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Nuclear Dumps by the Riverside:

**Threats to the Savannah River from
Radioactive Contamination at the Savannah River Site**

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March 11, 2004

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Preface

This report is the third in IEER's series of reports concerning threats to water resources from wastes dumped at nuclear weapons complex sites.² We chose to focus on the Savannah River Site (SRS) in South Carolina because waste management and disposal practices at SRS have created risks for future water resource integrity and have already led to severe contamination of the surface and groundwater onsite with radionuclides and hazardous chemicals. The site sits above the most important aquifer system in the southeast United States--the Dublin-Midville Aquifer System (also called the Tuscaloosa aquifer)--and borders the Savannah River, which provides drinking water, fishing, and recreation to residents in both South Carolina and Georgia.

No single report, including this one, can provide a comprehensive evaluation of the past contamination of the SRS site or of all the actual and potential threats that it poses to the surface and groundwater resources of the region. Such a study is well beyond the time and financial resources of IEER. We focus on the sources of radioactivity currently at SRS that pose the most serious threats to the environment, and especially to the water resources of the region.

This report does not cover contamination from continuing, proposed or possible future activities at the site, including the current operation of one reprocessing plant, a new tritium separation facility being built there, a proposed plant to make reactor fuel from a mixture of weapon-grade plutonium oxide and depleted uranium oxide, and possibly a plant to mass manufacture plutonium pits for nuclear weapons. These projects will not enhance national or global security; rather they will aggravate present problems and further jeopardize the Nuclear Non-Proliferation Treaty, as IEER has argued in other reports and studies. These prior recommendations are on grounds quite independent of the issues that we have analyzed here. However, as this report shows, the problems of managing the wastes and implementing a cleanup program from the legacy of the Cold War is daunting enough without adding the financial, technical, human resource, and managerial complexities associated with new nuclear weapons or nuclear fuel production programs, not to speak of the diversion of focus from the protection of future generations from the vast amounts of radioactivity at SRS.

We have also not covered environmental aspects of the continued operation of the reprocessing plants at SRS under the guise of waste management. It has even been put in the cleanup budget and has, over the past decade, diverted literally billions of dollars of scarce resources from urgent cleanup priorities, while at the same time aggravating the problem of high-level waste management by generating even more liquid high-level waste. We have previously addressed the issue of reprocessing at SRS.³

Democracy and openness are crucial to reducing the risks to human health and the environment posed by nuclear weapons production. For example, for long-term stewardship to be effective, adequate information (e.g., detailed data, including maps, showing the location of contamination)

² The first report, *Poison in the Vadose Zone: An Examination of the Threats to the Snake River Plain Aquifer from the Idaho National Engineering and Environmental Laboratory*, by Arjun Makhijani and Michele Boyd was released in October 2001 and is available at <http://www.ieer.org/reports/poison/pvz.pdf>. The second report, *Setting Cleanup Standards to Protect Future Generations: The Scientific Basis of the Subsistence Farmer Scenario and Its Application to the Estimation of Radionuclide Soil Action Levels (RSALs) for Rocky Flats*, by Arjun Makhijani and Sriram Gopal, was released in December 2001 and is available at <http://www.ieer.org/reports/rocky/fullrpt.pdf>.

³ Sachs, 1996

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must be widely available to the general public, local and state governments, and prospective site developers to allow them to protect themselves from being exposed to chemical or radioactive contamination during well drilling and soil excavation (exposures due to inadvertent exhumation). Workers involved with future uses of the site after institutional memory has been lost (which is very likely given the long periods involved) could also be harmed more than estimates that presume institutional memory and control.

Also, detailed information on the sources of contamination should be developed and made available so that the same costly mistakes will not be repeated. However, the gates of information that were opened at the end of the Cold War are being slammed shut in the name of the War on Terrorism. There is no credible evidence that the proliferation of nuclear weapons, for instance, has been promoted by openness in regard to information on waste, cleanup, environmental and health data and related issues. There is evidence that safety, health, and environmental protection, and even security, in terms of better plutonium accounting, for instance, have been promoted by openness. The terrorist attacks of September 11 appear to have provided an excuse for the DOE to greatly restrict information about the site that has no relationship to national security, but that does fit in with the decades-old DOE habit of operating in secret outside of independent scrutiny.

Arjun Makhijani
March 5, 2004

Executive Summary

The Savannah River Site (SRS) is an 803-square kilometer (310-square mile) nuclear weapons plant located in South Carolina on the northeast bank of the Savannah River and above the most important aquifer system in the southeastern United States, commonly called the Tuscaloosa aquifer. The plant was constructed in the early 1950s, mainly to produce plutonium and tritium for nuclear weapons. The availability of ample water resources was one important reason that the site was selected. These same resources are vitally important to the region for drinking, agriculture, fishing, industry, and recreation to residents in both South Carolina and Georgia.

The long-term health of the water resources in the region depends, among other things, on keeping the vast amount of radioactivity at SRS, which amounts to about two-thirds of the total radioactivity in the whole U.S. nuclear weapons complex, out of the surface and groundwater, and, hence, also out of the Savannah River. This report focuses on three areas:

1. High-level radioactive waste in storage tanks (SRS has the largest amount of radioactivity in high-level waste of any site in the United States).
2. Buried wastes, including plutonium-contaminated wastes, which DOE plans to leave at SRS, which pose potentially significant threats to water resources.
3. Some aspects of current water resource contamination that will continue to pose significant threats, with a special focus on tritium contamination.

A. Most Important Findings

1. *Water contamination at SRS:* Waste disposal practices at SRS have led to severe contamination of portions of the surface and groundwater at SRS, especially with tritium and trichloroethylene (TCE). This contamination in the ground and surface water often greatly exceeds safe drinking water limits with both radioactive and non-radioactive toxic materials.
2. *Threats to regional water resources:* The main threats to the Savannah River and possibly other water resources in the region due to SRS come from radioactive and hazardous wastes that were dumped in shallow trenches and pits, contaminated soil, contaminated water that is flowing in the Savannah River, and high-level wastes in tanks that are not being retrieved.
3. *Pollution of the Savannah River:* The Savannah River is contaminated as a result of highly contaminated surface water flowing into it from SRS, though the pollution level is low enough to keep the water well within present safe drinking water limits. However, there are spots, notably near the outfall of Four Mile Creek, where contamination may exceed those limits.
4. *Tritium contamination:* Tritium, a radioactive isotope of hydrogen, is the most common radioactive pollutant at SRS that flows into offsite water. Radioactive waste from SRS has caused tritium contamination of the Savannah River. Tritium is present at levels of about 5 percent of the drinking water limit in the Savannah River in the environs of SRS. Though there is some further reduction of this by dilution, elevated tritium levels due to SRS are present all the way to the mouth of the Savannah River at Savannah, Georgia.

5. *Tritium contamination in Georgia:* Rainfall and groundwater in parts of Georgia across the river from the Savannah River Site are contaminated with air emissions of tritiated water from SRS, though well below safe drinking water limits. Rainfall carries this contamination across the river. There may or may not be groundwater pathways from the site under the Savannah River that may also carry tritium to Georgia. Investigations have been inconclusive. If pathways under the river exist, they may pose a long-term risk to groundwater in Georgia in the environs of SRS. As of this writing (mid-February 2004), DOE funding to the State of Georgia for environmental monitoring related to SRS is set to expire April 30, 2004.
6. *Tritium in drinking water standards:* Tritiated water is far more dangerous to children and developing fetuses than to adults. Recent research indicates that current safe drinking water standards for tritium are not adequate to protect developing fetuses to a level comparable to that for non-pregnant adults.
7. *Subsistence fishing:* Many people use the Savannah River for subsistence fishing – that is, as a primary source of food; the practice is more common among African-Americans. Fish in the Savannah River have bioaccumulated cesium, mercury, and tritium from SRS. Studies have found that African-American fishermen consume considerably more fish than the maximum recommended for health reasons by the South Carolina Department of Health and Environmental Control. This is clearly an environmental injustice, because people who rely routinely on the river for a large portion of their protein are disproportionately impacted by the pollution from the site. A sound and stringent cleanup plan must be implemented at SRS in order to address this environmental injustice and to protect the health of anyone who depends on the river for their subsistence.
8. *Inadequate cleanup plans:* The DOE practice of capping shallow dumps and seepage basins is not suited to long-term protection of the water resources of the region, unless there is some provision for recovery of the wastes in the medium term. Grouting and/or capping waste are stopgap measures that will likely lead to problems once the grout and the caps start to break down. It will be even more technically difficult and expensive, and perhaps impossible, to remediate grouted material should contaminants leak from it. Provision for recovering the buried waste is essential to a sound long-term stewardship program, which must have as its basic assumption that there will be an eventual loss of institutional control over the site.
9. *Unsafe and illegal high-level waste management:* DOE is leaving large amounts of residual radioactivity from high-level waste in tanks that are being “closed” by pouring grout into them. The total amount of residue left in the ground from such practice, if extended to all 51 high-level waste tanks may eventually amount to a million or more curies and include significant amounts of plutonium-238 and plutonium-239. The concentration of alpha-emitting plutonium isotopes in the two closed tanks (17 and 20) is well above the maximum allowed for shallow land disposal of radioactive waste and generally required by regulations to be disposed of in a deep geologic repository. DOE has diluted this waste by grouting. This means that grouting is being used to create *de facto* shallow high-level waste dumps at SRS, treating high-level waste as if it were low-level waste. This practice violates the 1982 Nuclear Waste Policy Act. Even if the practice were to be declared legal, it would pose a significant threat to the Savannah River over the long term. The closure plan for Tank 19 is another example of this

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dangerous DOE policy. The residual waste would be more than 14 times greater than the highest limit allowed for the most radioactive waste permitted for shallow land burial. DOE plans to dilute the waste with grout so that the net result would squeak in under the low-level waste limit (0.997 times the limit for Class C waste). This will create another *de facto* high-level nuclear waste dump by the riverside.

B. Key Recommendations

1. *Recover buried wastes and highly contaminated soil:* DOE should urgently develop plans to recover buried wastes and highly contaminated soil at SRS, so that the main sources of water pollution over the long-term are minimized.
2. *Stop grouting residual waste:* DOE should stop grouting of residual radioactive materials in high-level waste tanks so as not to abandon vast amounts of radioactivity near the Savannah River. It should make a commitment to removing nearly all the radioactivity from the tanks and to decommissioning the tanks by removing them from the ground for safer, retrievable storage. (It should be noted that these underground tanks are, in some cases, partially below the shallow water table).
3. *Restore funding for monitoring to Georgia:* DOE should restore funding for water monitoring to the State of Georgia and expand such funding. It should also provide funds for an independent investigation of long-term threats to the Tuscaloosa aquifer if large amounts of residual radioactivity are left at SRS.
4. *Commission a conclusive study of groundwater pathways:* The U.S. government should provide sufficient funds for a geological investigation that would be thorough enough to settle conclusively the question of whether radioactivity is migrating into Georgia groundwater by pathway(s) under the Savannah River. This could be crucial to understanding what needs to be done to protect groundwater from SRS contamination both in Georgia and South Carolina.
5. *Retrieve wastes and inform the subsistence fishing population:* The States of Georgia and South Carolina, as well as the federal government and local governments, should initiate efforts to inform those who rely on subsistence fishing of the risks of large-scale fish consumption from the Savannah River and of efforts being made to reduce those risks. More complete studies of diets of the people, especially African Americans, living along the Savannah River are needed. These should be done with the involvement of local communities, historically Black colleges, the states of Georgia and South Carolina, with technical assistance as needed from the federal Centers for Disease Control and Prevention, which is headquartered in Atlanta, Georgia, and funding from the federal government. The DOE should take urgent steps to develop a plan to recover the buried wastes and contaminated soil that are the main sources of contamination of the Savannah River.
6. *Address tritium risks:* The National Academy of Sciences panel on the effects of low-level radiation (called the BEIR VII panel) should fully address the non-cancer risks of tritium and the risks of tritium to pregnant women and developing fetuses, as well as risks from combined exposure to tritium and non-radioactive toxic materials.
7. *Tighten tritium standards:* The EPA should tighten current standards for tritium contamination of drinking water so as to protect pregnant women and developing fetuses,

with due regard for the fact that the nourishment of the fetuses comes via the woman, so that protecting both is essential.

8. *Investigate Iodine-129 risks:* More extensive monitoring of Iodine-129 in Savannah River water and fish should be conducted. The health implications of Iodine-129 contamination of the Savannah River should be studied, including its effect on pregnant women, and communicated to the public.

C. Other Findings and Recommendations

1. Other Findings

a. DOE does not have a reliable inventory of how much waste and contamination is at SRS. Monitoring data taken by numerous entities on and near SRS is not comprehensively reviewed, evaluated, and interpreted.

Estimating and controlling future releases of contamination from SRS requires knowing, among other things, how much waste there is at SRS and in what condition. However, DOE does not have a reliable inventory of how much waste and contamination is at SRS. DOE's own assessment of its buried transuranic inventories concludes that the lack of adequate records and the lack of formal waste characterization of these wastes means that DOE has "generally low confidence in the reported numbers."⁴ Nor is there information on volumes of soil contaminated by leaching from the buried solid wastes.

b. DOE's cleanup plan depends unrealistically on long-term institutional controls.

DOE plans to abandon large amounts of waste at SRS by grouting waste tanks or leaving buried waste in place by capping dumps and seepage basins. The grouting of some tanks containing large amounts of residual radioactivity is already being carried out. Given the half-life of many of the radionuclides, including plutonium-239, DOE must maintain institutional control in perpetuity to monitor the effectiveness of the barriers and prevent human intrusion. It is unrealistic to expect such control over hundreds of years, much less the tens of thousands of years that the wastes will pose risks to human health.

c. DOE is continuing to dispose of low-level waste in unlined and unregulated trenches at SRS.

DOE is continuing to dispose of low-level waste in shallow, unlined trenches in the E-Area, which are exempt from independent external regulation. Such ongoing disposal of low-level waste could result in two potentially significant groundwater contamination problems. First, this disposal of low-level waste increases the inventory of waste in the ground at SRS that could later migrate to groundwater or surface water, resulting in increased contamination. Second, continuing to have the trenches open causes existing contamination to be driven further into the ground. As water collects in trenches from rainfall and percolates downward, it can remobilize contamination in the soil from prior releases, and carry them to the aquifer.

⁴ Huntoon, July 2000

d. The Defense Waste Processing Plant (DWPF) has not made adequate progress in vitrifying radioactivity in the high-level waste tanks

The DWPF was started in 1996 to vitrify essentially all the radioactivity in the high-level waste tanks at Savannah River Site in about 6,000 glass logs cast into steel canisters. After six years of operation more than 1,200 canisters, that is, over 20 percent of the total planned number, of glass logs had been cast. But only about one percent of the radioactivity in the tanks was in these logs. This progress is inadequate and a cause for concern both as regards the number of glass logs that might be needed and the potential that a large amount of radioactivity may be left in the tanks for the long term. A larger number of logs would create larger demands on repository space in any eventual geologic disposal site. Leaving larger amounts of radioactivity at SRS would create larger risks to the region's water resources. Another problem is that there is as yet no replacement technology for extracting cesium-137 from the saltcake in the tanks, which creates additional uncertainties for the vitrification program and for the management of the liquids in the high-level waste tanks. The technology chosen for cesium-137 extraction was written off as a failure in 1998, after 16 years of development and \$500 million in expenses.⁵

e. Cleanup technologies are lacking for trace water contaminants of significant health and environmental concern, notably tritium.

There are currently no adequate cleanup technologies for trace contamination of water, notably for tritium. Remediation by using trees as an evapo-transpiration medium, as DOE is currently doing at SRS, could present long-term genetic risks to forests and hence ecosystems that have not been evaluated. DOE should set 500 picocuries per liter as an action level for tritium contamination at SRS, which it has already adopted at Rocky Flats.

2. Other Recommendations

a. DOE should develop a reliable inventory of how much waste and contamination is at SRS, and publish a full and accurate inventory of volumes and radioactivity in the Central Internet Database.

It will be difficult or impossible to devise sound cleanup plans and waste management strategies without accurate waste inventories, both in terms of radioactivity and volume. DOE's data improved (under pressure from IEER) in the period 1997-2000 but the quality remains inadequate to provide a technically sufficient basis for decision-making. Creating accurate and sufficiently precise waste inventories should be a high priority.

b. Cleanup standards should be based on the subsistence farmer exposure scenario.

At SRS, current remediation goals are based on the industrial worker scenario for soil and on drinking water standards for groundwater. This scenario assumes unrealistically that DOE will control land use in perpetuity or at least for hundreds or thousands of years. Long-term cleanup

⁵ Wald, 1999

standards for soil and groundwater at SRS should be based on the subsistence farmer exposure scenario, which assumes that a person who grows all of his or her own food would unknowingly use contaminated water for drinking and farming. Further, this scenario assumes that such exposure would last a lifetime, and not just a few years. It assumes that the people in the critical group spend most of their time on the contaminated site. In addition, it assumes that the diets of future populations will be similar to those of today.

As with other risk-based standards, the subsistence farmer scenario assumes that people's health is protected if their lifetime exposure is less than an assigned limit. The reasoning is that in such a case all other people would be protected because their doses would be lower than that of the hypothetical subsistence farmer. The subsistence farmer scenario complies with the recommendations made by the International Commission on Radiological Protection (ICRP) for exposure, risk estimation procedure, and definition of the critical group. DOE should not rely on long-term institutional controls to prevent exposure to future generations.

c. DOE should stop disposing of low-level radioactive wastes by burial.

It is important to the future of protection of water resources that shallow-land burial of low-level radioactive wastes be stopped. Such wastes should be retrievably stored.

d. A new, sustained national R&D program aimed at trace contaminants should be created.

