACU), is listed as a RCRA 3004(u) Solid Waste Management Unit/ CERCLA unit in Appendix C of the Federal Facility Agreement (FFA) for the SRS. The media associated with the GSACU are soil, sediment, and debris. Two interim actions have taken place at the ORWBG: installation of a soil cover to decrease stormwater infiltration into the underlying waste and emptying, stabilizing and grouting in place the OSTs [3,4]. The final source action as documented in the Record of Decision for the GSACU was placement of a low-permeability geosynthetic cover system. This action was completed August 2007; thus, mitigating the potential for future leaching of contaminants to the groundwater.

The corrective action for the groundwater contamination associated with the ORWBG is managed under the RCRA Part B permit for the Mixed Waste Management Facility (MWMF) [5]. The remedial goal associated with tritium is a 70% reduction of tritium flux to Fourmile Branch. The approved corrective action for the tritium began as an interim measure in 2000. This action is the

current forest irrigation system. The corrective action for VOCs is natural degradation with a requirement for ongoing effectiveness monitoring and continual assessment to evaluate if future enhancements or modifications are necessary [5]. At present, no corrective action has been defined in the permit to address 1,4-dioxane. However, the latest permit modification request submitted in 2012 by SRS proposes use of the forest irrigation system as the remedy.

## **TRITIUM MANAGEMENT**

### **Tritium Treatment at the ORWBG**

A water collection and irrigation system downgradient of the ORWBG has been used at the SRS for over a decade to reduce the discharge of tritiated water to Fourmile Branch. The system consists of a small sheet pile dam over the portion of the seeps with the highest tritium concentration, a surface pond that collects the contaminated groundwater behind the dam and an irrigation system to that distributes the water to a mixed pine/hardwood forest and to a planned, planted and managed pine forest. Taking advantage of the local topography, hydrology and location of the tritium plume, the collection pond was constructed within a small valley with sheet pile driven approximately 40 below surface. The location of the pond and the placement of sheet pile help to intercept the tritiated water and promote redirection to the pond. The collection pond intercepts surface water emanating from springs down-gradient of the ORWBG. The flux of water into the retention pond is dependent on many factors (e.g., seep rate, prevailing rainfall rate, and stormwater runoff rate). A pumping/transfer system dispositions the collected water to the irrigation system. The irrigation system located over the plume area covers an area of approximately 50 acres, as shown in Figure 2. The irrigation process causes direct evaporation of water containing the tritium, TCE and 1,4-dioxane, oxidation of the VOCs, and uptake of water into trees for transpiration to the atmosphere. The water level within the pond is maintained at a level to minimize subsurface bypassing around the sheet pile.

Pine trees were chosen for the expansion of the system because pine plantations provide a higher vegetative density and a higher wetted surface evaporation and evapotranspiration potential. This additional irrigation capacity will help operations during winter months when the evaporative losses associated with the irrigation rates/acre are greatly reduced. It is necessary to be able to irrigate the forests plots, without over wetting, at a rate to maintain the pond level so there is a positive flux of seep/ground water into the pond. This supports capture of the tritium.

The results from the ongoing sampling program are evaluated to determine the effectiveness of the forest irrigation system. This includes sampling of monitoring wells, pond and stream surface waters, wetland samples and soil cores within the irrigation plots. Tritium monitoring of Fourmile Branch surface water downstream of where the tritium plume enters the Branch indicates an approximate 70 % decrease in tritium concentrations in Fourmile Branch after the irrigation

system began operation, as illustrated in Figure 3. Operation of the system has resulted in decreasing concentrations of tritium in the water applied to the forested plots, as shown in Table I, Column E. Long-term weather patterns impact the operation and monitoring of the system. For example, the drought conditions in 2011 resulted in a reduction in curies being irrigated through the system as the evaporator could not operate for 6 months due to lack of water infiltrating the system.

While the system is having the intended impact of reducing the tritium flux to Fourmile Branch, mass is conserved. Through the irrigation system, the tritium is transferred to the atmosphere by evaporation from the pond surface, and after irrigation, wetted surface evaporation and evapotranspiration through the forest vegetation. In order to assess the impact to site workers and offsite maximally exposed individuals, mass balance and dose studies are conducted. Annually forest soils within the irrigation system are sampled for tritium and estimates of evapotranspiration are calculated. As illustrated in Figure 4, the annual evapotranspiration rate is 85 to 90%, indicating that most of the tritiated water that is irrigated is transferred to the atmosphere. Dose studies associated with this treatment system indicate the exposure to site workers and offsite maximally exposed individuals is very low, approximately 6 mrem/year and 0.004 mrem/year, respectively [6].



