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# Composite analysis of LLW disposal facilities at the U.S. Department of Energy's Savannah River Site

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## ABSTRACT

Composite Analyses (CA's) are required per DOE Order 435.1 [1], in order to provide a reasonable expectation that DOE low-level waste (LLW) disposal, high-level waste tank closure, and transuranic (TRU) waste disposal in combination with Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), Resource Conservation and Recovery Act (RCRA), and deactivation and decommissioning (D&D) actions, will not result in the need for future remedial actions in order to ensure radiological protection of the public and environment. This Order requires that an accounting of all sources of DOE man-made radionuclides and DOE enhanced natural radionuclides that are projected to remain on the site after all DOE site operations have ceased. This CA updates the previous CA that was developed in 1997. As part of this CA, an inventory of expected radionuclide residuals was conducted, exposure pathways were screened and a model was developed such that a dose to the MOP at the selected points of exposure might be evaluated.

## INTRODUCTION

The U.S. Department of Energy (DOE) Savannah River Site (SRS) is located within the western most part of South Carolina, situated in the south-eastern United States, as shown in Figure 1. The SRS incorporates approximately 780 $km^2$ in 3 counties and approximately 32 km of the Savannah River forms the west boundary of the SRS. Construction of and subsequent operations at the Savannah River Site (SRS) began in 1951 under the direction of the Atomic Energy Commission (AEC). The primary mission of SRS has been to produce defense materials including tritium (H-3) and plutonium (Pu-239). As a result of operations, SRS has generated a variety of radioactive, non-radioactive, and mixed (radioactive and hazardous) wastes. The SRS waste management practices (past and present) include the use of seepage basins for liquids, pits and piles for solids, tanks for high-level radioactive mixed wastes, and landfills for low-level radioactive wastes. DOE is investigating environmental releases on the SRS under its Environmental Restoration Program and under its RCRA permit.

Disposal of Low-level radioactive waste is regulated internally within the DOE complex as per guidance provided in DOE Order 435.1 [1]. This order requires that Performance Assessments (PA's) be conducted for disposal facilities to provide reasonable assurance that the facility design and method of disposal will comply with the performance objectives of the Order, which are concerned with protection of public health and safety in limiting doses to members of the public and limiting releases of radon and protecting the environment.

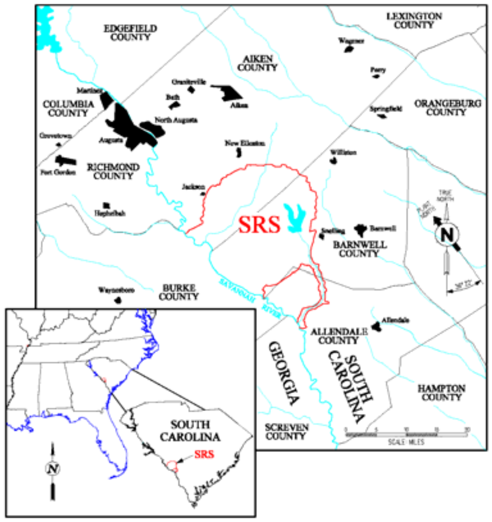


Figure 1 Location of SRS, its LLW disposal facilities and POA's utilized in CA

Composite Analyses (CA's) are also required per DOE Order 435.1 [1], in order to provide a reasonable expectation that DOE low-level waste (LLW) disposal, high-level waste tank closure, and transuranic (TRU) waste disposal in combination with Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), Resource Conservation and Recovery Act (RCRA), and deactivation and decommissioning (D&D) actions, will not result in the need for future remedial actions in order to ensure radiological protection of the public. This Order requires that an accounting of all sources of DOE man-made radionuclides and DOE enhanced natural radionuclides that are projected to remain on the site after all DOE site operations have ceased.

The focus of the CA is on sources which may interact with radionuclide transport from the low-level waste (LLW) disposal facilities, closed high-level waste tanks, and TRU waste disposals resulting in a potential dose to the public. A 1 mSv/yr primary dose limit, based upon USDOE Order 5400.5, "Radiation Protection of the Public and the Environment" [2], has been established as the CA performance measure. However to prevent the potential dose from exceeding a significant fraction of the primary dose limit, an administrative dose constraint of 0.3 mSv/yr has been established. A CA evaluates the dose to a hypothetical member of the public (MOP) at points of assessment, which are selected based upon the site's land use plans, over a minimum 1,000 year period after disposal facility and tank closure and/or all DOE site operations have ceased.