The federal government should create a well-funded basic science research program and a technology development program linked to it through the National Science Foundation to address the issue of cleaning up trace contaminants in soil and water. Such a program, if properly conceived and implemented, could be of immense value in long-term protection of water resources from the threats posed by radioactive wastes in the nuclear weapons complex, and probably also in many other industrial pollution situations.

e. Congress should request two investigations of the Defense Waste Processing Facility

The small amount of radioactivity that has been vitrified in the Defense Waste Processing Facility to date should be investigated because it poses a number of potential problems for waste management, for repository planning, and for long-term threats to southeastern water resources. Because of the vast budgetary, economic, health, and environmental implications, Congress should authorize two separate investigations of the issue – one by the General Accounting Office and one by a specially constituted panel of the National Academy of Sciences. Input and review by environmental officials and experts designated by the States of South Carolina and Georgia should be included as a prominent part of the scope of work of both investigations.

Chapter I: The Site

A. Background⁶

The Savannah River Site (SRS) is a nuclear weapons material production facility located in South Carolina adjacent to the Savannah River. Its area is about 310 square miles (about 800 square kilometers). Originally called the Savannah River Plant, the site was built by the U.S. government in the early 1950s to produce plutonium-239 and tritium for the U.S. nuclear weapons program. SRS also produced plutonium-238 for both nuclear weapons and civilian applications (including space program applications). Neptunium-237, which is irradiated to produce plutonium-238, was also produced at SRS. The site also produced other nuclear materials, including californium-252 and americium-241, for research and commercial applications.⁷ Plutonium-242, a non-fissile isotope of plutonium that is used to study the properties of plutonium-239 in sub-critical experiments, was also made at SRS.

SRS has had three main missions:

1. Nuclear materials production
2. Environmental management
3. Nuclear materials disposition

SRS produced 36 metric tons of plutonium, or somewhat more than one-third of the U.S. plutonium-239 stock during the Cold War.⁸ SRS also produced essentially all the tritium used in the nuclear weapons program. In this report we will focus on the present contamination of water resources on and off the Savannah River Site and the main threats to those resources from the large amount of radioactive and hazardous waste at the site. Each discrete area within SRS is named by the operations performed in that area and a code letter.

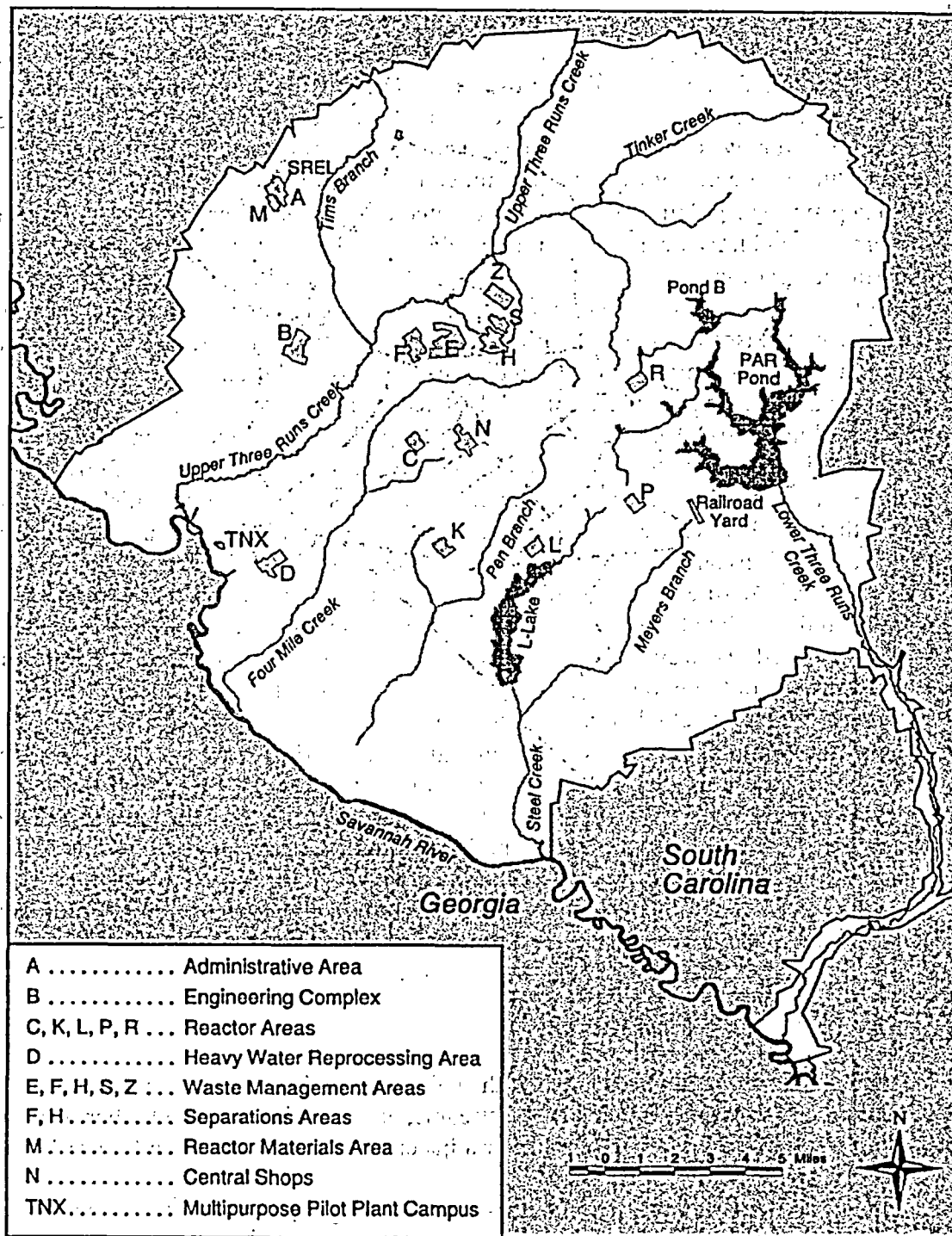
⁶ For general background on the site, see Makhijani, Hu, and Yih, eds., 2000, pages 246 to 253; NRDC, 1987, pages 98 to 124, including descriptions of the facilities onsite and periods of operation.

⁷ DOE, January 2001, Volume II, South Carolina section, page 3

⁸ DOE, February 1996, page 25

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Figure 1: SRS map with operational areas and surface water.



Source: Based on WSRC, 2000b, page 6

The main activities at SRS were:

- **Five nuclear materials production reactors:** These were heavy-water-moderated production reactors (C, K, L, P, and R reactors, located in areas named with those letters), which operated for a variety of periods, ranging from 1953 to past the end of the Cold War. See Figure 1 above. All the reactors are now closed. The heavy water moderator in these reactors was a primary source of tritium contamination, since the heavy hydrogen (deuterium) in the heavy water is transmuted to tritium during reactor operation.
- **Two reprocessing plants:** These are integrated complexes of large industrial buildings centered around huge "canyon" buildings, designated F- and H-canyons, used to separate specific nuclear materials from the fission products created in the reactors during operation and also from unused uranium. The separated materials were: plutonium-239 (and associated isotopes), tritium, plutonium-238, neptunium-237, plutonium-242, and uranium of various enrichments, including highly enriched uranium (from the driver rods that were used to fuel the reactors) and depleted uranium (from the target rods used to produce plutonium-239). One of the reprocessing plants continues to operate ostensibly to process irradiated materials for the purpose of waste management. In 2001, a comprehensive study of the need for nuclear materials stabilization published by DOE found that the chemical separation activities for currently identified canyon missions in the F- and H-Canyons would be completed by the end of Fiscal Year 2002 and in 2008, respectively.⁹ As of early 2003, all chemical separation operations were completed in F-Canyon and all related operations are undergoing suspension and "de-activation" has been authorized. However, decommissioning has not been authorized.¹⁰ It appears that F-canyon will continue to be a drain on cleanup resources for a considerable time, without progress on actual decommissioning.
- **Waste management activities:** These included transferring highly radioactive waste from separations activities to the high-level waste "tank farms" (the F and H Tank Farms), inter-tank transfers of high-level waste, evaporation to reduce waste volume, operation of the vitrification plant for high-level waste, discharge of "low-level" liquid waste into seepage basins, dumping of radioactive waste in unlined pits and trenches, often packaged in nothing more than cardboard boxes, and open burning of radioactive and mixed waste.

B. Water Resources at SRS

SRS is located in a coastal plain ecosystem with shallow groundwater. It is "covered by hardwood and pine forests and contains lakes, streams, and Carolina bays and other wetlands".¹¹ Natural and artificial surface-water bodies on or adjacent to SRS are shown in Figure 1 above.

Several layers of aquifers are separated by clay-rich confining units under SRS. The principal aquifer is the Dublin-Midville Aquifer System (also called the Tuscaloosa aquifer). The vadose zone (the unsaturated zone between the ground surface and the water table) under SRS is very

⁹ DOE-EM, February 2001

¹⁰ DOE-EM, Spring 2003. See also SRS CAB, February 2004

¹¹ DOE, January 2001, Vol II, South Carolina section, page 3

thin. In fact, in some areas, the groundwater discharges to the surface water.¹² The proximity of groundwater and surface water bodies and the outcropping of groundwater into surface streams plays a crucial role in the continuing contamination of the Savannah River originating in the waste disposal areas at SRS.

SRS is located in one of the wettest areas of the United States, with annual rainfall averaging about 120 centimeters (48 inches).¹³ About 42 centimeters (16.5 inches) of annual precipitation, which is about one-third of the total, traverses the vadose zone and goes into the upper aquifer.¹⁴ The Savannah River as well as the Tuscaloosa aquifer are used for drinking, agricultural, industrial, and other uses.

1. The Savannah River

The Savannah River, on the southwest border of SRS, is the most prominent geographic feature in the area. With a watershed larger than 27,400 square kilometers,¹⁵ the Savannah River basin is one of the major river systems in the southeastern United States, flowing southeast from North Carolina, forming the border between South Carolina and Georgia, and emptying into the Atlantic Ocean. Approximately 21 percent of SRS (182 square kilometers) consists of wetlands.¹⁶

The Savannah River Swamp is a 3,020-hectare (about 30 square kilometer) "forested wetland on the floodplain of the Savannah River",¹⁷ along the southeast border of SRS. It "is separated from the main flow of the Savannah River by a 3-meter-high natural levee along the river bank." An area of the Savannah River Swamp, called Creek Plantation Swamp, is outside the SRS boundary, located between Steel Creek Landing and the Little Hell Landing. The Creek Plantation Swamp is "mostly uninhabited" and "access is limited to occasional hunters and fishers."¹⁸

The Savannah River is classified as "Freshwaters,"¹⁹ by the South Carolina Department of Health and Environmental Control. The regulation in Chapter 61, R.61-68 covers water Classifications and Standards and defines "Freshwaters" as water "suitable for primary and secondary contact recreation and as a source for drinking water supply after conventional treatment," and for fishing, industrial, and agricultural uses.²⁰

The Beaufort-Jasper Water Treatment Plant (also known as the Beaufort Public Water Works Plant or the Chelsea Water Treatment Plant), in South Carolina, is approximately 120 river miles downstream from SRS and provides drinking water to about 97,000 people. The City of Savannah Industrial and Domestic Water Supply Plant (also known as the Cherokee Hill plant)

¹² DOE, May 2002b, Section 3.2; and DOE, September 2000

¹³ WSRC, 2000b, page 2

¹⁴ DOE, September 2000, page 1

¹⁵ DOE, August 1987, page 3-87

¹⁶ McAllister, et al., September 1996, page 9.8

¹⁷ Nelson, et al., 2000, page S23

¹⁸ DOE, August 1987, page 3-90

¹⁹ WSRC, 2000b, page 216

²⁰ SCDHEC Regulation R.61-68, Section G.10; DOE, August 1987, page 3-90

in Port Wentworth, Georgia, is approximately 130 river miles downstream from SRS and a few miles upstream of Savannah, Georgia. This plant provides water largely for industrial and manufacturing purposes, but also potable water for approximately 11,000 people.²¹

Water from the Savannah River has been used extensively in SRS operations. Beginning in the 1950s, SRS withdrew about 28.3 cubic meters per second (about 450,000 gallons per minute) of water from the river for cooling purposes, an amount equal to about 10 percent of the entire river flow. "This secondary cooling water [was] used mainly to cool the reactor primary coolant (heavy water, D₂O)" and was "returned to the Savannah River" via SRS streams. These discharges amounted to "10 to 20 times the natural flows of these streams" and regularly caused them to "overflow their original banks along much of their length."²² The secondary water was not in direct contact with the radioactivity in the reactors.

All of the major surface water streams on or adjacent to SRS flow into the Savannah River, including the following six streams:²³

- **Upper Three Runs Creek:** It traverses SRS but originates outside the SRS boundary, Upper Three runs has two principal tributaries: Tim's Branch and Tinker Creek. It has the largest watershed of any stream at SRS.
- **Beaver Dam Creek:** This is a small stream that joins Four Mile Creek before reaching the Savannah River via the swamp.
- **Four Mile Creek** (also known as Fourmile Branch): It flows 24 kilometers on the SRS site and drains into the Savannah River via the swamp.
- **Pen Branch:** This creek and Grave Branch together have a watershed area of 55 square kilometers."
- **Steel Creek:** The main tributary of Steel Creek is Meyers Branch.
- **Lower Three Runs Creek:** It drains an area second only to that of Upper Three Runs Creek. It was dammed in 1958 to create PAR Pond.

Surface water bodies at SRS have been used for the discharge of effluent from the SRS operations since the early 1950s. "Consequently, thermal, biological, chemical, and radiochemical effects have been observed in the SRS streams."²⁴ About 200 "Carolina bays, which are naturally occurring pond formations found in parts of the southeast, are scattered throughout the site," covering a total of about 472 hectares (about 1,100 acres). These bays "serve as natural habitats for many species of wildlife on the site," and have not been used for effluent discharge.²⁵

²¹ WSRC, 2000b, pages 2 and 111. A river mile is a mile as measured along the navigation channel of a river.

²² DOE, August 1987, page 3-93

²³ DOE, August 1987, pages 3-93, 3-96, 3-97, and 3-98

²⁴ DOE, August 1987, page 3-87

²⁵ WSRC, 2000, page 2; McAllister, et al., page 9.4; DOE, August 1987, page 3-87

2. Artificial Surface-Water Bodies

There are two major artificial bodies of water on the SRS site: PAR Pond and L-Lake. PAR Pond was created in 1958 by the construction of an earthen dam on Lower Three Runs Creek to provide cooling water for, and to receive cooling water from, the P- and R-Reactors (hence the name PAR).²⁶ The pond covers 10.7 square kilometers (2,640 acres) and has an average depth of 6.2 meters (20 feet) and a maximum depth of 18 meters (59 feet).²⁷

L-Lake, which covers about 4 square kilometers (1,000 acres), was created in 1985 by an earthen dam across Steel Creek to receive cooling water discharges from the L-Reactor. In addition to Steel Creek waters, the "lake was filled with 110 million gallons of water diverted from Par Pond." The object was "to provide L-Lake with an initial source of lake species" and to help accelerate "the development of a biologically balanced community. Water from L-Lake flows to Steel Creek and eventually to the Savannah River."²⁸

Both PAR Pond and L-Lake are contaminated. Before they were constructed, cooling water was discharged directly to Lower Three Runs Creek (from P- and R-Reactors) and to Steel Creek (from L-Reactor).²⁹

3. Groundwater

The hydrogeology under SRS is complex due to heterogeneities in the vadose zone and in the multilayer aquifer system. There are several productive aquifers that drain into the Savannah River, its tributaries, and the Savannah River Swamp. Groundwater velocities in SRS aquifers range "from tens to hundreds of feet per year." While the aquifers are, broadly speaking, separated by relatively impermeable confining layers, water does move slowly between them, at a rate of "several inches to several feet per year."³⁰

²⁶ Dunn et al., March 2000

²⁷ DOE, May 1997, page S-3

²⁸ DOE, August 1987, page 3-99

²⁹ RAC, April 2001, page 5-2

³⁰ WSRC, 2000b, page 156

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Figure 2: Hydrostratigraphic units at SRS

Epoch		Rock-Stratigraphic Unit		Hydrostratigraphic Unit				
				Northern SRS		Central-Southern SRS		
Miocene		Altamaha Formation		Steep Pond Aquifer	M Area Aquifer zone	Upper Three Runs Aquifer		Floridan Aquifer System
Eocene		Tobacco Road Sand				Upper zone		
		<div><div>Dry Branch Formation</div><div><div><div>Inverton Sand Mbr.</div><div>Griffin Landing Mbr.</div><div>Tungas Clay Mbr.</div></div></div></div>				Tan Clay confining zone		
						Lower zone		
						Santee Formation		
		Warley Hill Formation				Gordon confining unit		
Congaree Formation		Lost Lake Aquifer zone		Gordon aquifer unit				
Paleocene		Fourmile Branch Formation		Crouch Branch confining unit				Meyers Branch confining system
		Snapp Formation						
		Lang Syne Formation						
		Sawdust Landing Formation						
		Steel Creek Formation		Crouch Branch aquifer				
		Black Creek Formation		McQueen Branch confining unit				
		Middendorf Formation		McQueen Branch aquifer				
Cape Fear Formation		Undifferentiated				Dublin-Midville (also known as Tuscaloosa) Aquifer System		
Paleozoic Crystalline Basement Rock or Triassic Newark Supergroup				Piedmont Hydrogeologic Province				Southeastern Coastal Plain Hydrogeologic Province

Source: Based on WSRC, 2000b, page 157

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Groundwater in the area can occur as perched water, normal aquifers, and artesian aquifers.³¹ Deeper aquifers flow toward the major streams. The deepest aquifers (the Dublin and Midville aquifers) flow toward the Savannah River. The vertical groundwater flow can change or even reverse in successively deeper aquifers. Under most of the site, vertical flow of water is downward, so water flows from shallower to deeper zones. In some areas, however, groundwater flows up towards the upper aquifers. The complexities of the regional geology are considerable and there can be no assurance of long-term integrity of the deep aquifers if large amounts of long-lived radioactive wastes are abandoned on site.