Figure 2. Irrigation pond and plots layout for the forest irrigation of tritium.

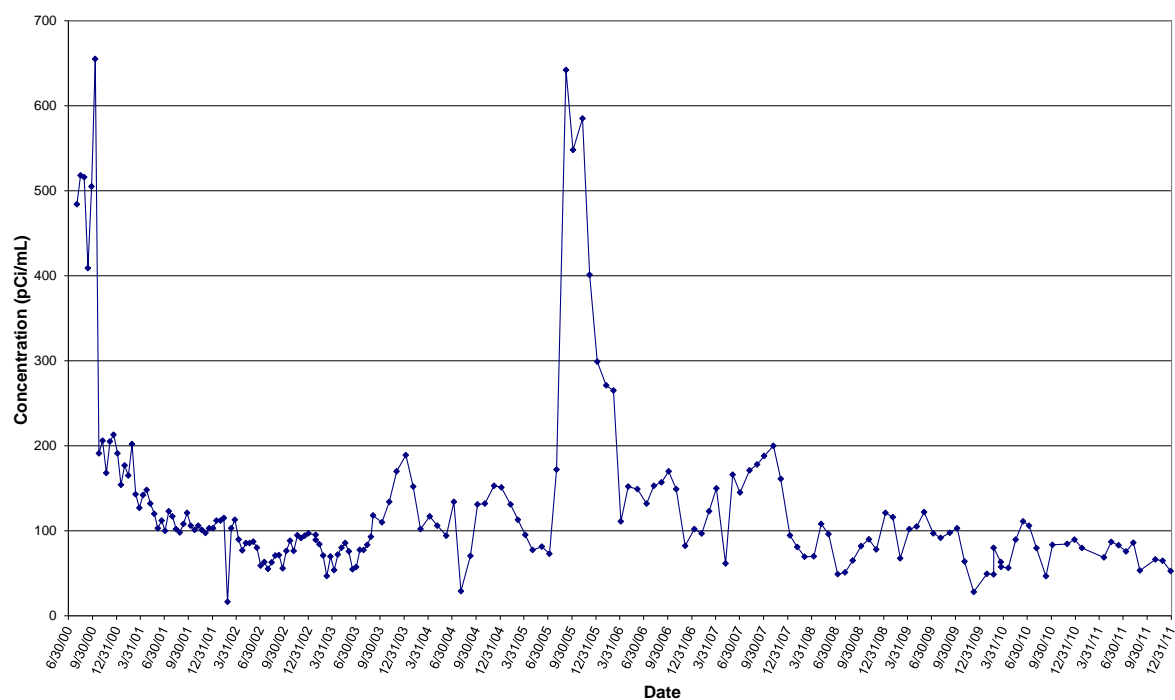


Figure 3. Tritium concentrations in Fourmile Branch

Table I. Annual Phytoremediation Irrigation Rates and Tritium Concentrations

A	B	C	D	E	F
Year	Annual Total Irrigation (million gallons)	Total Tritium (in Curies) Irrigated to Plots/Yr	Annual Total Tritiated Water Sprayed by Evaporator (million gallons)	Total Tritium (in Curies) Evaporated by Evaporator/Yr	Average Annual Tritium Concentrations in the Water (pCi/mL)
2003	9.8	306	NA	NA	9014
2004*†	23.0	169	26.7	23.4	8596
2005*	5.0	151	9.4	29.0	7951
2006‡	7.4	245	0.0	0.0	9000
2007	8.8	275	8.2	29.7	8446
2008	10.7	301	16.2	50.4	7088
2009	8.3	150	21.5	39.6	4353
2010	9.3	96	21.6	22.3	2579
2011	11.4	175	1.0	2.4	3930

\* Available data for period January thru June.

† Evaporator became operational February 2004.

‡ Due to low pond water levels, the evaporator did not operate.