**Previous CA and enhanced scope of current CA**

The SRS issued a CA performed for the two active low-level radioactive waste disposal facilities to the DOE-HQ Low-Level Waste Disposal Facility Federal Review Group (LFRG) for review and approval in November 1997 [3]. The 1997 CA analysis calculated potential releases to the environment from all sources of residual radioactive material expected to remain in the General Separations Area (GSA). The GSA is the central part of SRS and contains the two low-level

radioactive waste disposal facilities along with chemical separations facilities and associated high-level waste tank farms as well as numerous other sources of radioactive material.
While the LFRG CA review team granted conditional approval to the CA it indicated that there was an additional concern that sources of residual radioactive material from the entire SRS, and not just from the GSA alone, should be considered. The current CA is regarded as an update to the 1997 CA and addresses this concern by identifying those potential sources and assessing their potential to intermingle with the releases from disposal facilities. This intermingling occurs in different places depending on the source location within the SRS and which site stream the source will eventually discharge into. Those sources located within the same watersheds as the LLW disposal facilities are evaluated at the mouths of those streams at the Savannah River. For sources located in different watersheds, the evaluation is performed where the sources intermingle, namely within the Savannah River, itself.

## STRUCTURE AND COMPONENTS OF THE SRS CA

The CA investigation has been conducted in several distinct phases, each of which developed important precursor information before an assessment model could be developed. These include the following.

### Radionuclide Inventory Assessment

An assessment was made of the radionuclide inventory expected to remain at the SRS when its End State is reached. The purpose of this assessment was to develop the radionuclide source term to be utilized in the CA analytical model. The term “end state” refers to the status of a facility or waste site after decommissioning and closure activities are complete. There are two possible end state alternatives for SRS facilities: Demolition or In-Situ Disposal (ISD) [4]. Demolition includes demolishing and removing the entire facility to grade, and decontaminating as necessary to meet established release criteria.

45 primary facilities were identified to have the potential to contribute to the offsite dose to a member of the public. Many of these primary facilities also have sub-components that were evaluated individually. Individual facilities are not mentioned here but include the following types of entities:

- Buildings in their anticipated end state
- Seepage basins
- Buried sewer lines
- Groundwater plumes
- Contaminated Streambeds

### Exposure Pathway Screening

For calculating exposure to humans, pathways resulting in contamination of agricultural crops and animals as a result of irrigation with contaminated surface water and deposition or inhalation from the atmosphere as a result of gardening activities, as well as direct ingestion of contaminated surface water, and external radiation from surface water sediment and soil are considered in the dose analysis for the CA. Because the CA points of assessment are assumed to be at the mouths of the SRS streams and in the Savannah River [5], exposure scenarios involving contact with, and use of, contaminated surface water (i.e., stream or river water) were considered. Two exposure scenarios were judged to bound exposures, a recreational scenario and a residential scenario.

### Radionuclide Screening Evaluation

The approach taken in this screening analysis is an extension of the National Council on Radiation Protection and Measurements (NCRP) methodology as described in NCRP 1996 [6]. The screening analysis starts with an arbitrarily large number of curies of a radionuclide (i.e., 3.7E+10GBq) directly in the ground which is then transported through representative unsaturated and saturated regions to a surface water body. The dose was thus calculated based on the radionuclide concentration at the mouths of streams traversing the SRS and did not consider mixing in the Savannah River. The CA screening model was implemented in the GoldSim™ programming environment [7]. The model took advantage of previous modeling work conducted at SRS to guide the selection of material properties and in development of the dose module and compared screening doses against the applicable CA dose limit and constraint. The screening of the 826 radionuclides in [6] resulted in a set of 52 radionuclides to be further analyzed in the CA.

### Conceptual Model

The conceptual model is a conceptualization of the system to be simulated in the CA in order to determine the dose to a hypothetical member of the public at points of assessment, which are selected based upon the site's land use plans, over a minimum 1,000 year period after disposal facility and tank closure and/or all DOE site operations have ceased.

The system evaluation includes the radionuclide releases from near surface sources across the SRS, the vertical transport downward through the vadose zone, lateral transport of these radionuclides through the aquifer to the discharge points along SRS streams, and the determination of dose through the Recreational and Residential exposure scenarios at the points of assessments (POA's) in the stream mouths and Savannah River, respectively. Sources contributing to the releases are from near-surface sources across the SRS and from groundwater plumes and radionuclides adsorbed to streambed sediment. The conceptual model is displayed graphically in Figure 2, as are the locations of the POA's.