The vadose zone at SRS is relatively thin, ranging from zero to 37 meters (120 feet) thick, so groundwater regularly intercepts surface water bodies (e.g., streams, Carolina bays and the Savannah River).³² This has important consequences for contaminant migration at SRS, because contaminants can and do migrate from groundwater to SRS streams.

Groundwater is widely used throughout South Carolina. Over half of the people of the state rely on it for their drinking water, via public water supplies or individual wells. Groundwater is also widely used in industry.³³

SRS uses approximately 5.3 million gallons of groundwater per day. This includes withdrawal of water for drinking, and for sanitary and industrial processing purposes. SRS is the largest self-supplied industrial consumer of groundwater in South Carolina.³⁴

³¹ RAC, April 2001, page 5-7

³² DOE, May 2002b, Section 3.2; DOE, September 2000

³³ RAC, April 2001, page J-3 and SCDHEC, May 2001

³⁴ WSRC, 2002b, page 55

Chapter II: Sources of Contamination

The Savannah River Site contains the largest amount of radioactivity in waste of any nuclear weapons site in the United States. Roughly 99 percent of this radioactivity is in 49 high-level waste tanks that contain fission products as well as plutonium, uranium and other radionuclides comprising the main waste discharges from the reprocessing plants (F and H canyons). The largest volume of discharged waste was in liquid form into seepage basins. Solid radioactive waste was buried in landfills and trenches at the site. The largest volume of solid radioactive waste is in a catch-all category called "low-level" waste. Broadly speaking, the main threats to water resources arise from the long-lived radionuclides in the waste, which includes the high-level waste in the tanks, the radioactivity in buried wastes and seepage basins, the radioactivity in the vadose zone, and radionuclides already in the groundwater under SRS. These risks from radioactivity are compounded by the presence of toxic non-radioactive contaminants.

Table 1 shows official estimates of the amounts of radioactive waste, both in terms of volume and of total radioactivity content.

Table 1: Official estimates of waste at SRS resulting from nuclear weapons production, as of mid-2001 or early 2002.

Type of waste	Volume (cubic meters)	Radioactivity (curies)
Total high-level waste	144,000	484,200,000
Comprised of:		
sludge in tanks	10,600	320,000,000
salt cake & supernate in tanks	133,500	160,000,000
vitrified waste in canisters	1221 canisters	4,200,000
Stored transuranic	15,000	560,000
Buried transuranic	4,530	21,900
Active low-level	680,000	Not given
Mixed low-level	7,300	Not given
Stored low-level	1,600	Not given
TOTAL (rounded)	~852,000	~490,000,000

Sources: HLW: Caldwell et. al, 2002, pp. 1, 2, and 80 and DOE-SRS, June 2001, p. 2-1. Sources for the rest: DOE, June 2000 and DOE-EM, January 1997, Chapter 3. HLW waste volume changes due to increasing from sludge washing operations.

Note: All numbers are rounded. DOE sources are not internally consistent regarding waste data. We have used what appears to be the best available data. In some cases, such as additions to high-level waste tanks arising from sludge washing, the waste volumes change from year to year considerably, leading to difficulties in creating a single date for compiling all the waste data.

The risks to water resources can also be viewed in terms of the various waste disposal and discharge methods, because the disposal method determines how the waste enters the watershed and its contribution to groundwater and surface water contamination. These disposal and discharge methods may be put into the following categories for the purpose of compiling data:

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1. Landfills/Trenches/Pits
2. Seepage basins
3. Ponds (PAR Pond/L-Lake)
4. Tanks (F- and H-Area high-level waste tanks and smaller tanks)
5. Direct discharge to streams

A. Landfills/Trenches/Pits, Seepage Basins, and Ponds

SRS used trenches, rubble and burning pits, and landfills to dispose of radioactive and mixed wastes. Much of the buried waste has been left in the ground and capped. Table 2 summarizes the major landfills, trenches, and pits that have contaminated both groundwater and surface water at SRS.

Table 2: Summary of major landfills, trenches, and pits contaminating water at SRS

Landfill/Trench/Pit	Affected water system	Contaminants
Burial Ground Complex <ul style="list-style-type: none"> • Old Radioactive Waste Burial Ground • Low-Level Radioactive Waste Disposal Facility 	Four distinct groundwater plumes <ul style="list-style-type: none"> • Southwest plume contaminated with tritium outcropping into Four Mile Creek • Northern plumes outcropping into Upper Three Runs Creek 	Tritium and other radionuclides, volatile organic compounds (primarily trichloroethylene), metals
TNX Burial Ground	Groundwater; discharges to the Savannah River Swamp and the Savannah River	Trichloroethylene; radionuclides, including uranium and radium-226
A-Area Burning/Rubble Pits	Groundwater	Trichloroethylene, tetrachloroethylene, methylene chloride
C-Area Burning/Rubble Pit	Groundwater; outcrops to Four Mile Creek	Trichloroethylene, tetrachloroethylene, vinyl chloride, tritium (the tritium is from other sources in C-Area)
Chemical, Metals, and Pesticides Pits	Groundwater; outcrops to Pen Branch	Trichloroethylene, tetrachloroethylene, metals

Sources: WSRC, 2000a and DOE, January 2001, Vol. II, South Carolina section

One of the largest and most contaminated areas at SRS is the Burial Ground Complex, which is located between the F-Area and H-Area reprocessing plants. Its principal use was for the disposal of low-level radioactive and mixed wastes.³⁵ DOE estimates that there are more than 1.3 million curies of low-level waste (decay-corrected to 2001) and about 18,500 curies of transuranic waste (decay-corrected to 2006) in the Burial Grounds.³⁶ "The Burial Ground Complex is divided into a southern area and a northern area." The Old Radioactive Waste Burial Ground, in the southern section, was the first part of the "Burial Ground Complex to receive waste and was filled to capacity." As an interim remediation action, it was "covered with a low-permeability interim cap" that is supposed to reduce "water infiltration by 70 percent."³⁷ The Old Radioactive Waste Burial Ground may be the most important source of future contamination among the various burial and burning sites because of the large quantity and variety of waste,

³⁵ WSRC, 2000b, page 55. Also see Chapter V below.

³⁶ WSRC, August 2002, page 35; WSRC, December 2000, pages ES-11 to ES-16; DOE, June 2000, page 21

³⁷ DOE, January 2001, South Carolina section, page 37

including radioactive and non-radioactive toxic materials dumped there.

SRS also used a dozen seepage basins for the discharge of billions of gallons of liquid wastes contaminated with radionuclides, organic toxic chemicals, and heavy metals. The largest amount of liquid wastes came from the two reprocessing plants (F- and H-canyons).

Table 3: Summary of the primary seepage basins contaminating water at SRS

Basin	Affected water system	Contaminants
F-Area Seepage Basins	Groundwater; outcrops into Four Mile Creek	Tritium, uranium-238, iodine-129, strontium-90, curium-244, americium-241, technitium-99, cadmium, aluminum
H-Area Seepage Basins	Groundwater; outcrops into Four Mile Creek	Tritium, strontium-90, mercury
Old TNX Seepage Basin	Groundwater; Savannah River and swamp	Trichloroethylene
New TNX Seepage Basin	Groundwater; Savannah River and swamp	Trichloroethylene
M-Area Seepage Basin	Groundwater; outcrops into Upper Three Runs Creek	Trichloroethylene, tetrachloroethylene
Old F-Area Seepage Basin	Groundwater	Tritium, iodine-129, uranium
K-Area Seepage Basin	Groundwater; outcrops into Indian Grave Branch	Tritium
R-Area Reactor Seepage Basins	Groundwater	Strontium-90, VOCs
L-Area Reactor Seepage Basin	Groundwater	Trichloroethylene, tetrachloroethylene, tritium
P-Area Reactor Seepage Basins	Groundwater; outcrops into Steel Creek	Tritium, trichloroethylene
Ford Building Seepage Basin	Groundwater	Lead, mercury, nitrates
C-Area Reactor Seepage Basins	Groundwater	Tritium, trichloroethylene

Sources: DOE SRS fact sheets; WSRC, 2000a.

Finally, there are also artificial ponds on the site, with the largest being PAR Pond. PAR Pond and L-Lake are no longer actively used because all reactors at SRS are permanently shutdown. However, they remain contaminated. The sediment in PAR Pond is contaminated primarily with cesium-137. There are also smaller concentrations of strontium-90, plutonium-238/239, americium-241, curium-244. There is also tritium in the water. The total inventory of cesium-137 was estimated to be 44 curies in 1991. Non-radioactive contaminants include mercury.³⁸

B. High-Level Waste Tanks

The largest inventory of radioactivity at SRS is in the high-level waste tanks in the F- and H-Areas. As noted in Table 1, as of mid-2001, 49 tanks contained 144,000 cubic meters (about 38 million gallons) of liquid waste with approximately 480 million curies of radioactivity (decay-corrected). The high-level waste in the tanks is in the form of sludge waste and salt waste. The sludge contains about two-thirds of the radioactivity and represents about 7 percent of the volume; the salt and supernate contain almost all the rest. Less than one percent of the

³⁸ Whicker, Niquette, and Hinton, January 1993, pages 475 and 478; Whicker et al., October 1993, pages 619 and 620

radioactivity had been vitrified as of early 2002. Two additional tanks that still contain residual high-level waste have been "closed" with grout (see below).

The potential sources of groundwater contamination from the high-level waste tanks are

- leakage of operational tanks through the primary and secondary containment as well as associated equipment (e.g., pipelines and valves),
- leakage and spills during withdrawal and transfers of wastes from the tanks,
- migration of contaminants from the "closed" tanks in which residual high-level waste has been left in place and grouted,
- contamination resulting from disposal of wastes deriving from high-level waste processing, and
- migration of any high-level radioactive waste that might be abandoned on the site in grouted or other form.

The past history of the tanks is mixed so far as tank integrity is concerned. Two of the four types of high-level waste tanks at SRS have leaked radioactive waste, while another type has had in-leakage of water. One type, the latest, has performed well thus far and is not known to have leaked.

- Twelve Type I tanks were built between 1952 and 1953. Five of these tanks have leak sites through which waste leaked from the primary containment to the secondary containment (i.e., 5-foot high annulus "pans"). In one case, the secondary containment of the tank was observed to be generally corroded "creating the potential for significant degradation of the tank secondary containment."³⁹ Four of the leaking Type I tanks, including the tank with corroded secondary containment, sit in the water table.⁴⁰
- Four Type II tanks were built in 1956. Like Type I tanks, these also have 5-foot high annulus "pans" as secondary containment. All Type II tanks have leak sites through which waste leaked from the primary containment to the secondary containment. In one case, "tens of gallons of waste overflowed" the secondary containment and leaked into the soil.⁴¹
- Eight Type IV tanks at Savannah River were built between 1958 and 1962. This type has a single steel wall. Two of these tanks have known cracks and small amounts of groundwater have leaked into the tanks. Four of the Type IV tanks are in a perched water body "caused by the original construction of the tank area."⁴²
- None of the 27 Type III tanks have currently known leak sites. These tanks are of the newest design, built between 1969 and 1986, with full-height secondary containment. Although the probability of a significant release may be relatively low compared to other sources of contamination, the consequences are higher than most other sources because the waste has

³⁹ DNFSB, April 1999

⁴⁰ DOE-SRS, May 2002b, page S-4; Caldwell, et al., 2002, page 75

⁴¹ DOE-SRS, May 2002b, page S-4; Caldwell, et al., 2002, page 75

⁴² DOE-SRS, May 2002b, page S-4; Caldwell, et al., 2002, page 75

decayed less than in the older tanks.⁴³ This difference is likely to disappear over time periods that are well short of the very long-lived components of the waste, like plutonium-239.

By 2022, DOE is required to close all of the tanks that have leaked or that do not have full-height secondary containment, which includes all the Type I, II, and IV tanks. Type III tanks are projected to be in use until almost 2030.⁴⁴

As of 2002, DOE had completed "closure" of two tanks in the F-Area, numbers 17 and 20.⁴⁵ The bulk waste was removed, but the residual waste, which consists of solids firmly attached to the tank surfaces as a "crust" or "heel," was left in the tanks.⁴⁶ Grout was pumped into the tanks using a "three-layered backfill system" consisting of a "chemically reducing grout at the bottom of the tank, a controlled low-strength material in most of the empty space, and a high-strength grout at the top of the tank." Grout is a filler material consisting of sand and gravel with a cement binder that sets after it is poured. The chemical composition of the grout is reducing because such a composition would "reduce the mobility of technetium-99."⁴⁷ Of course, the degree to which this design function succeeds will depend, in part, on the integrity of the grout over the long-term.

The grouting of two tanks still containing residual wastes has already created a *de facto* high-level nuclear waste dump on the site. The main radionuclides remaining in the tanks are strontium-90, cesium-137, technetium-99, and cobalt-60, but the residual waste also includes selenium-79, carbon-14, iodine-129, plutonium-238, -239, -240, -241 and -242, neptunium-237, americium-241, and curium-244 and -245.

The residual radioactivity level in Tank 20 is estimated to be about a quarter of a curie per gallon and that in Tank 17 almost half a curie per gallon.⁴⁸ The total plutonium concentration of the residual wastes in both tanks (for isotopes 238, 239 and 240) is well above the limit for Class C low-level waste, putting the waste in the category that must generally be disposed of in a deep geologic repository. The total residual volume was estimated at 1000 gallons in Tank 20. DOE estimates of residual volume in Tank 17 appear to be inconsistent. Caldwell, et al. reported the residual volume as 2,200 gallons of sludge in a 2002 publication, while a DOE tank closure report published in the same year reported the volume to be 4,000 gallons.⁴⁹ It is not clear whether the Caldwell et al. estimate included the volume of interstitial liquid.

C. Other Wastes

The waste management practices over time at SRS have caused extensive contamination of surface and groundwater, and some migration of contamination outside the present SRS boundary, including into the Savannah River. There is extensive documentation of such

⁴³ DOE-SRS, May 2002b, page S-9

⁴⁴ DOE-SRS, May 2002b, page 1-9

⁴⁵ See Caldwell et al., 2002, for details on "closure" of Tanks 17 and 20

⁴⁶ DOE-SRS, May 2002b, page 1-9

⁴⁷ NRC-NAS, 2001, page 72

⁴⁸ NRC-NAS, 2001, pages 70-71

⁴⁹ Caldwell et al., 2002, pages 77 to 78. DOE-SRS, May 2002b, page 2-1

contamination, which includes both radioactive and non-radioactive components. For example, groundwater underlying the Burial Ground Complex, has been highly contaminated with tritium, other radionuclides, volatile organic compounds (primarily trichloroethylene), and metals. Short-term threats to the groundwater include tritium and volatile organic compounds, strontium-90, mercury, cadmium, and lead. Long-term threats include iodine-129, technetium-99, neptunium-237, uranium isotopes, and plutonium-239.⁵⁰

The burning and rubble pits also pose environmental risks. SRS burned a variety of wastes every month in the A-Area Burning/Rubble Pits, including wastes contaminated with hazardous materials like solvents and waste oils. In 1973, SRS stopped burning the wastes and added a layer of soil over the "debris." However, SRS continued to dump paper, wood, empty steel barrels, and cans into the pits until they were filled to capacity.⁵¹ This continued use of the pits is another example of exacerbating a waste and contamination problem even after ceasing hazardous substance disposal. Groundwater beneath the area is contaminated with trichloroethylene, tetrachloroethylene, and methylene chloride.⁵² The soil under the C-Area Burning/Rubble Pit, which was built in the early 1960s, and similarly used until 1973, is contaminated with trichloroethylene, tetrachloroethylene, and dioxins. The groundwater is contaminated with trichloroethylene, tetrachloroethylene, and tritium (the tritium is from other sources in C-Area).⁵³

As discussed Chapter 1, the groundwater is so shallow at SRS that it commonly breaks out into surface streams, where it eventually flows to the Savannah River. In most natural hydrological systems, groundwater, which is filtered by nature, provides a cleansing effect when it flows into surface waters. However, after several decades of nuclear weapons materials production and poor waste disposal practices at SRS, the groundwater is severely contaminated under the industrial areas of the site, which cover 5 to 10 percent of the total area.⁵⁴ This contaminated groundwater affects the entire Savannah River watershed in this area.

D. Water Monitoring

Several organizations are involved in environmental monitoring of surface water and groundwater on or near SRS, including the U.S. Department of Energy site management contractor, the Westinghouse Savannah River Company, the South Carolina Department of Health and Environmental Control (SCDHEC), the Georgia Department of Natural Resources (GDNR), the U.S. Geological Survey, and the Georgia Geologic Survey.

The Westinghouse Savannah River Company conducts water sampling programs to monitor a variety of contaminants including mercury, lead, organics, and a variety of radionuclides.⁵⁵

Through its Environmental Surveillance and Oversight Program, the South Carolina Department of Health and Environmental Control (SCDHEC) monitors 75 groundwater wells, consisting of

⁵⁰ WSRC, August 2000, pages 2-23 to 2-24

⁵¹ DOE-SRS, December 2001a

⁵² DOE-SRS, December 2001a

⁵³ DOE-SRS, September 2003

⁵⁴ DOE, May 2002b, page 3-13

⁵⁵ WSRC, 2000b, page 163

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public supply wells, irrigation wells, and monitoring wells within 10-miles of the SRS boundary.⁵⁶ SCDHEC also collects "monthly raw drinking water samples from water treatment plants that use the lower portion of the Savannah River as a source, and quarterly grab samples from selected municipal and large community drinking water systems within 30 miles of SRS. Samples are analyzed for gross alpha, nonvolatile beta, and beta-gamma emitting radionuclides, and tritium."⁵⁷

The Georgia Department of Natural Resources, Environmental Protection Division, "regularly monitors drinking water from the [City of Savannah Industrial and Domestic Water Supply Plant], as well as seven ... locations on the Savannah River." The Georgia Department of Natural Resources planned to install a continuous water monitor at River Mile 120 (at U.S. Highway 301) during 2003, but could not do so because DOE refused to fund it. "The City of Savannah also monitors surface water from U.S. Highway 301 on a daily basis, and both raw and finished water on a once-per-shift basis."⁵⁸ DOE funding to the State of Georgia for environmental monitoring related to SRS is set to expire April 30, 2004, as of this writing (mid-February 2004).⁵⁹ In the absence of state and federal funding, the people of Georgia will not have adequate knowledge of the risks to which they are being subjected from contamination originating at SRS. The federal government is, in effect, imposing an unfunded federal mandate on Georgia. The State of Georgia has the responsibility to protect the health of its people, and the federal government is imposing risks on those people via radioactive contamination. At the same time it is refusing to provide funds to Georgia to monitor that contamination.