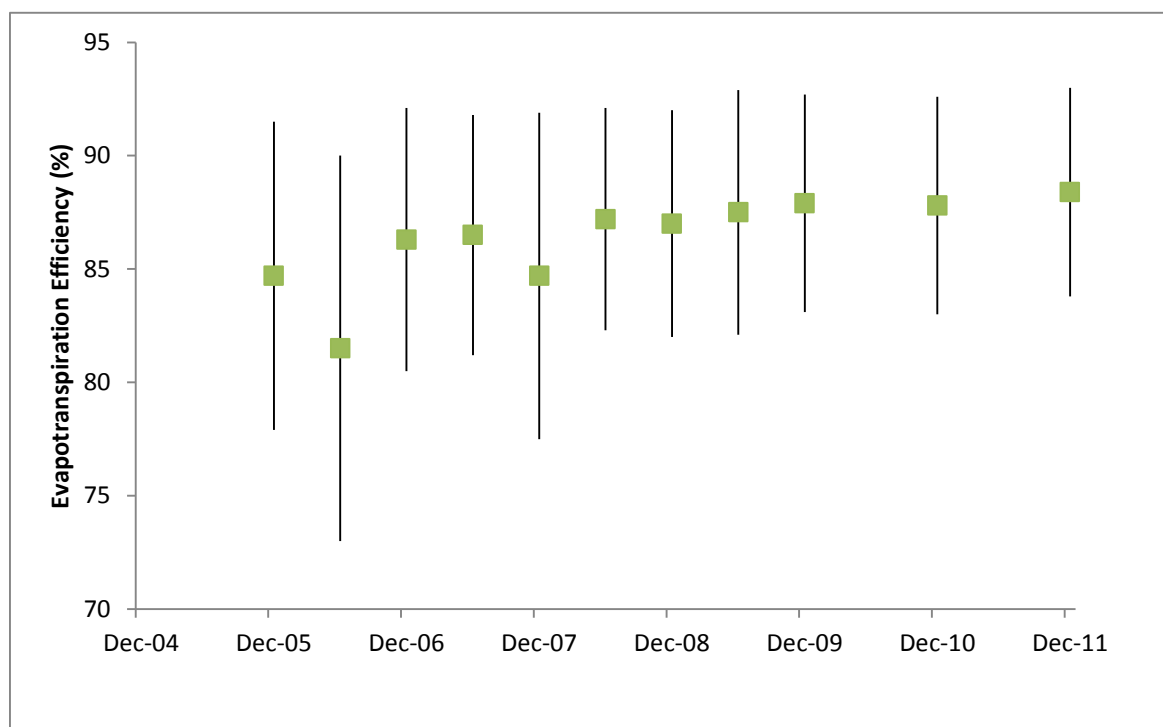


Figure 4. Estimated evapotranspiration efficiency of the irrigation plots for tritium

### Potential for Treating Co-Contaminants

TCE and 1,4-dioxane plumes are co-mingled with the tritium plume. Thus, they are captured by the irrigation system. Henry's law indicates volatilization of TCE and its daughter products from water occurs at a high rate [7,8] while volatilization of 1,4-dioxane occurs at a moderate rate [9]. Once in the atmosphere, both are readily degraded via photo-oxidation [10,11].

Analysis of the forest soil does not indicate the presence of TCE and daughters or 1,4-dioxane after 10 years of operation. These findings are supported by the results of independent scientific laboratory and field studies [12,13,14,15] that indicate TCE is biodegradable in the rhizosphere. Likewise researchers have reported that 1,4-dioxane is highly degradable in biologically active soils by filamentous bacteria and fungus present in leaf mulch [16,17,18]. However, no duplication of these research studies have been conducted on soils from the SRS irrigation plots.

### CONCLUSIONS AND PATH FORWARD

The remedial goal of a 70% reduction of tritium flux to Fourmile Branch and the continuing upgradient source of tritium has led to SRS upgrading the system to increase and optimize the capacity. The system is expected to continue to be effective in managing amount of tritium to

impact Fourmile Branch. SRS expects to operate the system until the tritium decays to levels that represent a minimal impact to Fourmile Branch and the Savannah River. A Western Expansion, for another 17 acres, is proposed to increase the acreage under irrigation. The expansion will improve the wintertime operation that is impacted by reduction in irrigation, will maintain pond volume at a level to reduce hydraulic head on the pond and prevent water from outcropping from under the dam, and will provide the needed treatment capacity necessary in the event of existing tree die-back or damage from insect blight, forest fire, heavy storm events, etc.

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