### Analysis Model

An analytical model has been developed to evaluate the release and transport scenario described in the conceptual model. The components include near surface, groundwater plumes and streambed sources, vadose zone and aquifer zone transport and stream dilution to the POA's and a dose calculation module. A schematic of these components is indicated in Figure 2. Separate transport regions are indicated in the conceptual model that forms the basis for the analytical model construction. The model was implemented in the GoldSim™ programming environment.[7] The program is a 1-D analytical model that allows simulation of relevant transport and radioactive decay processes involved in delivering a dose to a member of the public at the POA's. The code does not simulate water flow, and therefore the flow terms utilized in this model were based on abstractions from other numerical flow models that have previously been developed at SRS. The basic model element is a mixing cell, in which material properties, water flux terms, and transport parameters are defined. The GoldSim model generic transport regions, the mixing cell definition of those regions and a brief description are provided in Table 1 and a schematic diagram of the components is illustrated in Figure 3.

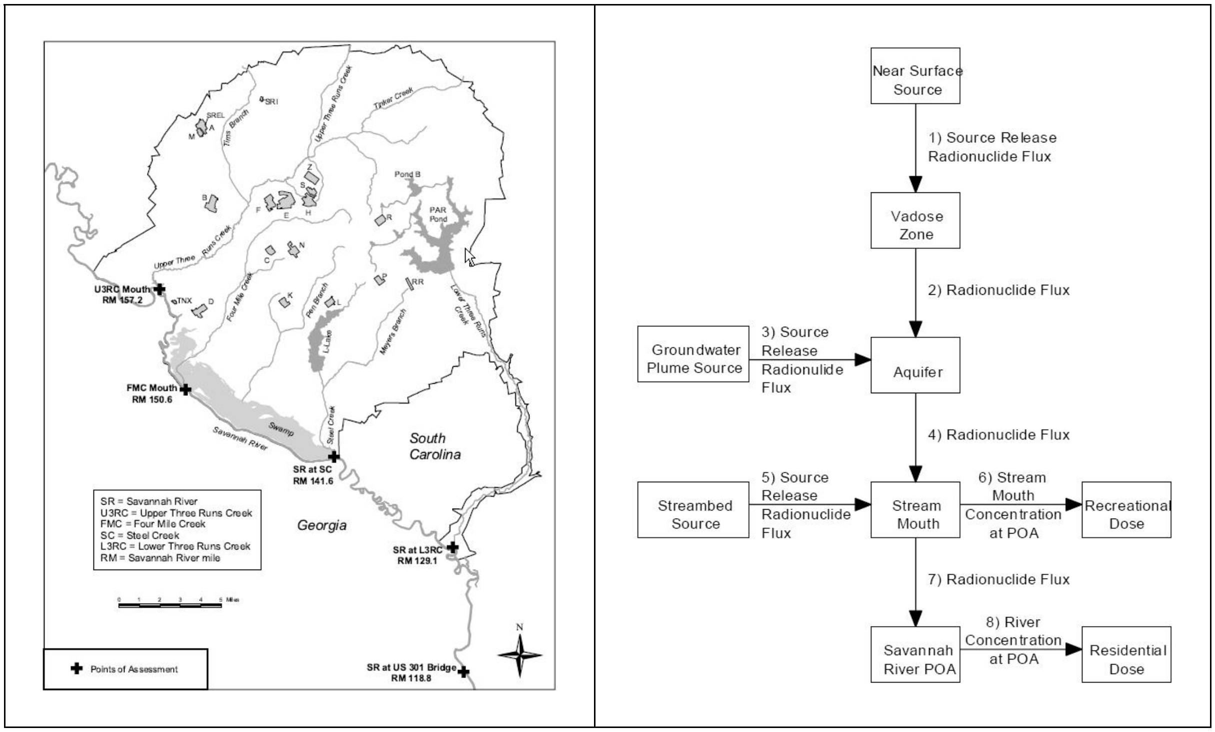


Figure 2 Location of Points of Assessment and Conceptual Model schematic [8].