⁵⁶ SCDHEC, December 2001, page 7

⁵⁷ SCDHEC, December 2001, page 7

⁵⁸ Hardeman, 2002

⁵⁹ Hardeman, 2004a

Chapter III: Tritium and Radioactive Water

Tritium is radioactive hydrogen. Tritium in gaseous form generally presents a low health risk because it is exhaled before it can deliver substantial radiation doses to the body. However, tritium can displace one or both of the hydrogen atoms in water, thereby creating radioactive water (see box), which behaves chemically like ordinary water. Since water is essential to life, radioactive water means that radioactivity seeps into all parts of the body and its constituents – cells, as well as DNA and proteins, for instance. Tritium that is in organic materials is called organically-bound tritium (OBT). Both tritiated water and organically-bound tritium can cross the placenta and irradiate developing fetuses *in utero*, thereby raising the risk of birth defects, miscarriages, and other problems (see below). Tritium discussed in this report is either in the form of tritiated water or OBT, unless otherwise specified.

About Tritium

Tritium is a radioactive form of hydrogen with two neutrons, resulting in a total atomic weight of 3 (1 proton and 2 neutrons). Most tritium is man-made. Some tritium occurs naturally due to interactions between the atmosphere and cosmic radiation. With its relatively short half-life (12.3 years), tritium decays at about 5.5 percent annually.

As a gas, tritium is a light and small atom and hence diffuses readily through all but the most highly engineered containment vessel and mixes freely with the other forms of hydrogen in water and water vapor. It forms tritiated water by replacing one or both atoms of non-radioactive hydrogen in water. Tritiated water is often designated as HTO and T₂O, depending on whether it has one or two atoms of tritium in the water molecule respectively. When tritium is generated by neutron absorption in heavy water (D₂O), it is DTO. All these forms of water containing tritium are rendered radioactive as a result. They behave in a manner that is chemically the same as ordinary water. The pervasiveness of tritium is due to the mobility of tritiated water in the environment along with non-radioactive water (both H₂O and D₂O).

The specific activity of tritium is very high – almost 10,000 curies per gram. Hence a small amount (weight) of tritium can contaminate a large amount of water. The combination of these two properties -- tritiated water is chemically like ordinary water and tritium is highly radioactive – makes tritium a very pernicious pollutant that is difficult to contain and, once in the water difficult to remediate, especially when in trace amounts.

Tritium's primary function in a nuclear weapon is to boost the yield of the fissile material used both in pure fission weapons and in the primary of thermonuclear weapons. Contained in removable and refillable reservoirs in the warhead, it increases the efficiency with which the nuclear fissile materials are used. Although no official data are publicly available, each warhead is estimated to require an average of approximately four grams of tritium. However, neutron bombs, designed to release more radiation, have been estimated to require more tritium (10-30 grams).¹

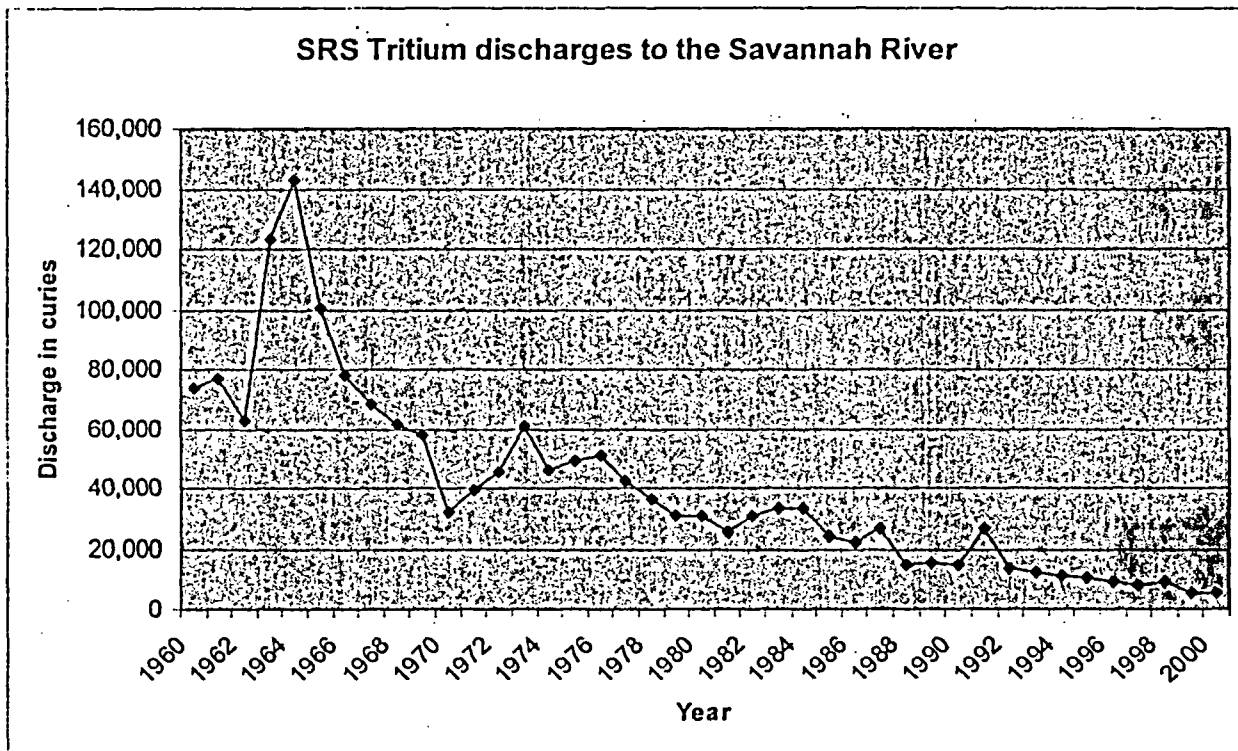
1. Reproduced from Zerriffi, January 1996, page 1

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There are two types of tritium releases from SRS: (1) direct releases into streams; and (2) migration of tritium from seepage basins, buried wastes, and the K-Area containment basin to groundwater and outcropping to SRS streams. At first direct releases, mainly from reactors and the reprocessing plants, accounted for almost all tritium releases to streams. Since the mid-1970s, however, groundwater outcropping to streams has been the major source of tritium releases to the streams.⁶⁰ The amount of tritium discharged to the river has declined substantially over the years as the reactors have been shut down.

Annual releases of tritium to SRS streams from both direct releases and migration ranged from more than 100,000 curies per year in the mid-1960s to about 3,100 curies in 2002.⁶¹ The highest estimated release of tritium to surface water was about 143,000 curies in 1964.⁶² Figure 3 shows the annual tritium transport summary from both direct releases and migration from 1960 to 2000, as well as the resulting tritium transport in SRS streams and in the Savannah River downriver of SRS.

Figure 3. Tritium Discharges into the Savannah River – Historical Data



Source: WSRC, 2000a, Table 20, pages 72 and 73. These estimates are based on tritium measurements in the Savannah River. Other methods of estimation yield somewhat different results.

⁶⁰ RAC, April 2001, page 5-43. Also see WSRC, 2000a.

⁶¹ WSRC, 2002d

⁶² WSRC, 2002a

Between 1954 and 1988, a total of 1.5 million curies of tritium were released directly into SRS streams and 7.2 million curies of tritium were released into seepage basins and burial grounds. Of the tritium released directly into the streams, about three-fourths was from the reactors, about 15 percent from the F- and H- canyons, and the rest from other facilities. Much of this tritium has decayed into non-radioactive helium-3; about 5.5 percent of the tritium inventories decays each year. But there is still enough for tritium to be the most ubiquitous contaminant at SRS.

Table 4: Sources and activities of cumulative tritium discharges at SRS, 1954-1988 (not decay-corrected)

Facility	Amount discharged to streams (curies)
Reactors	1,144,000
Separations	237,000
D-Area	145,000
Subtotal	1,526,000
	Amount discharged to the ground, curies
Seepage basins (See Note 1)	3,015,000
Burial grounds	4,200,000
Subtotal	7,215,000
Total	8,741,000

Source: Murphy *et al.*, May 1991, pages i, 16.

* Note 1: In this case, as with other waste data, DOE data are internally inconsistent. The seepage basins number above is taken from page 16 of Murphy *et al.*; it differs from the number given in the table on page 17, which is 1,208,000 curies. But the subtotal, 7,215,00, is more in line with the number, "about 7 million," given on page i of Murphy.

Currently, most of the tritium released directly to SRS streams comes from the Effluent Treatment Facility, which discharges wastewater into Upper Three Runs Creek.⁶³ In 2000, the Effluent Treatment Facility accounted for about 94 percent (by activity) of the direct releases of tritium at SRS. The releases from this facility have varied in recent years, increasing from 308 curies in 1996 to 1,680 curies in 2000 and back down to 989 curies for 2002.⁶⁴ This indicates that discharges probably depend on rainfall and other factors that are mobilizing tritium at varying rates. Approximately 30 percent of the tritium released to the seepage basins evaporated; the remaining tritium decays or percolates through the soil to the shallow aquifer.⁶⁵ Table 4 lists the sources and activities of tritium discharges to streams and to the ground at SRS from 1954 to 1988. In addition, about 25 million curies of tritium was discharged into the atmosphere between 1954 and 1992.⁶⁶

⁶³ WSRC, 2002d; DOE-SRS, April 2002a

⁶⁴ WSRC, 2000a, Table 18, page 66 and WSRC 2002d

⁶⁵ Murphy *et al.*, May 1991, pages i and 11

⁶⁶ GDNR, 1994, Table 2, page 8. This table does not specify the partition between tritiated water and tritium gas

The shallow groundwater at SRS is contaminated to levels far above the drinking water standard. Shallow groundwater at SRS is generally not used for drinking or process water,⁶⁷ but the tritium in it migrates into SRS streams that flow into the Savannah River, which is used for drinking. The U.S. Environmental Protection Administration regulation, pursuant to the federal Safe Drinking Water Act (SDWA), establishes a concentration of 20,000 picocuries/liter (pCi/L) for tritium.⁶⁸ Although it is not accurate to say that tritium concentrations in water exceeding 20,000 pCi/L violates the safe drinking water act, the limit is a useful basis of comparison for measuring a legally established concentrations level for what is considered "safe." The EPA regulation applies to public drinking water supplies for the concentrations of contaminants in drinking water at the point of delivery (i.e., at the kitchen sink tap). It does not, strictly speaking, apply at the point of intake before treatment and polishing, but because there is no practical and effective treatment method for removing tritium from water, the same concentrations found at the point of intake should be assumed to be present at the point of delivery, unless dilution with uncontaminated water supplies occurs. The drinking water limit is enforced on the water supply system operator, rather than the polluter who contaminated the water (in this case, the DOE). Therefore, we use Safe Drinking Water regulations as a benchmark for comparison, and not as a conclusion of a violation of law or present-day risk. (The Department of Energy and the State of Georgia use the same benchmark in their environmental monitoring reports).

Tritium is the most widespread radioactive contaminant in groundwater under SRS. More than half of all shallow groundwater monitoring wells at SRS indicate tritium contamination at concentrations exceeding drinking water standards in the separations (F- and H-Areas) and the waste management areas (E-, F-, H-, S- and Z-Areas). Some of the wells in the F and H separations areas have tritium concentrations hundreds and even thousands of times above the drinking water limit. The proportion of wells contaminated with tritium above the drinking water limit went up in the separations and waste management areas from 51 percent in 1998 to 63 percent in the year 2000. It has gone up from 60 percent to 100 percent of wells in the K-area in the same period.⁶⁹ The most contaminated well in SRS in the year 2002 with regard to tritium had a level of 78.2 million picocuries per liter, up from 64.2 million in the year 2001. Groundwater under the L and P reactor areas is also highly contaminated.⁷⁰

Because the groundwater is so shallow at SRS, the tritium-contaminated groundwater outcrops into streams along seep lines. Tritium migration from seepage basins and the Solid Waste Disposal Facility accounts for most of the tritium in SRS streams.⁷¹ In 1995, an independent group of technical, health and legal experts hired by the SRS Citizens' Advisory Board, called the Independent Scientific Peer Review (ISPR), indicated that, "Concentrations of tritium exceeding 10,000 picocuries per milliliter (10 million picocuries per liter) have been measured in the groundwater in the vicinity of Fourmile Branch."⁷²

discharges to the atmosphere.

⁶⁷ DOE, May 2002b, page 3-13

⁶⁸ EPA, 2003

⁶⁹ WSRC, 2000b, pages 181, 182, and 184

⁷⁰ WSRC, 2002b, Table 6-1, page 59.

⁷¹ WSRC, 2000b, pages. 88 to 89. See Figures 6-7 and 6-8.

⁷² ISPR, October 1995, page 14

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Table 5 lists the main sources of tritium and the annual total tritium migration to surface water from 1996 to 2002.

Table 5: Main sources of tritium and annual total tritium migration to surface water, 1996-2002

Source	Surface water outcrop	Radioactive migration (curies)						
		1996	1997	1998	1999	2000	2001	2002
Solid Waste Disposal Facility and General Separations Area*	Upper Three Runs	164	267	386	467	483	470	275
Solid Waste Disposal Facility and H-Area seepage basin*	Four Mile Creek	3,200	2,960	3,488	2,090	1,920	411	381
F-Area seepage basin	Four Mile Creek	1,620	1,000	1,477	648	353	284	226
H-Area seepage basin	Four Mile Creek	505	400	515	258	139	161	95
K-Area disassembly basin, reactor seepage basin, and retention basin	Indian Grave Branch, a tributary of Pen Branch	1,290	2,150	3,090	1,160	1,040	1,040	853
P-Area seepage basin	Steel Creek	320	393	507	369	265	309	177
Sub-Total		7,099	7,170	9,463	4,992	4,200	2,675	2,007
Total direct releases and migration		7,560	8,350	10,555	6,111	5,995	4,423	3,096

Source: WSRC, 2002d

Note: * It is not possible to distinguish between the two sources at the outcrop point.

The Georgia Department of Natural Resources (GDNR) monitors tritium concentrations along the Savannah River and at the Four Mile Creek outfall to the Savannah River.⁷³ The maximum concentration at the Four Mile Creek outfall between 1997 and mid-1999 was 220,000 picocuries per liter in April 1999.⁷⁴ According to GDNR, between 1997 and mid-1999 "positive tritium results, attributable mostly to SRS, were found in most types of samples and at most locations, within 30 miles of SRS."⁷⁵

Historically, the highest tritium concentrations at the Savannah River have been those due to discharges from Four Mile Creek. The South Carolina Department of Health and Environmental Control (SCDHEC) also monitors the SRS streams and the outfalls to the Savannah River. These 1999 data, in Table 6, show that water entering the Savannah River from Four Mile Creek

⁷³ GDNR, 1999, pages A-10 and D-58

⁷⁴ GDNR, 1999, pages A-10 and D-58

⁷⁵ GDNR, 1999, page A-10

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was contaminated well above drinking water standards.

Table 6: Maximum and mean tritium concentrations at outfalls to the Savannah River, South Carolina Department of Health and Environmental Control data, 1999

Sample location	Maximum concentration (picocuries per liter)	Mean concentration (picocuries per liter)	Percent of drinking water standard (mean concentration)
Upper Three Runs	34,649	4,189	21
Four Mile Creek	213,646	176,767	884
Four Mile Creek (30 feet from creek mouth)	206,764	127,599	638
Four Mile Creek (150 feet from creek mouth)	132,286	57,722	229
Beaver Dam Creek	1,788	797	4
Steel Creek	34,466	13,060	65
Lower Three Runs	1,576	973	5

Source: SCDHEC, 1999, Appendix D, pages 13, D-24 and D-25

The relatively large flow of the Savannah River dilutes the tritium and lowers its concentration, normally to below the drinking water standard, as can be seen in Table 7 below. Yet, it is clear that SRS operations and past dumping have a significant effect on levels of tritium in the river, with concentrations downstream being ten to twenty times those upstream from SRS discharge points. It must be noted that the portion of the Savannah River that is close to the Four Mile Creek discharge point is significantly above the safe drinking water limit of 20,000 picocuries per liter (Table 6).

Table 7: Mean concentration of tritium in the Savannah River, 2000 to 2002, picocuries per liter

River Mile (description)	Tritium concentration 2000	Tritium concentration 2001	Tritium concentration 2002
160.0 (upstream of SRS)	110	82.3	171
150.4 (at Four Mile Creek)	2,220	2,280	2530
150.0 (south of Four Mile Creek mouth)	2,130	1,230	1080
141.5 (south of Steel Creek mouth)	1,420	1,220	1120
118.8 (south of the swamp and SRS)	1,180	1,020	1010

Source: WSRC, 2000a, page 69, for Year 2000; WSRC, 2001a, Excel Table "Radioactivity in Savannah River Water, for Year 2001; WSRC, 2002f, Excel Table in CD entitled "Radioactivity in Savannah River Water," for Year 2002.

The concentration at the mouth of the river at Savannah, Georgia, in 2002, was 774 picocuries per liter (see Table 8 below).⁷⁶ This means that the entire length of the Savannah River from the south end of SRS to the Atlantic Ocean is affected by SRS tritium discharges. In the past few years, the concentrations of tritium in the Savannah River have been at about 5 percent of the present safe drinking water standard -- that is, it is well within the regulatory limit. While we may conclude from this that the cancer risk to adults from Savannah River water is very low (i.e., well below regulatory limits), it does not put to rest all the essential health-risk-related questions such as non-cancer risks and risks to children and fetuses (see Chapter V).

A. SRS Tritium in Georgia

Tritium from SRS affects Georgia in several ways:

- SRS discharges pollutants, including tritium into the Savannah River, which means that river water is polluted with tritium, though at levels that are well below safe drinking water limits.
- Rainwater on the Georgia side of the Savannah River contains levels of tritium that are attributed to SRS air emissions.
- The groundwater from the Upper Three Runs Aquifer in Georgia is contaminated with tritium attributed to rainfall contaminated by SRS emissions (see below).
- The fish in Savannah River are contaminated with tritium and other radionuclides from SRS (see Chapter IV).

None of these sources of contamination give radiation doses that are near or above present regulatory limits.

In 1991, tritium was discovered in drinking water wells in Burke County, Georgia, which borders the Savannah River across from SRS. A subsequent study found tritium contamination in 15 wells with an average of 500 picocuries per liter and a maximum of 3,500 picocuries per liter. The latter figure is almost 18 percent of the regulatory limit for drinking water. Data indicate that the wells drew water from the Upper Three Runs Aquifer, where the contamination appears to be centered in Georgia groundwater.⁷⁷

There has been considerable investigation of the source of tritium contamination in Georgia groundwater. As we have discussed, SRS is the principal source of tritium discharges to the Savannah River. The issue that has been investigated is how the contamination gets from SRS, which is on the South Carolina side of the Savannah River, to the Georgia side. These investigations have led to a generally accepted conclusion that at least some of the contamination in Georgia groundwater comes from the contamination of rainwater by SRS air emissions (evaporation of tritiated water). Isopleths of the tritium content of rainwater clearly show the highest levels of tritium closest to the site, declining with distance.⁷⁸

⁷⁶ WSRC, 2002d

⁷⁷ GDNR, 1994, pages i and p. 44

⁷⁸ GDNR, 1999, pages A-11 to A-12. A 2002 report of an official investigation also concluded that contaminated

The Georgia Department of Natural Resources has summarized data for tritium in rainfall on the Georgia side of the Savannah River. Their summaries show rainwater contamination of several thousand picocuries per liter in the 1980s, declining to several hundred to 1,000 or more picocuries per liter in the 1990s.

The issue that remains unresolved is whether tritium migrates directly from contaminated aquifers at SRS beneath the Savannah River into Georgia (called transriver flow). In 1991, DOE asked the U.S. Geological Survey to study the groundwater flow and stream-aquifer relations in the Savannah River basin near SRS to determine whether transriver flow is occurring. The first part of the study, which included drilling wells and water quality analysis, was completed. The study was published in 1994.⁷⁹

In 2001, DOE funded a panel of four scientists to determine whether "tritium-contaminated water from SRS releases can migrate and/or have migrated" into Georgia aquifers.⁸⁰ In January 2002, the panel released its report, which concluded that based "on the available data, there is insufficient evidence to confirm or refute whether tritium has or may in the future migrate under the Savannah River from the SRS site."⁸¹ It recommended that the U.S. Geological Survey (USGS) be funded to complete the studies that it was conducting under DOE, including "more localized groundwater modeling" and "a more thorough evaluation of the impact of different groundwater withdrawal scenarios."⁸² In late 2002, DOE "contracted with the USGS to continue looking at groundwater flow on the SRS plant site, but many of the recommendations of the [panel] are not included within the scope of work and thus are going unfunded."⁸³ DOE funding to the State of Georgia for environmental monitoring related to SRS is set to expire April 30, 2004, as of this writing (mid-February 2004).⁸⁴

B. Tritium in Drinking Water

SRS drinking water is supplied by 18 separate systems, all of which use groundwater. Only three of the systems, A-Area, D-Area, and K-Area, are classified as "nontransient/noncommunity systems" and thus "are actively regulated by SCDHEC [South Carolina Department of Health and Environment Control]."⁸⁵ Many of the water systems require treatment to meet the SCDHEC and U.S. Environmental Protection Administration (EPA) drinking water standards.⁸⁶ Treatment includes "aeration to remove dissolved gases; filtration to remove iron; and addition of ... chemicals to adjust pH, prevent piping corrosion, and prevent bacterial growth." The biological

atmospheric tritium transport from South Carolina contributed to the well water contamination in Burke County. (See Moeller et al., 2002, page 4)

⁷⁹ GDNR, 1994

⁸⁰ Moeller et al., 2002, page 2

⁸¹ Moeller et al., 2002, page 4

⁸² Moeller et al., 2002, page 7

⁸³ Setser and Hardeman, 2002

⁸⁴ Hardeman, 2004a.

⁸⁵ WSRC, 2000b, pages 23, 138, and 139. The three nontransient/noncommunity systems serve more than 25 people.

⁸⁶ SCDHEC Regulation R.61-58 and EPA, 2003

and chemical compliance samples were below maximum contaminant levels in 2000.⁸⁷

Municipal drinking water systems near SRS, in South Carolina, use both groundwater and surface water, with 25 of 28 depending on groundwater. However, about 57 percent of the customers depend on the 3 surface water systems.⁸⁸ Table 8 shows the mean concentration of tritium in one upstream and two downstream drinking water systems in 2000 and 2002.

Table 8: Mean concentration of tritium in drinking water systems offsite, finished water, in 2000 and 2002

Treatment plants	Tritium, finished water, pCi/liter, 2000	Tritium, finished water, pCi/liter, 2002
North Augusta Public Water Works (upstream of SRS)	41.2	132
Beaufort Public Water Works	1030	824
City of Savannah Industrial and Domestic Water Supply Plant	950	774

Source: WSRC, 2000a, Table 21, p. 75; WSRC, 2002e. The EPA safe drinking water limit is 20,000 picocuries per liter.

C. Comments on tritium contamination

DOE argues that there is not a problem with tritium contamination, because the concentration of tritium is ten times lower than the drinking water standard for tritium (20,000 picocuries per liter). But DOE must also adhere to keeping releases "as low as reasonably achievable" (the ALARA principle), so the fact that the level is below the maximum limit is not a sufficient argument for meeting regulations or public safety requirements.

For reference, it is important not only to note that while the levels of contamination of some groundwater are well below the safe drinking water limit, they are well above natural background. The natural concentration of tritium in lakes, rivers, and potable waters was 5 to 25 picocuries per liter prior to nuclear weapons testing.⁸⁹ Nuclear weapons testing greatly increased the amount of tritium in the atmosphere and though most of this has decayed away, there is still sufficient tritium from bomb testing to elevate global tritium levels. Rainwater over Atlanta in the early 1990s was about 39 picocuries per liter. For purposes of analysis, this might be considered as background (natural and bomb-testing) unaffected by SRS operations.⁹⁰ The figure of 1,000 picocuries per liter is 20 times below the safe drinking water limit; however, it is also more than 25 times above the rainwater tritium content in Atlanta.

The South Carolina Department of Health and Environmental Control allows for the use of

⁸⁷ WSRC, 2000b, pages 138 and 24

⁸⁸ SCDHEC, December 2001, page 7

⁸⁹ Eisenbud and Gesell, 1997, page 18

⁹⁰ GDNR, 1994, pp. 13-14

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groundwater mixing zones only under certain situations.⁹¹ Specifically, all of the following requirements must be met:

1. The contamination source must be under control and/or commitments have been made and steps implemented "to minimize the addition of contaminants to ground water."
2. The contaminated shallow aquifer is unlikely to be used or will not be used as a source of drinking water and discharges of pollutants to surface water will not result in violation of applicable standards.
3. The contaminants will likely remain within the property and are unlikely to flow offsite.
4. "The contaminants in question are not dangerously toxic, mobile, nor persistent."⁹²

These criteria are not met with the tritium contamination at SRS for the following reasons:

1. Capping has slowed but not stopped the release of contamination from seepage basins and landfills.
2. The contamination flows offsite, via surface streams, to the Savannah River.
3. The contamination is toxic and mobile. While tritium does decay, its half-life of 12.3 years is long enough and the source of contamination large enough that the contamination persists and continues to migrate offsite and contaminate the Savannah River.
4. Some contaminants are very long-lived and DOE is highly unlikely to be able to ensure that the shallow groundwater will never be used for drinking (see Chapters V and VI).

⁹¹ SCDHEC Regulation R.61-68, Section C.11, page 10

⁹² SRS CAB, October 2001

Chapter IV: Other Radioactive and Non-Radioactive Contamination

A. Radionuclides

In addition to tritium, other radionuclides also migrate from the burial grounds and seepage basins to the groundwater. Concentrations of some radionuclides are above drinking water standards in the groundwater under many of the site areas. Currently, concentrations of these radionuclides are low both in the SRS streams and in the Savannah River. However, large source terms— that is, sources from which radioactivity could migrate into water — remain in the buried wastes and contaminated soils at SRS.

For instance, in the F- and H-Areas, migration from the burial grounds and seepage basins has led to highly contaminated groundwater, especially with strontium-90 and iodine-129, which have half-lives of 28.1 years and 16 million years, respectively. Radium-226, uranium isotopes, iodine-129, and strontium-90 are significantly above drinking water standards in the groundwater. Some of these radionuclides have migrated from the groundwater under the seepage basins to Four Mile Creek. Iodine-129 concentration at point of discharge into the Savannah River averaged 40 percent of the drinking water standard in 1998.⁹³ Technetium-99 migration from the F- and H-areas also contributes to groundwater contamination. Alpha and beta-emitting radionuclides are also present in other SRS surface streams.⁹⁴ Those concentrations are generally measured to be below current drinking water standards.

B. Organic Toxic Compounds

Volatile organic compounds, particularly trichloroethylene (TCE) and tetrachloroethylene (PCE), were used as degreasers throughout SRS. TCE is one of the primary groundwater contaminants throughout the site. "The highest concentrations of volatile organics ...generally are found under seepage and settling basins in central and southern portions of the [A-Area and M-Area]."⁹⁵

TCE and PCE are also classified as dense non-aqueous phase liquids (DNAPL), because they are more dense than water and relatively insoluble in it. DNAPLs are particularly difficult to remove from groundwater, because they tend to migrate along vertical fractures and form lateral structures of pollution when they encounter less permeable layers. DNAPLs trapped in pore space slowly dissolve into the groundwater over a long period of time. These "sinks" of DNAPLs found in pockets and pore spaces are particularly difficult to locate and remove.

Large amounts of solvents were discharged into unlined basins in the 350-acre A/M-Area.⁹⁶ And although DOE ceased its massive dumping of toxic chemicals years ago, there are some locations at SRS where concentrations of TCE in groundwater are increasing. For example, the TCE concentration in a southwestern well (MSB 2B) increased nearly three-fold from 1996 to 2000 (4,880 micrograms per liter to 13,000 micrograms per liter). The highest concentration in the

⁹³ GDNR, 1999, pages A-4 and D-58

⁹⁴ WSRC, 2001b, pages 49 and 53

⁹⁵ WSRC, 2000b, page 166

⁹⁶ Massman, November 1999, page 1 and DOE-SRS, January 2002d

year 2000 was in a northern well with a concentration of 40,300 micrograms per liter. The drinking water standard for TCE is 5 micrograms per liter.⁹⁷

In order to slow the spread of contamination, the basins in the A/M-Area have been capped⁹⁸ and a program of pump-and-treat with air strippers is being used to remove the volatile organic compounds from the groundwater. One air-stripper is located in the northern section of the A/M-Area and the other is located south of the M-Area Hazardous Waste Management Facility. According to Westinghouse, "The two ... air strippers have removed more than 400,000 pounds of solvent from over 4.3 billion gallons of groundwater."⁹⁹

Since 1995, DOE has also been using another method, called "soil vapor extraction" or "soil vacuum extraction" to clean out solvents from the vadose zone. There are currently six vapor extraction systems operating in the A/M-Area. Soil vapor extraction has been used to remove almost 600,000 pounds of solvents from the vadose zone.¹⁰⁰ Monitored natural attenuation is planned for the most dilute portion of the plume.¹⁰¹

The total amount of solvent that had been removed from both the groundwater and the soil was about 950,000 pounds as of January 2002.¹⁰² Uncertainties in the amount and the distribution of the solvents in the soil mean that the total time and resources that will be required to clean up the contamination are essentially unknown. Vapor extraction suffers from a problem similar to pump-and-treat systems for water: the cleaner the soil becomes, the more difficult it is to extract the remainder of the contamination with vapor extraction.¹⁰³

TCE is also present in the D-Area and in the TNX shallow aquifers¹⁰⁴ The plume of TCE contamination in the TNX area seems to be moving via the Savannah River Swamp and was within a several hundred feet of the Savannah River by 1990.¹⁰⁵ The groundwater pump-and-treat system at TNX has decreased TCE concentrations over time, but concentrations exceed drinking water standards in seven wells.¹⁰⁶

TCE concentrations above the drinking water standard are also found in the groundwater in the E-, F-, and H-Areas. The range of contamination in these Areas is between 14.7 and 1,160 micrograms per liter.¹⁰⁷ The drinking water standard for TCE is 5 micrograms per liter.

⁹⁷ WSRC, 2000b, pages 166 and 169

⁹⁸ DOE-SRS, January 2002d

⁹⁹ DOE-SRS, January 2002e. "An air stripping system works by pumping contaminated groundwater to the top of an air stripping column. As the groundwater cascades downward through the column, pumped air is forced upward from the bottom of the column. When the water mixes with air, solvents in the groundwater move from a liquid phase into a vapor phase, and volatile contaminants are stripped and released to the atmosphere. The cleaned water is discharged through a permitted outfall to a nearby stream at levels less than 1 part per billion." (DOE-SRS, January 2002e)

¹⁰⁰ DOE-SRS, January 2002e, page 2; WSRC, 2000b, page 169

¹⁰¹ Bergren and Huber, 1999, page [8]

¹⁰² DOE-SRS, January 2002e, page 2

¹⁰³ Massman, November 1999, pages 2 and 29

¹⁰⁴ WSRC, 2000b, page 174

¹⁰⁵ RAC, April 2001, page J-8, citing Cummins, et al. 1991

¹⁰⁶ WSRC, 2000b, pages 174 to 176; DOE-SRS, March 2002b

¹⁰⁷ DOE, May 2002b, page 3-17 to 3-19

Volatile organic compounds, especially TCE and PCE, are also in the groundwater under other areas at SRS, such as the K- and L-areas and the Burning/Rubble Pits.¹⁰⁸ In the case of the K- and L-areas, the TCE and PCE contamination exists along with the tritium in the groundwater.¹⁰⁹

C. Mercury and Cadmium

Mercury was used at SRS mainly to produce lithium-6, which is the material irradiated in a reactor to produce tritium. It was also used for other purposes, such as a sealant in tritium gas pumps.¹¹⁰ Specifically, mercury was used to separate lithium-6 from lithium-7, with the former being used as target material in reactors for producing tritium. Over 10 metric tons (about 24,000 pounds) of mercury are mixed in the waste in the Burial Ground.¹¹¹ Mercury and cadmium appear to be migrating into the groundwater in the F- and H-areas. The average concentration of cadmium in the F-area shallow groundwater and for mercury below the H-area exceeded maximum allowable concentrations in 1999.

Table 9: Cadmium and mercury in F- and H-Area groundwater, 1999

Metal	Concentrations (micrograms per liter)				Regulatory limit
	F-Area		H-Area		
	Average	Maximum	Average	Maximum	
Cadmium	7.8	37	BAL	BAL	5
Mercury	0.63	7.4	2.4	16	2

Source: Serkiz *et al.*, 2000, page 3

Note: BAL=Below allowable limit

The solubility of mercury in water depends on a variety of conditions, including the chemical form of the mercury and parameters (such as pH) of the solvent water. In the Burial Grounds, average mercury concentrations have exceeded 3 micrograms per liter in at least four areas of the site.¹¹²

D. Contaminant Levels in Fish

Fish bioaccumulate certain elements, especially cesium-137 and mercury.¹¹³ By the mid-1950s,

¹⁰⁸ WSRC, 2000b pages 183 to 187

¹⁰⁹ WSRC, 2002b, Table 6-1, page 59

¹¹⁰ WSRC, August 2000, pages C-1 to C-3

¹¹¹ WSRC, August 2000, page C-1

¹¹² WSRC, August 2000, page 2-64

¹¹³ WSRC, 2000b, page 114 and 141. "Cesium is chemically similar to potassium and tends to replace potassium in animal flesh. (Connor, 1996). Mercury in streams and rivers is "converted to ... methylmercury by bacterial and other processes....Fish absorb methylmercury from food they ingest and from water as it passes over their gills; the methylmercury then is bound in their tissues." (WSRC, 2000b, page 142). "High-dose human exposure of mercury results in mental retardation, cerebral palsy, deafness, blindness, and dysarthria in utero and in sensory and motor impairment in adults Data on cardiovascular and immunological effects are also beginning to be reported and provide more evidence for toxicity from low-dose methylmercury exposure." (EPA-OST, January 2001, pages ix to x).

it was evident that fish in the Savannah River were impacted by SRS activities, including bass, bream, and catfish.¹¹⁴

Fish in the Savannah River have concentrated about 3,000 times more cesium than levels found in the water.¹¹⁵ The highest level of Cs-137 was 1.58 picocuries per gram of fresh weight. Most measurements are an order of magnitude below this.¹¹⁶

Neither South Carolina nor Georgia has issued fish consumption guidelines based on cesium-137 concentrations in fish.¹¹⁷ The Georgia Department of Natural Resources found a maximum of 2 picocuries of cesium-137 per gram (fresh weight) in SRS outfalls, with a mean of 0.200 picocuries per gram (fresh weight).¹¹⁸ According to Georgia's Department of Natural Resources, the mercury guidelines are sufficient to be protective for cesium-137.¹¹⁹ Given the present mix of contaminants, limiting fish consumption based on the mercury guidelines would keep doses from cesium-137 below 1 millirem and therefore under any applicable standards. However, DOE is leaving an enormous amount of residual cesium-137 and other radionuclides in the tanks, which may create a greater threat in the future. This problem will be multiplied many fold if DOE does not implement some method to extract most of the cesium-137 from the tank waste (see Chapter V). Further, the problem of cesium-137 in the river and the fish should be evaluated together with that of Iodine-129 (see below), tritium, and mercury. Further, the issue of subsistence fishing needs to be addressed. Current standards and guidelines may not be sufficient to protect some populations when all pollutants and vulnerabilities are taken into account.