Table 1. Cell structure for generic transport regions

| Transport Region | Cells | Descriptions |
|---|---|---|
| | | |
| Cap | 3 | Cap material above waste, clay soil or other materials, as needed |
| Waste | 5 | Unit specific inventory placed uniformly into these cells, source type(s) and associated release mechanisms established |
| Barrier | 3 | Barrier material below waste, usually clay soil or concrete |
| Vadose Zone | 20 | Moisture content and water flux obtained from external models, soil properties, contaminant interaction with soil by partitioning coefficients (Kd’s) for specific nuclides in specific materials |
| Footprint | 5 | Transition cells for placement of contaminants into aquifer |
| Saturated Zone | 200 | Water fluxes obtained from external models, soil represented as either sand or clay, radionculide Kd’s material dependent |
| Site stream | 2 | One cell for streambed soil and one for surface water |
| Savannah River | 1 | A single cell to define dilution of contaminants at POA |

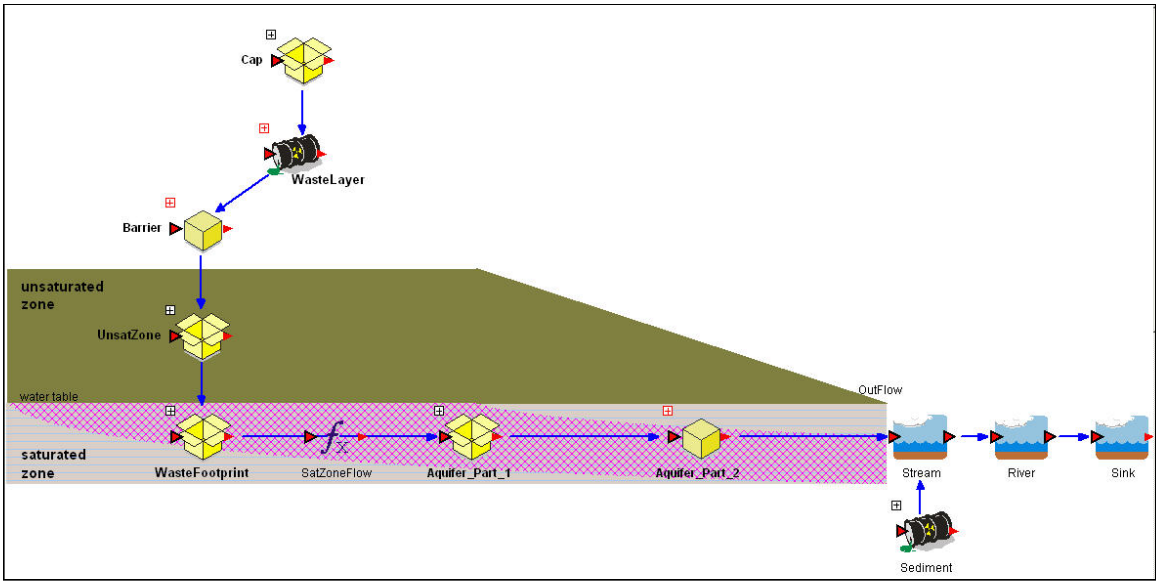


Figure 3 Schematic diagram of the CA GoldSim model.

Within GoldSim, the different regions of the model are organized into compartments, referred to as "containers", for ease of use. The mixing cells described in Table 1 are situated within the relevant containers.

Initially, the contaminant species and their half-life and transport properties and the physical properties of the different soils, water and waste types were defined for global use throughout the model. Model switches were defined to control the key features of the model, for example the timing of the facility closure and/or placement of physical barriers to impede the release of contaminants from the waste source. Representative infiltration rates associated with each waste unit throughout the simulation duration(s) were extracted from external models. Vadose zone thicknesses were obtained by determining the elevation of the base of the specific waste unit and subtracting the elevation of the water table at that locality. Within the aquifer module, the lengths of lateral flowpaths from individual waste sources to the surface discharge zone were obtained from external numerical models where they existed, or from tracing the path length using a contour map for water table elevation in the vicinity of the specific waste unit.

The calculation of dose to the member of the public (MOP) is also performed within analysis model in the Dose module. In this module contaminants discharging to site stream are evaluated at the POA's. The two exposure scenarios evaluated were discussed earlier. In-stream contaminant concentrations were based on the long-term average streamflow at each POA.

Simulations were performed for the 1000-year CA period of assessment to evaluate the total doses to the MOP. Simulations were also extended to much longer periods to determine the expected timing of peak doses. Sensitivity cases will be evaluated to identify key parameters uncertainty in the dose calculations will be evaluated in the GoldSim stochastic mode.

## RESULTS

The model computes the individual radionuclide dose to the MOP for the aggregate release to surface water for all residual sources of radionuclides at the SRS, including LLW disposal facilities in the central portion of the SRS. The dose is a total dose derived from accumulating the dose from all radionuclides to assess the impact against the performance measures of 1 mSv/yr and the administrative control measure of 0.3 mSv/yr. Results of the CA analysis model are presented as graph of the dose calculation versus time.