Tritium, some of it organically bound (and hence with a longer residence time in the body relative to tritiated water), is also found in the area's fish. The Georgia Department of Natural Resources found a maximum of 13 picocuries of tritium per gram (fresh weight) in SRS outfalls, with a mean of 2.1 picocuries per gram (fresh weight).¹²⁰

Although it is illegal to fish within the SRS boundary, some people may poach fish from within its boundary.¹²¹ Over the long run it would be virtually impossible to guarantee that areas currently within the SRS boundary will remain so and be off-limits to fishing. Radionuclide concentrations in fish from SRS locations have been consistently higher than offsite locations.¹²²

According to Westinghouse: "Mercury concentrations in offsite fish ranged from a high of 1.629 [micrograms per gram] in a bass ... to a low of 0.016 [micrograms per gram] in a mullet." Mercury concentrations in fish caught at SRS "ranged from a high of 1.817 [micrograms per gram] in a bass from Par-Pond to a low of 0.094 [micrograms per gram] in a bream in L-Lake."

¹¹⁴ RAC, April 2001, pages 14-2 and 14-3. "Routine collection of fish began in July 1957," though limited sampling was conducted prior to 1957.

¹¹⁵ WSRC, 2000b, page 114

¹¹⁶ WSRC, 2000a, pages 94 to 96

¹¹⁷ SCDHEC, 2003a, SCDHEC, 2003b

¹¹⁸ GDNR, 1999, page A-18

¹¹⁹ GDNR, 2003, page 39

¹²⁰ GDNR, 1999, page A-10

¹²¹ RAC, April 2001, page 14-1

¹²² RAC, April 2001, page 14-21

Bass were found to accumulate the highest levels of mercury.¹²³

According to the South Carolina Department of Health and Environmental Control, bluegill, sunfish, catfish and crappie from the Savannah River along SRS should be limited to one meal (8-ounces or 0.227 kg) a week (1.14 Oz./day), while largemouth bass and bowfin from the Savannah River along SRS should be limited to one meal per month. This is based on the mercury content of the fish, and not on the radionuclide levels.¹²⁴

Social research indicates that some people use the Savannah River for subsistence fishing, usually defined to include those individuals who consume approximately 50 kilograms (110 pounds) of fish per year (about 2 pounds per week). A 1996 survey by Morris, Samuel, and students of Benedict College indicated that people fish near the SRS outfalls that are contaminated.¹²⁵ A 1999 survey of people fishing along the Savannah River found that some individuals eat as much as 50 to 100 kilograms of fish from the Savannah River per year.¹²⁶ There are people from various segments of the population who practice subsistence fishing, including Whites, but both surveys found that the practice is more common among African-Americans, who, on average, also eat more fish from the river than Whites. The average daily consumption among African-Americans indicated by the 1999 survey was about four ounces, or four times the maximum limit recommended by the South Carolina Department of Health and Environmental Control. *Reducing pollution in the Savannah River along SRS is therefore an essential aspect of environmental justice as well as of protecting the health of all people who depend on the river for their subsistence and as an important source of protein.*

¹²³ WSRC, 2000b, page 141

¹²⁴ SCDHEC, 2003b, Table II

¹²⁵ Milton Morris and May Linda Samuel, *A Study of Factors Relating to Fish Subsistence/Consumption Within Communities Near the Savannah River Site* (Benedict College, Columbia, South Carolina), November 26, 1996, pages 29, 89, and 91. See answers to questions 10 and 21. Benedict College is an historically Black college in Columbia, South Carolina. IEER thanks Dr. May Linda Samuel for providing us with the research data and making a presentation on the subject at an IEER workshop.

¹²⁶ Burger et al., 1999, pages 432 and 433

Chapter V: Remediation of SRS

There are four threats to the water resources of South Carolina and Georgia from SRS:

1. Migration of radionuclides from shallow land disposal of wastes at SRS due to processing of existing waste, such as that now stored in high-level waste tanks and other containment structures.
2. Flow of contaminants from plumes presently onsite into offsite water bodies, both via groundwater and surface water transport.
3. Migration of radionuclides from dumps and burial grounds into aquifers onsite and from there to offsite groundwater and surface water.
4. Migration of waste disposed of onsite from future production or processing activities.

We will discuss the first three items in this chapter. The last is beyond the scope of this report.

A. High-level waste tanks

More than 99 percent of the radioactivity in the waste at SRS is contained in the high level waste. Of this only about one percent (about 4.2 million curies) has been extracted from the tanks, mixed with molten glass and cast into glass logs at a vitrification plant for high-level waste, called the Defense Waste Processing Facility, which was opened in 1996. The 1221 glass logs that have been cast are in steel-alloy canisters, and are stored onsite pending disposal in a high-level waste repository. In the short- and medium-term, this vitrified waste poses the least risk of contaminating the environment at the site. In the long term, it must be disposed of in a deep geologic repository.¹²⁷

DOE has not yet determined how the bulk of the waste from the tanks will be disposed of. The original waste management plan, adopted in the 1980s was to treat the salt and supernate wastes, which is about 90 percent of the volume, remove the key radionuclides (especially cesium-137) and vitrify almost all the radioactivity. The bulk liquid that would remain was planned to be mixed with cement and disposed of onsite as low-level waste called saltstone.

DOE's original plan to separate the cesium-137 from the salt wastes ran into severe technical difficulties. The method originally chosen, large-scale in-tank precipitation (ITP) using tetraphenyl borate, was abandoned in 1998.¹²⁸ The main problem was that the residual waste generated benzene, a flammable and toxic gas whose presence in the tanks gave rise to risks of fire in radioactive wastes.

¹²⁷ The only high-level waste repository being investigated in the United States at present is the site at Yucca Mountain, Nevada. Laboratory experiments have shown that the geology of this site is not compatible with glass as a waste form. (See Makhijani, January 1991). DOE's own modeling shows that the geology of the site is not estimated to play a significant role in retaining the wastes, leaving almost the entire function of radionuclide containment to be performed by metal canisters into which spent fuel or the SRS high-level waste would be inserted. (See DOE charts in Makhijani, 1999). But Yucca Mountain is an oxidizing environment, raising the possibility that the canisters may corrode faster than the DOE projects.

¹²⁸ NRC-NAS, 2001, page 24

In July 2001, DOE announced that it had decided to extract cesium-137 from the salt solution using specific organic solvents with a technology called Caustic Side Solvent Extraction.¹²⁹ Currently, DOE is researching this technology, as well as back-up technologies, including an ion-exchange method and small tank tetraphenylborate precipitation.¹³⁰ This latter approach is chemically identical to the earlier in-tank precipitation method, with the main exception that smaller tanks are to be used in this version. The extracted cesium-137 waste would be vitrified.

In its August 2002 Record of Decision, DOE decided to follow the same procedure to close the remaining 49 tanks as it has with the two tanks it has closed so far -- filling the tanks with grout after the bulk of the waste has been removed.¹³¹ As we have noted in Chapter II, the "heels" of radioactive materials left in these tanks contain substantial amounts of radionuclides. The residual cesium-137 activity of the residual waste in Tank 19 *alone*, over 48,000 curies,¹³² exceeds the *total estimated* cesium-137 activity for the residual waste in *all* the tanks in the F- and H-Area Tank Farms (9,900 curies) in the High-Level Waste Tank Closure Final Environmental Impact Statement.¹³³ The tank waste that remains to be vitrified contains far more radioactivity than the tanks that have been emptied so far. The Tank Closure EIS estimates the residual radioactivity in the F and H Tank Farms as about 170,000 curies; the far higher actual residual waste means that closure of over four dozen high-level waste tanks may result in a million curies or more remaining onsite as a future threat to the groundwater and streams onsite and, therefore, to the Savannah River

In fact, the closure plan for Tank 19 is a blatant, illegal, and dangerous example of "dilution is the solution to pollution." The residual waste in the tank is estimated to have a concentration of radioactivity over 14 times the Class C low-level waste limit, which defines the most radioactive waste allowed to be put into shallow land burial. The Class C limit is exceeded for each one of four radionuclides by itself: plutonium-238, plutonium-239, plutonium-240, and americium-241. The tank residuals are therefore "Greater than Class C waste," or equivalently, transuranic waste, of the type that is generally required to be disposed of in a deep geologic repository. But once the tank residual wastes are diluted with a huge amount of grout, the closure document estimates that the resultant waste will be 0.997 times the Class C limit -- that is, it would squeak under the wire of present "low-level" waste rules. Allowing such dilution and dumping could open the door to diluting even more radioactive wastes and leaving them by the riverside to threaten people far into the future.¹³⁴

Plutonium is another concern. The "emptied" Tank 19 is estimated to contain 30 curies of plutonium-239, and almost 11 curies of plutonium-240.¹³⁵ This Pu-239/240 inventory amounts to about half a kilogram. Given that less than two percent of the radioactivity in all of the sludge has been vitrified (4.2 million curies out of 320 million curies) and that almost all of the

¹²⁹ DOE, July 2001

¹³⁰ Contardi, July 2001, page 2

¹³¹ DOE, August 2002. Residual waste consists of solids firmly attached to the tank surfaces as a "crust" or "hard-heel," which is more difficult to remove from the tanks than the bulk of waste, as well as interstitial liquids.

¹³² d'Entremont and Thomas, November 2002, Table 3, page 16

¹³³ DOE, May 2002b, page C-18, Table C.3.1-1

¹³⁴ d'Entremont and Thomas, November 2002, Table 6, page 19

¹³⁵ d'Entremont and Thomas, November 2002, Table 3, page 16

plutonium is in the sludge, the eventual residual plutonium-239/240 in the tank farm may be very substantial. In addition, the Tank Farms contain well over a million curies of plutonium-238,¹³⁶ which has a half life of about 87 years. Residual radioactivity of even one or two percent in these tanks would leave a vast amount of total alpha-emitting plutonium radioactivity in the tanks as low-level waste.

DOE is planning to evaluate each tank on a case-by-case basis, in what DOE calls "Closure Modules."

Each tank system or group of tank systems would be evaluated to determine the inventory of radiological and nonradiological contaminants remaining after bulk waste removal. This information would be used to conduct a performance evaluation as part of the preparation of a Closure Module. In the evaluation DOE would consider (1) the types of contamination in the tank and configuration of the tank system, and (2) the hydrogeologic conditions at and near the tank location, such as the distance from the water table and distance to nearby streams.¹³⁷

Therefore, "the closure configuration for each tank or group of tanks would be determined on a case-by-case basis through the development of the Closure Module."¹³⁸ The South Carolina Department of Health and Environmental Control must approve the Closure Modules, but it is unclear how SCDHEC could make such a determination on a case-by-case basis. The General Closure Plan involves estimating the performance of all tank closure together. For example, a total 4 millirem-per-year limit in drinking water in the receiving stream from all tanks and all radionuclides must be premised upon some overall plan that includes a tank by tank evaluation, and adds it up for all tanks. The DOE approach cannot provide a basis for such an evaluation, especially since the actual tank-by-tank plans indicate that there will be far more residual radioactivity than that estimated in the Final Closure EIS. The DOE plan is risky, to say the least. A large part of the risk lies in the fact that the preferred alternative is closure of the tanks by grouting. If grouting is found to be unsatisfactory from the point of view of a 4 millirem drinking water standard in the receiving stream, it cannot be undone or remediated.

1. DOE Contingencies

DOE broached the possibility of abandoning most high-level waste onsite in November 2001:

HLW [High-level waste] processing is the single largest cost element in the EM [Environmental Management] program today. Eliminate the need to vitrify at least 75 percent of the waste scheduled for vitrification today. Develop at least two (2) proven, cost effective solutions to every high-level waste stream in the complex.¹³⁹

¹³⁶ DOE's then-contractor for SRS, Dupont, listed the Pu-238 content of the Tank Farm in 1986 as being 1.5 million curies. See Makhijani, Alvarez, and Blackwelder, 1987, Table 1, and associated discussion. This would have decayed to about 1.3 million curies by 2003.

¹³⁷ DOE, August 2002

¹³⁸ DOE, August 2002

¹³⁹ Roberson, November 2001

DOE's initial approach to getting around the high-level waste act, which requires deep geologic disposal of high-level waste, was to redefine the waste from high-level to a newly created category, not established in law: "waste incidental to reprocessing." DOE laid the basis for this new waste classification in 1999 in Order 435.1 and in its Radioactive Waste Management Manual, DOE M 435.1-1.¹⁴⁰ DOE acknowledged in DOE G 435.1-1 that its definition of high-level waste is "slightly modified from the Nuclear Waste Policy Act of 1982."¹⁴¹ However, the change is much larger than this phrase would imply, because DOE has introduced the criteria of technical and economic practicality of processing into its definition. DOE claims that incidental wastes that can be managed as low-level wastes "may include, but are not limited to, spent nuclear fuel reprocessing plant wastes that ...[h]ave been processed, or will be processed, to remove key radionuclides to the maximum extent that is technically and economically practical."¹⁴²

DOE claims that the waste left in the two closed tanks is "incidental waste," even though in the past DOE itself had classified it as high-level waste. According to a 2000 report by the National Academy of Sciences (NAS), there are several obstacles to reclassifying the high-level waste as waste incidental to reprocessing. To declare the waste as incidental, DOE Order 435.1 in Appendix D requires that the "waste must receive processing to remove key radionuclides to the maximum extent that is technically and economically practical." However, the authors reasoned that the evidence indicates that the waste is practically and economically treatable, though the costs are slightly higher than with direct grouting. In addition, the level of cesium-137 that would be incorporated in the grout is several orders of magnitude higher than the current state permit limits. Further, in Tank 19, the residual radioactivity is well beyond Class C waste limits. It will have high residual plutonium content, which puts it in the category of waste that must be disposed of in a deep geologic repository. Finally, SRS would also have to demonstrate that the waste would meet the long-term performance objectives in DOE Order 435.1. The authors of the NAS report concluded that the direct grout waste stream is high in long-lived radionuclides and "the ability of the site to reliably meet long-term safety performance objectives remains uncertain."¹⁴³

The Natural Resources Defense Council, the Confederated Tribes & Bands of the Yakama Nation, and the Snake River Alliance filed a lawsuit against DOE alleging that reclassification is in contravention of the Nuclear Waste Policy Act.¹⁴⁴ In July 2003, the court ruled in favor of the plaintiffs that the redefinition is illegal.¹⁴⁵ DOE is appealing. Thereafter, DOE has attempted to get Congress to give it clear authority to make such classification changes, but, as of this writing (mid-February 2004), without success.

¹⁴⁰ DOE, July 1999, page II-3. It could be argued that the foundation for the new waste category was in DOE Order 5820.2A, which preceded DOE Order 435.1, because DOE's closure of Tank 20 was based on performance assessment objectives contained in DOE Order 5820.2A. This allowed DOE to determine that the residuals in the tank after repeated cleaning are "incidental wastes" that could be disposed of as low-level waste as long as they were not greater than Class C wastes.

¹⁴¹ DOE, July 1999, page II-1

¹⁴² DOE, July 1999, page II-13

¹⁴³ NRC-NAS, 2000b, pages 76-79

¹⁴⁴ NRDC v. DOE, 2002

¹⁴⁵ NRDC v. DOE, 2003

2. Performance of Grout

There is insufficient understanding of the long-term risks to groundwater and surface water from shallow land burial of grouted wastes. Given past experience with grouting of wastes (discussed below), these contaminants could leach out into the groundwater much faster than anticipated and add to the existing contamination in the groundwater, and eventually to the surface water. Moreover, grouting the tanks in place would put the residual wastes in a form that would be very difficult or impossible to retrieve were they found to be leaking. Grouting would also make remediation of the vadose zone even more difficult. DOE admits that "tank closure is, for all practical purposes, irreversible. DOE would have great difficulty undoing a closure [with grout] if it were later discovered that [a dose] estimate had been improperly developed, or that the performance had been improperly evaluated."¹⁴⁶

According to a report on long-term stewardship by the National Academy of Sciences:

Predicting performance in resisting water infiltration can be difficult because of uncertainties that include the degree to which the first layers of grout take up the residue, the water pathway effects of the cold joints between successive pours of grout, and the effects of preferential corrosion of the tank metal and penetrating structures (thereby offering a partial bypass path). Moreover, waste tank residue is likely to be highly radioactive and not taken up in the grout, so there is substantial uncertainty associated with the volumetric classification and average concentration of the waste and prediction of the isolation performance of the system.¹⁴⁷

While experience at other sites with grout does not correspond in its details with that at SRS, it is indicative of the kinds of problems that have already been experienced with grouting. We examine two such cases here.

DOE sponsored studies on grout durability in the context of a grouting program at Hanford. The durability of grout depends on many factors, such as temperature and moisture, and the composition of the grout. The heat due to radioactive decay, for instance, and/or the heat that is released when the grout sets can raise the temperature above 90° Celsius (194° F). At such temperatures the grout may not set properly, and hence it may subsequently crack. According to a 1992 study of the durability of double-shell tank waste grouts at Hanford:

The grouts will remain at elevated temperatures for many years. The high temperatures expected during the first few decades after disposal will increase the driving force for water vapor transport away from the grouts; the loss of water may result in cracking, dehydration of hydrated phases, and precipitation of salts from saturated pore solution. As the grout cools, osmotic pressure caused by the high salt content may draw moisture back into the grout mass. The uptake of moisture may have detrimental impacts on the behavior of the grout.¹⁴⁸

¹⁴⁶ DOE-SRS, November 2001

¹⁴⁷ NRC-NAS, 2000c, page 40

¹⁴⁸ Lokken, Martin, and Shade, December 1992, page 2

Nuclear Dumps by the Riverside

The history of grout at Rocky Flats, the nearly decommissioned DOE plant near Denver, Colorado, where plutonium pits for nuclear bombs were made, indicates the risks in the real world, even in the absence of elevated temperatures.

Rocky Flats operations resulted in the generation of liquid and solid wastes containing radioactive and hazardous materials and large quantities of contaminated soil and groundwater. From 1953 to 1986, five ponds lined with asphalt and concrete (called Solar Ponds) were used to store and evaporate low-level waste contaminated with nitrates and radionuclides. Other waste was also dumped in the ponds from time to time.¹⁴⁹ The linings were ineffective, as demonstrated by the fact that the shallow groundwater in the area became contaminated with radioactive materials, nitrates, VOCs, and heavy metals.¹⁵⁰

Because of the existing contamination and possible further contamination, DOE began phasing out the use of the ponds in early 1980s; it soon began another experiment with cement. In 1985, sludge from the solar evaporation ponds began to be mixed with cement to form large blocks of "pondcrete," which were packaged in fiberglass boxes and shipped to the Nevada Test Site for disposal. Soon after the project began, the waste had to be reclassified from low-level to mixed waste, because it was determined that the waste contained hazardous chemicals, regulated under the Resource Conservation and Recovery Act (RCRA). Over 16,500 pondcrete blocks of mixed waste were manufactured and stored onsite, outdoors, for nearly two years, while the permitting necessary for offsite shipment was being pursued.¹⁵¹

In 1988, it was discovered that some of the fiberglass boxes on the outdoor pad had deteriorated while exposed to the weather and some of the pondcrete blocks had crumbled and cracked. At least one box had spilled open. It was later determined that the ratio of cement to sludge waste in making the pondcrete was incorrect. The problem apparently arose because the equipment used to introduce cement plugged up intermittently. Over 8,000 pondcrete blocks, that is, about half of the blocks stored outdoors, had to be remixed and repackaged.¹⁵²

The Nevada Test Site found that 25 of the 28 blocks of pondcrete that had not yet been buried were, contrary to specifications, with surfaces soft enough to be scored by a stick; it was decided to bury them anyway because no liquids were found. The Nevada Test Site determined that the approximately 2,000 blocks that had already been buried posed little threat of contaminant migration, based on its assessment of the 28 blocks, the distribution of the containers throughout the burial ground, and the dryness of the soil. However, in October 1988, the Nevada Test Site changed its acceptance criteria for the pondcrete. It required that the pondcrete be packaged in plywood boxes with a compressive strength of 4,000 pounds per square foot.¹⁵³

Rocky Flats has been left with some of the legacy of the mess as well, despite the shipment of the pondcrete blocks to Nevada. The quantity of underlying contaminated soil under the Solar Ponds has not been fully determined, but is estimated to be slightly less than 153,000 cubic

¹⁴⁹ BEMR, 1996. Rocky Flats Environmental Technology Site section

¹⁵⁰ GAO, January 1991, page 3

¹⁵¹ GAO, January 1991, pages 1 to 6

¹⁵² GAO, January 1991, pages 2 to 4

¹⁵³ GAO, January 1991, page 5

meters (200,000 cubic yards) in that general vicinity.¹⁵⁴

DOE is pursuing a cleanup program under which soil with contaminant concentrations greater than specified radionuclide soil action levels (RSALs) will be removed. However, the proposed RSALs at Rocky Flats are quite high: 50 picocuries per gram of plutonium in the top three feet, and 3000 pCi/g (based upon concentration and area/volume) in the three to six foot depth range.¹⁵⁵ These levels are far too lax and represent an unacceptable risk to future generations by traditional radiation protection standards, which aim at protecting future farmers or ranchers who might settle on the site, in case site control and information about the contamination are lost.¹⁵⁶

In sum, grouting residual high-level waste in tanks that contains significant quantities of long-lived radionuclides (including cesium-137 and plutonium-238, and plutonium-239/240) is a policy that poses considerable risks to the long-term health of the water resources in the region.

B. Buried Waste

A variety of wastes have been buried, often literally dumped, at SRS. These include what came to be defined as transuranic waste (with high levels of alpha-emitting plutonium and/or other transuranic radionuclides), low-level radioactive waste, and mixed radioactive and non-radioactive toxic waste.

1. Transuranic Waste

Even though the TRU waste category was created in 1970 and TRU waste was designated for repository disposal, DOE buried transuranic (TRU) waste at SRS well into the 1970s. While the intent of these burials may have been retrievable storage, most of these wastes are currently believed to be essentially irretrievably buried.¹⁵⁷ Approximately 17,100 curies (4,530 cubic meters) of transuranic wastes are buried in the Old Radioactive Waste Burial Ground at SRS. Transuranic waste is also buried at the Low-Level Radioactive Waste Disposal Facility (38 curies) and the Mixed Waste Management Facility (1,390 curies).¹⁵⁸ The TRU activity associated with the buried TRU-contaminated wastes at the three locations at SRS is approximately 18,500 curies (decay-corrected to 2006).¹⁵⁹ The DOE Field Offices ranked the level of confidence associated with these data as "generally low to medium." At SRS, the estimates of the activity of the transuranic waste at the three locations are considered to be "reasonably good," but volume estimates for the Low-Level Radioactive Waste Disposal Facility and the Mixed Waste Management Facility are not known.¹⁶⁰

The volume of transuranic-contaminated soil associated with buried transuranic wastes is highly uncertain. DOE has estimated that the volume is 38,000 cubic meters, but this value is more than

¹⁵⁴ BEMR, 1996. Rocky Flats Environmental Technology Site section

¹⁵⁵ Rocky Flats, 2003, General Response, page 1

¹⁵⁶ See Makhijani and Gopal, December 2001, for further discussion of setting radionuclide soil action levels for Rocky Flats.

¹⁵⁷ Fioravanti and Makhijani 1997, pages 110 to 113

¹⁵⁸ Decay-corrected to 2006. DOE, June 2000, pages 22 and 23

¹⁵⁹ DOE, June 2000, page 12

¹⁶⁰ DOE, June 2000, page 12

10 years old and was derived by reviewing historical disposal records or from pit and/or trench dimensions rather than from field characterization activities.¹⁶¹

There is a huge area of 195 acres (78 hectares) called the Burial Ground Complex, where radioactive and mixed radioactive and non-radioactive hazardous wastes were dumped. A part of this, including 58 acres involving mixed wastes, has been closed and capped. Another 25 acres are also capped. Because of the hazardous materials, it is required to be, and is, regulated under the Resource Conservation and Recovery Act.¹⁶²

The purpose of surface caps is to reduce water infiltration and hence the leaching of contaminants from the buried waste and the contaminated vadose zone to the groundwater. They are not a remediation method for already contaminated groundwater. Vegetation planted on the caps increases evapotranspiration and hence can reduce water infiltration. But vegetation also reduces runoff and may therefore sometimes increase water infiltration. In any case, caps are a short term palliative, not a long-term remedy. Physical and biological processes can also decrease the long-term performance of compacted soil caps. They include wetting and drying cycles, soil erosion, root intrusion, worms, and burrowing animals. Table 10 lists some of the main physical and biological processes that can decrease the long-term performance of compacted soil caps.

Table 10: Physical and Biological Processes Influencing Long-Term Performance of Compacted Soil Caps

Physical Processes	Biological Processes
Wetting and drying cycles	Root intrusion
Freeze-thaw effects	Worms
Soil erosion	Insects
Subsidence	Burrowing animals

Source: Smith, Luxmoore, and Suter, 1997, pages D-61 to D-67

The way in which physical, chemical, and biological processes interact to disperse radionuclides in the environment over the long term is not very well understood. For instance, it is often assumed that clay acts as a strong retardant for radionuclides through ion-exchange that binds metal cations in the waste to the soil. This assumption has been shown not to apply under certain field circumstances, as for instance when organic materials from decaying leaves accelerate the movement of radionuclides.¹⁶³ As for biological processes and radioactivity dispersal, DOE is sponsoring research on how bacteria might be used to concentrate radioactivity for the purpose of remediation.¹⁶⁴ But if bacteria can, under controlled circumstances, be used for remediation, they may equally well disperse radioactivity under natural circumstances where there are no means to prevent the microorganisms from spreading in the environment.

¹⁶¹ DOE, June 2000, page 14

¹⁶² DOE, January 2001, South Carolina Section, page 26

¹⁶³ For more discussion and evidence, see Makhijani and Boyd, 2001, Fioravanti and Makhijani, 1997, and Makhijani and Gopal, December 2001.

¹⁶⁴ LBL, 2000

2. Low-level waste

In addition to transuranic wastes, DOE is planning to leave almost 1.4 million cubic meters of in-situ media contaminated with low-level waste in place, most of which will be covered with a surface cap or grouted.¹⁶⁵ (See Table 11).

Table 11: SRS management of in-situ media contaminated with low-level waste

Method	Volume (cubic meters)	Radioactivity (curies)*
Cap in place	898,576	Not given
Soil mixing/grouting	431,770	Not given
Monitoring	27,799	Not given
TOTAL	1,358,145	1,326,000

Source: DOE-EM, April 2001, page 10-19

Note: * Decay corrected to 2002: 571,000 curies in the Old Radioactive Waste Burial Ground. Decay corrected to: 755,000 curies in the Low-Level Radioactive Waste Disposal Facility. WSRC, August 2002, page 35; WSRC, December 2000, pages ES-11 to ES-16

In addition to the threat to surface and groundwater from the low-level waste in the Burial Grounds, DOE is continuing to dispose of low-level waste in unlined trenches in E-Area, which are exempt from independent external regulation. In the February 2000 Record of Decision for low-level waste disposal, DOE specified regional disposal sites at the Hanford Site and Nevada Test Site, with continued disposal of wastes generated onsite at SRS in E-Area Trenches, the Low Activity Waste Vaults, and the Intermediate-Level Waste Vaults.¹⁶⁶

DOE's ongoing disposal of low-level waste using shallow unlined trenches could aggravate groundwater contamination problems in two ways. First, this disposal of low-level waste increases the inventory of waste in the ground that could later migrate to groundwater and/or surface water. Second, continuing to have the trenches open causes existing contamination to be driven further towards the aquifers. As rainwater collects in trenches and percolates downward, it can dissolve chemicals in the waste, as well as remobilize vadose zone contaminants, and carry them to the aquifer.

According to the original Performance Assessment for the E-Area Low-Level Waste Facility, which was issued in 1994, the trenches could only be used for radioactively contaminated soil. In 2000, the Performance Assessment was revised to include disposal of grouted radioactive ash and other grouted waste.¹⁶⁷ Disposal of waste is continuing despite the past record of substantial groundwater pollution from past dumping.¹⁶⁸

¹⁶⁵ DOE-EM, April 2001, pages 10-18 and 10-19

¹⁶⁶ DOE, February 2000 and DOE-SRS, April 2002a

¹⁶⁷ "Components in grout" means placing the item on a one-foot thick grout base, filling any void space with grout, and grouting around the item using the trench walls as a form. (DOE-SRS, April 2002a, pages 2-3)

¹⁶⁸ DOE, January 1998b and WSRC, 2000b, pages 177 and 179

C. Tritium

As discussed in Chapter III, the principal radioactive surface discharge from SRS into the Savannah River is tritium, both now - 13 years after the last reactor start-up attempt at SRS - and for the immediate future.¹⁶⁹ The long-term threat that the serious shallow aquifer contamination on the SRS site poses to the deeper aquifers needs to be carefully and independently evaluated, given the importance of this aquifer to the southeastern United States.

Currently, tritiated water plumes are being managed with hydraulic pumping. In order to reduce the amount of tritium-contaminated water discharging through the seepage line to Four Mile Creek, DOE installed a small dam, creating a small pond. An irrigation system pumps water from the pond to 30 acres of adjacent pine and hardwood-mixed forest. The trees and other plants take up the tritium-contaminated water and release some to the atmosphere through transpiration. DOE is calling this the "tritium phytoremediation project." The dam, completed in October 2000, and the irrigation system, operating since February 2001, have reduced tritium discharges to Four Mile Creek by about 50 percent.¹⁷⁰ However, equipment failure caused three large releases of tritium into the creek in 2001. While DOE states that this remediation is an "interim measure" there are no other specific plans to reduce tritium discharges to the river, other than simply waiting for it to decay, which will take many decades.¹⁷¹

Phytoremediation may reduce the pollution of SRS streams but it may carry a stiff, but, at present, unquantifiable penalty because it may compromise the genetic integrity of the forest. Some of the tritiated water will become incorporated into the DNA of the trees and into seeds with unknown long-term effects.¹⁷² The main approach to reducing tritium must be to remove the primary source: the solid waste in the burial grounds. While there is currently no technology to remove the relatively highly dilute levels of tritium found in the surface water at SRS, it may be possible to strip some of the tritium from the most contaminated water. DOE does not plan to do this because the technology is not considered practical on a large scale.

We will deal with tritium in more detail in the policy chapter (Chapter VI), since the problem is connected to the issue of the adequacy of present safe drinking water standards to protect public health.

¹⁶⁹ The last tritium production reactor to operate at the SRS shut down in August 1988, for safety upgrades and repairs. The K-reactor restarted briefly for a test in 1991, but shut down immediately and permanently when tritium leakage into the Savannah River was discovered.

¹⁷⁰ DOE-SRS, October 2003

¹⁷¹ WRSC, 2001b, page 47

¹⁷² Makhijani 2001, Chapter 5. See discussion of the genetic uncertainty principle.

Chapter VI: Policy Considerations for Cleanup¹⁷³

DOE plans for SRS, which involve leaving significant amounts of waste and contamination in place, are dependent on the use of long-term stewardship, including institutional controls, for protection of human health and the environment.¹⁷⁴ DOE's general cleanup strategy for SRS to leave waste and contamination in place, grout it and/or put a cap over it, declare the site cleaned up, and assume that institutional controls will be effective in preventing inadvertent exhumation of the site. Meanwhile, DOE plans continuing non-environmental management missions, such as the mixed oxide plutonium-uranium (MOX) fuel fabrication plant, in the central industrial area for the foreseeable future.

This chapter will focus on policy changes that are essential for protecting surface and groundwater resources at SRS from further contamination. The measures discussed here as essential to protecting the Savannah River and possibly also the deep aquifers in the region. Most of our recommendations focus on preventing radioactive contaminants from migrating to the groundwater, because contaminants, notably tritium, are extremely difficult to remove once they reach the aquifer.

A. Assume Long-Term Stewardship Will Eventually Fail

DOE has pursued a course for "cleanup" at SRS that will result in the grouting and/or capping of substantial amounts of waste and contamination in place. DOE assumes that this waste and contamination will not present a risk to human health and the environment because the federal government will provide institutional and land use controls at SRS in perpetuity. According to its 2001 publication, *A Report to Congress on Long-Term Stewardship*:

DOE anticipates that DOE/EM [Environmental Management] Environmental Restoration operating activities at SRS, including well monitoring, maintenance of treatment facilities, maintenance of institutional and engineered controls, and compliance support will be completed by 2047. Following the operating period, the remediated release sites will be monitored and maintained in perpetuity (estimated, for the purposes of this report, through 2070) to ensure the containment of any residual contamination.¹⁷⁵

¹⁷³ In 2003, the DOE announced a policy of using "risk-based end states" to set the approach and goals for clean-up. This new formulation of an old approach is being used to try to relax cleanup criteria and reduce costs. It is widely opposed, including by the U.S. and Ohio Environmental Protection Agencies, both of whom rejected the proposed document for Fernald (See EPA Region 5, 2003 and Ohio EPA, 2003). For the DOE Risk-Based End States Cleanup Project policy see http://www.em.doe.gov/doe/em/cda/channel_front_door/0.2116.68296_69747.00.html. The new policy is likely to increase risks rather than reduce them. We will not consider it explicitly in this report.

¹⁷⁴ Long-term stewardship is "the physical controls, institutions, information and other mechanisms needed to ensure protection of people and the environment at sites where DOE has completed or plans to complete 'cleanup' (e.g., landfill closures, remedial actions, removal actions, and facility stabilization)." (NRC-NAS, 2000c, page 11, quoting DOE in 64 FR 54280, October 6, 1999) Institutional controls, often an element of stewardship, "consist mainly of land use or access restrictions, and they can take the form either of legal restrictions imposed through covenants, easements, and the like, or of physical restrictions, such as fences, warning signs, or the posting of guards." (NRC-NAS, 2000c, page 7)

¹⁷⁵ DOE, January 2001, Vol. II, South Carolina section page 10

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"Perpetuity" means for an eternal or unlimited duration – surely far longer than recorded history. Planning for a few decades does not begin to cover the number of years that the radioactive waste in the ground at SRS will remain dangerous. DOE does recognize in its June 2002 Predecisional Draft of its *Long-Term Stewardship Strategic Plan* that, "Given the long-lived nature of radionuclides and other residual hazards, it is reasonable to assume that, at some sites, long-term stewardship will be required for centuries or millennia."¹⁷⁶ Yet, DOE fails to analyze how maintaining stewardship for this length of time is possible, or what will be the consequences of failure.

There is simply no factual or analytical basis for DOE's assumption that federal control or any form of continuous institutional control of SRS can be maintained for hundreds of years or thousands of years, not to speak of "in perpetuity." The reality is that DOE is faced with the normal and unpredictable changes in government missions and priorities, in which land use and budget priorities shift, and government and contractor staffing shifts, and records and institutional memory are lost over time. In its draft *Strategic Plan*, DOE recognizes that some factors, such as regulatory structures, demographic and political changes, climate or geological changes, and economic changes could impact long-term stewardship. However, DOE does not acknowledge that any institutional controls put in place today will lapse with time from fallibility of memory or from political and economic pressures.

According to a 2000 study on long-term stewardship by the National Research Council:

The Committee on Remediation of Buried and Tank Wastes finds that much regarding DOE's intended reliance on long-term stewardship is at this point problematic. The details of long-term stewardship planning are yet to be specified, the adequacy of funding is not assured, and there is no convincing evidence that institutional controls and other stewardship measures are reliable over the long term. Scientific understanding of the factors that govern the long-term behavior of residual contaminants in the environment is not adequate. Yet, the likelihood that institutional management measures will fail at some point is relatively high, underscoring the need to assure that decisions made in the near term are based on the best available science.