An example of the typical result is presented in Figure 4. The administrative control measure of 0.3 mSv/yr is indicated by the red line. Below that, the All-Pathways dose is indicated by the blue line. In this case, the simulation was conducted for 10.000 years in order to capture the magnitude and timing of the peak dose to the MOP at a compliance point.

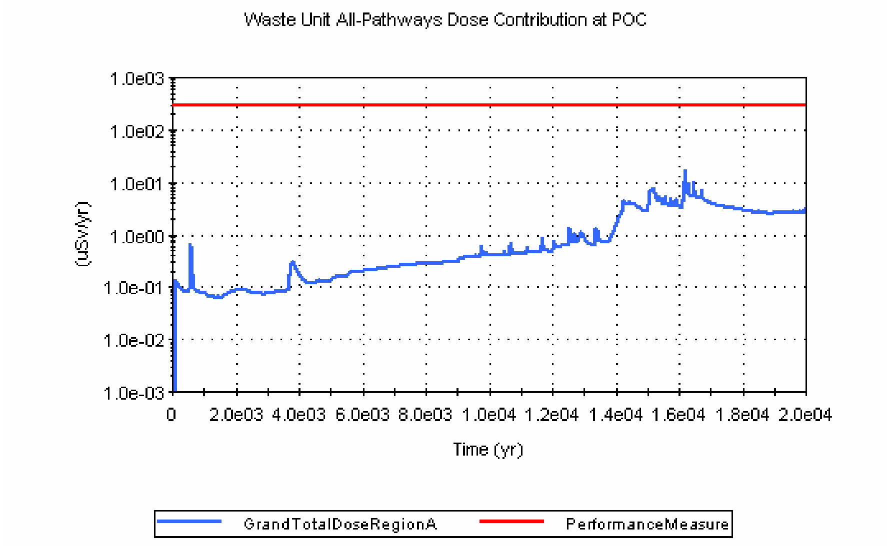


Figure 4 GoldSim dose result at the POA

Simulations are currently underway to evaluate the impact from all expected residual sources of radionuclides at the SRS in terms of aggregate dose to the MOP at the POA's. In addition, a sensitivity analysis will explore the different input parameters to identify the most influential in determining this dose. Finally, when these components of the CA model have been completed, the model will be adapted to evaluate uncertainty. Estimates of parameter distributions are being built into the deterministic model so that they can be readily invoked in the CA uncertainty analysis.

## CONCLUSIONS

A systematic approach has been undertaken to update the previous CA conducted at the SRS and to address the conditions of approval of that CA. In addition to addressing those concerns, a more rigorous model analysis was developed in this investigation than was previously attempted and an evaluation of sensitivity and uncertainty performed. These models are expected to serve as an important management tool that can be used to evaluate various SRS management scenarios in terms of future impact to a MOP.

**REFERENCES**

1. USDOE 1999a. *Radioactive Waste Management*, DOE Order O 435.1, Change 1: 8-28-01. U.S. Department of Energy, Washington, DC. July 9, 1999.

2. USDOE 1990. *Radiation Protection of the Public and the Environment*, DOE Order 5400.5, Change 2: 1-7-93. U.S. Department of Energy, Washington, DC. February 8, 1990.

3. WSRC 1997. *Composite Analysis E-Area Vaults and Saltstone Disposal Facilities*, WSRC-RP-97-311, Rev. 0. Westinghouse Savannah River Company, Aiken, SC 29808

4. WSRC 2003. *Savannah River Site Environmental Management Integrated Deactivation and Decommissioning Plan*, WSRC-RP-2003-00233, revision 1. Westinghouse Savannah River Company. September 2003.

5. Phifer, M.A. and E.L. Wilhite. 2008. *Comprehensive SRS Composite Analysis Program Points of Assessment and Assessment Period*. WSRC-TR-2008-00094. Washington Savannah River Company, Aiken, SC 29808.

6. NCRP, 1996. *Screening Models for Releases of Radionuclides to Atmosphere, Surface Water*, *and Ground*, NCRP Report No. 123, Vol. 1, National Council on Radiation Protection and Measurements, Bethesda, MD, January 22, 1996.

7. GTG (GoldSim Technology Group LLC). 2006. *GOLDSIM User's Guide*, Version 9.20, GoldSim Technology Group LLC, Issaquah, WA, January, 2006.

8. Phifer, M.A., F.G. Smith and E.L. Wilhite. 2008. *Conceptual Model for the Savannah River Site's Composite Analysis*. SRNL-STI-2008-00505. Savannah River National Laboratory, Aiken, SC 29808.