[...]

Other things being equal, contaminant reduction is preferred to contaminant isolation and imposition of stewardship measures whose risk of failure is high.

[...]

The committee believes that the working assumption of DOE planners must be that many contamination isolation barriers and stewardship measures at sites where wastes are left

Many types of failures in "institutional controls" can occur. For example, the definition and standards for "institutional control" may be changed or reinterpreted over time, such as with zoning laws, which are subject to change through local government ordinances or even by court order. Other problems with institutional control include maintaining institutional consistency, preventing the deterioration of oversight, and sustaining follow-up and enforcement. According to the 2000 National Research Council report, "Often the real issue is not *whether* use restrictions will eventually fail, but when and what the *consequences* will be when they do." [Original emphasis] For example, in the early 1990s, the federal government sold land near the DOE Oak Ridge Reservation in Tennessee to be used as a golf course. Although the deed prohibited the use of groundwater, which was contaminated with trichloroethylene (TCE) from the Y-12 plant, a well was drilled within only a few years to irrigate the course. Fortunately, the problem was discovered before the well was completed.¹⁷⁸

In some cases, the relevant information is not disseminated to the appropriate people. For instance, at the Oak Ridge Reservation, a contaminated building in the K-25 facility was decontaminated up to eight feet from the floor and leased to a private company, with the stipulation that no activities would be allowed above that height. According to an IEER analysis, the Occupational Safety and Health Administration (OSHA) found that, "some tenants had not been informed about all of the hazards present in the facilities" and "some of the information" that OSHA had "received about the condition of these facilities was 'out of date, inaccurate, and/or incomplete.'"¹⁷⁹

DOE should not use long-term stewardship as a substitute for cleanup. Long-term stewardship is useful only if the threat is reduced enough that even a complete failure of the stewardship program would not result in grave harm. It is a backup in case we are wrong in our estimates of the effects of the very low-levels of residual radioactivity that would inevitably remain even after thorough cleanup. When technologies do not exist for such cleanup, technology development to get that cleanup is needed, with careful monitoring and other measures being carried out as interim steps. Thorough cleanup is a *prerequisite* of a successful long-term stewardship program.

Hand-in-hand with an effective cleanup program (see specific recommendations below), DOE should seek to develop the elements of long-term stewardship that delay and reduce the impact of the failure of long-term stewardship. In developing this program, the DOE should assume that institutional controls will eventually fail. Therefore, the most optimistic scenarios (i.e. all wastes will be contained and human intrusion will be prevented) are unrealistic. DOE needs to build "failure scenarios" into the long-term stewardship program.

The cleanup strategy at the Savannah River Site is part of DOE's current policy to declare "cleanup" or "closure" to be completed as soon and as cheaply as possible, then transfer the highly uncertain and not-well-defined long-term responsibility to another federal or local entity if possible. For example, the Rocky Flats site in Colorado is slated to be turned over the Fish and

¹⁷⁸ NRC-NAS, 2000c, page 52

¹⁷⁹ Ledwidge, May 1999, pages 3 and 4

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Wildlife Service after DOE has declared "closure" complete.¹⁸⁰ DOE has also sought to abandon its long-term stewardship responsibilities altogether, in which case state and local governments would be stuck with them. The most compelling example of DOE's plans for sites after "closure" is the Weldon Spring site, just outside St. Louis, Missouri.¹⁸¹ This site was used to process uranium for nuclear weapons in the 1950s and 60s. The DOE spent more than \$900 million on cleanup at the site, constructing a 45-acre disposal cell now containing more than 1.5 million cubic meters of radioactive waste. DOE removed additional radioactive waste that was previously disposed of in a nearby rock quarry, which is within a few hundred yards of the Missouri River. Now with the waste in place and "cleanup" declared "complete" despite residual ground water contamination, there is serious concern about whether the site will be cared for in the future. The future for the Weldon Spring site is incomprehensibly long, given that the cell entombs uranium-238, which has a half-life of more than 4.4 billion years.

The need for long-term stewardship and the federal government's responsibility in this regard was stressed in clear terms by Missouri Department of Natural Resources Director, Stephen M. Mahfood, the state's top environmental official, in a 2001 letter to Assistant Secretary Jessie Roberson. He warned that other states may not be able to trust the DOE if it failed to act on its promises at Weldon Spring:

Since the Weldon Spring site is the first large and technically complex site where DOE will complete cleanup and begin long-term stewardship, we believe you will share our interest in assuring the processes work effectively. Other states may look to Weldon Spring to gauge whether the strategy of on-site capping of waste is prudent, based on the robustness of DOE's commitment to ensure post-closure protection of human health and the environment. Unfortunately, the inadequacy of DOE's draft Weldon Spring plan sends a clear message: any state considering a DOE proposal to leave waste on-site should think long and hard about accepting DOE's assurances the site will not present any risk to human health and the environment. DOE's long-term stewardship planning promises appear to be empty, based on the draft Weldon Spring plan. Their promise to provide an effective long-term stewardship program and to also continue investing in science and technology is unreliable.

Pursuant to the state of Missouri's duty to protect the health and environment of all Missourians, we are concerned the [Department of Energy] appears to be committing the same fundamental lapse which occurred during the Cold War: waiting until the project is done to consider the full, long-term and life-cycle environmental implications of the decisions that are made. We cannot stand idly by and allow the same mistake to be repeated. Those mistakes left us with the terrible environmental legacy from shortsighted decision-making that occurred during the perceived urgency of the Cold War.¹⁸²

¹⁸⁰ FWS, 2004

¹⁸¹ For information on Weldon Spring, see the website of the State of Missouri on the subject: <http://www.dnr.state.mo.us/alpd/hwp/ws-special/ws-toc.htm> (Missouri, 2004).

¹⁸² Mahfood, 2001

A year later, he again stressed the state's determination in this regard:

We do not intend to allow the federal government to walk away from its responsibility for perpetual stewardship of the site.¹⁸³

But the fact is that DOE is ignoring the state's concerns about the need of an effective long-term stewardship plan. The state does not have an effective decision-making role as a partner of the federal government. On the contrary, the DOE has cut funding to the state for performing even minimal monitoring of the site. By leaving waste in place, but cutting funds needed to independently monitor the site, DOE has, in effect, imposed an "unfunded mandate" on the state and its residents. Last year Missouri State Geologist, Mimi Garstang, R.G., wrote to DOE asking for DOE to involve the State of Missouri in decisions affecting future generations of Missourians:

I have grave concerns over DOE's position to exclude the state of Missouri in a legally binding agreement executed concurrent with this final [Record of Decision]...¹⁸⁴

Despite this objection, DOE and EPA signed the final Record of Decision for the site in February 2004, "without the concurrence by the state of Missouri..." and despite the fact that "[I]nstitutional controls on impacted property remain unresolved."¹⁸⁵

The Weldon Spring site provides a useful cautionary tale for other states and communities around other sites because it is the first large industrial scale nuclear weapons site where DOE has declared cleanup "complete." The question here is: "Will DOE honor its commitment to provide adequate long-term stewardship for sites where residual contamination and waste is left after cleanup is declared 'complete'?" The Weldon Spring experience indicates the drift of the answer: No. This bodes ill for SRS and other DOE sites. This is already in evidence in the cut-off of Georgia's funds for environmental monitoring with the argument that South Carolina is doing sufficient monitoring. But it is not and cannot, because some of the contamination is in Georgia groundwater, as we have discussed.

Grouting residual waste in high-level waste tanks is another egregious example of DOE's neglect of the long-term in its rush for cheap short-term solutions. There is no firm process to assure that there will be an iterative cycle for continuing to improve conditions where contamination remains. One reason for a lack of confidence is that the details about post-closure care, in most enforceable agreements, are limited. The Weldon Spring, Missouri, example cited above further erodes that confidence.

Finally, DOE cannot rely on the annual appropriations process to ensure adequate funding in the long-term. As priorities shift in Washington, sites could face insufficient funds to do basic monitoring and maintenance. Over time, this possibility becomes more likely as institutional memory is lost. The government should establish funding mechanisms that will enable the long-

¹⁸³ Mahfood, 2002

¹⁸⁴ Garstang, 2003

¹⁸⁵ Garstang, 2004

term stewardship program to be maintained without relying on annual appropriations. These would be similar in concept to entitlement programs, such as social security or the nuclear weapons workers compensation programs that are not subject to annual appropriations. Rather, a formula for meeting expenses that are needed to fulfill the purposes of the laws is used to determine the level of expenditures in any given year.

B. Manage Wastes at SRS

Given the findings of this report, the following are IEER's recommendations for managing wastes at SRS.

1. Close the reprocessing canyons; cease generating new wastes

DOE should permanently shut down and decommission both reprocessing canyons, which generate high-level, transuranic, and low-level wastes, and cost hundreds of millions of dollars annually to operate. Millions of additional gallons of liquid waste and large volume of solid radioactive low-level wastes from reprocessing are still being added to existing stocks.

In 1992, the first Bush administration decided to phase out reprocessing.¹⁸⁶ Since this decision to phase out reprocessing, the SRS canyons have been used to stabilize nuclear material. The original rationale for operating the canyons had some basis in a safety rationale. However the most dangerous materials left over from SRS production (the liquids and corroded irradiated materials) have already been reprocessed. DOE has closed the F-canyon, but it has not yet declared that it will permanently shut and decommission it. F-canyon continues to be a drain on the cleanup budget, as does H-canyon, which is to continue operating until 2008.

2. Empty and decommission the high-level waste tanks

The sludge from the high-level waste tanks is being vitrified at SRS. The radioactivity content of the first 1,200 or so canisters of vitrified waste is far lower than the projected average for the 6,000 glass logs that are eventually to be produced. Part of the problem is that the process for extracting cesium-137 from the salt and supernate failed after \$500 million in costs. A replacement process has not yet been decided upon.

Whatever the process, the residual waste in the tanks needs to be minimized, monitored and maintained in a state that will allow it to be retrieved at a later date. DOE should give up its attempts to redefine this waste as "incidental waste" that can be disposed of in shallow land burial in some form, whether by fiat or via getting the authority to do so through legislation.

We recognize that it will not be possible to remove all of the high-level waste from the tanks with present technology. However, grouting the residual waste, as has been done with Tanks 17 and 20, will make it essentially impossible to remediate them and will create a de facto high-level waste dump on the site in the vicinity of the Savannah River. Moreover, the radioactivity content of the residual waste is likely to be higher in the tanks that have not yet been washed,

¹⁸⁶ Claytor, 1992

because the wastes in most remaining tanks contain higher concentrations of fission products, especially if they continue to be washed with supernate (see Chapter V).

3. Recover and stabilize buried wastes

The low-level and transuranic wastes as well as associated contaminated soil should be recovered and stabilized. As discussed in Chapter III, grouting and capping waste is only a stopgap measure that will likely lead to long-term problems once the grout and the caps start to break down. It will be even more technically difficult and expensive, than it is today to dig up the grouted material and remediate the tank sites once contaminants start leaking. Such barriers have limited lifetimes compared to the time periods over which the wastes will remain hazardous. Recovering the buried waste is essential to establishing any long-term stewardship program, which must have as its basic assumption that there will be an eventual loss of institutional control over the site. Moreover, the problem of tritium contamination can only be realistically alleviated by recovering as much of the dumped waste as possible to strict standards.

4. Stop dumping low-level waste into unlined and unregulated trenches

The ongoing practice of disposing of low-level radioactive waste in unlined trenches must be ended. DOE could make greater use of existing above-grade vaults that are similar to the management technique used by most European states for low-level waste.¹⁸⁷ This disposal option would provide a greater degree of confidence in long-term protection of human health and the environment. Transuranic waste and all wastes that are equivalent to Class B, Class C, or greater than-Class C low-level waste should be designated for deep geologic disposal. This would correspond approximately to the European regulatory practice of designating such wastes for deep disposal rather than disposal in shallow, low-level waste dumps.

5. Research cleanup technologies for groundwater and soil

More research needs to be done on technologies to cleanup contaminants in groundwater and soil. According to the National Research Council, "Pump and treat systems ... are by far the most commonly used and proposed ... treatment method for contaminated groundwater." However, "pump and treat systems may be unable ... to remove enough contamination to restore groundwater to drinking water standards, or ... removal may require a very long time - in some cases centuries."¹⁸⁸

C. Minimize Health Risks from Tritium

Tritium in the burial grounds and in the soil under the seepage basins will remain a threat to water resources at SRS for at least two generations since its half-life is 12.3 years. In order to

¹⁸⁷ The vaults in E-Area include a Low Activity Waste (LAW) vault, an Intermediate-Level Non-Tritium (ILNT) vault, an Intermediate-Level Tritium (ILTV) vault. (DOE, January 1998b; DOE-SRS, April 2002a)

¹⁸⁸ NRC-NAS, 2000c, page 31

address the current source terms of tritium described in Chapters II and III, DOE should (1) stop the direct discharge of tritium-contaminated wastes to onsite streams; (2) retrieve tritium-tainted wastes in the burial grounds and seepage basins; and (3) continue the hydraulic pumping program to reduce tritium discharges in a manner that does not increase uptake of tritium by trees.

As we have discussed in Chapter III, tritium contamination of the Savannah River as well as offsite groundwater is well below the safe drinking water standards. Moreover, the EPA safe drinking water standard is somewhat more stringent for tritium than it is for other beta emitters, since the dose from the latter is restricted to 4 millirem per year (from drinking 2 liters of water per day), while the dose implied by a limit of 20,000 picocuries is just under one millirem per year.¹⁸⁹

However, there are questions that need to be addressed regarding the health risks from tritium that go well beyond cancer risks to adults. These include non-cancer risks, risks to children and developing fetuses regarding both cancer as well as non-cancer health effects, and synergistic effects of toxic non-radioactive materials with tritium.

1. Overview of tritium-related radiological issues

Tritium can be ingested in two forms: tritiated water or organically bound tritium (OBT). Due to its chemical properties, tritiated water can replace ordinary water in human cells (approximately 70 percent of the soft tissue in the human body is water). When tritium replaces hydrogen in a carbon-hydrogen bond, it is difficult to remove and is referred to as nonexchangeable organically bound tritium. Animal studies indicate that 1-5 percent of the tritiated water in a body is incorporated into biomolecules. Direct intake of organically bound tritium, for example through food, is more likely to be incorporated as organically bound tritium in biomolecules than tritiated water. However, organically bound tritium is a heterogeneous group of compounds that can behave very differently in metabolic processes, and more research is needed to understand the incorporation of tritium from a variety of compounds.¹⁹⁰

Current radiation protection standards assume that exposure to beta radiation (such as that from tritium) causes the same biological damage as whole-body exposure to gamma and x-rays. But the cancer risk from tritium per unit of radiation energy can be far higher. A 2002 study examined uncertainties in the assumptions of the International Commission on Radiological Protection (ICRP) models for calculating the dose of radiation from the intake of tritiated water and organically bound tritium. It also estimated dose conversion factors for tritiated water and for OBT. It found the relative biological effectiveness (RBE) of both tritiated water and OBT to be higher than ICRP models.¹⁹¹ This means that tritium is much more effective per unit of radiation energy deposited in the body than gamma rays or than assumed in ICRP models. It is also more effective in producing cancer in fetuses than it is in adults. The (RBE) of a unit of beta particle

¹⁸⁹ We have used a dose conversion factor of 1.73×10^{-11} sieverts per becquerel, which is the EPA guideline for tritium ingestion, to estimate this dose.

¹⁹⁰ Harrison, Khursheed and Lambert, 2002, pages 300, 303, and 304

¹⁹¹ Harrison, Khursheed and Lambert, 2002, page 308

energy from tritium decay for tritiated water and for organically bound tritium for adults and for fetuses relative to the values used by the EPA in current regulations can be estimated from the research of Harrison, Khursheed and Lambert. Our estimates based on their analysis are shown in Table 12 below:

Table 12: Relative Biological Effectiveness of Tritiated Water and Organically Bound Tritium

Age	Form of tritium	5% Confidence limit	median	95% confidence limit
Adult	HTO	1.2	2.3	3.8
Adult	OBT	2.3	5.0	11.6
Fetus (maternal ingestion during pregnancy)	HTO	2.1	4.4	8.1
Fetus (maternal ingestion during pregnancy)	OBT	4.0	9.8	23.1

Source: Estimated from Harrison, Khursheed, and Lambert 2002, Table 8. The RBEs shown above were calculated by dividing the tritium doses in sieverts per Becquerel shown in this table by 1.73×10^{-11} , which is the dose conversion factor for tritiated water in sieverts per Becquerel in the prevailing regulatory guide of the Environmental Protection Agency (EPA, 1988).

Note: HTO = tritiated water in which one atom of ordinary hydrogen has been replaced by an atom of tritium. OBT = organically bound tritium. The numbers in the columns for confidence intervals mean that the RBEs would be less than the cited number for the percent of times indicated by the confidence interval were a series of identical experiments to be performed.

The increased risks to pregnant women and fetuses do not stop at cancer. As discussed previously, the risks of tritium exposure to pregnant women and fetuses include miscarriages and genetic defects, as discussed below. The risks can be multi-generational.

2. The standard for tritium in drinking water

Recent research clearly indicates that the maximum contaminant level for tritium in drinking water should be re-evaluated in light of the significantly higher cancer risk created by fetal exposure, especially in regard to organically bound tritium. Rivers can be and are used by large numbers of people for drinking water, as is the case with the Savannah River. This indicates that the higher health risk created by organically bound tritium must be taken into account by creating more stringent drinking water standards.

Furthermore, current estimates of the health risks from exposure to organically bound tritium may underestimate the actual health impacts. Tritiated water is considered to be uniformly distributed throughout the body although at different concentrations (for example bone and fat have lower concentrations due to their relatively lower water content¹⁹²), but organically bound tritium can localize in relatively small numbers of cells at relatively high concentrations. Therefore, while the average dose to the tissues may be low, the dose to cells where the organically bound tritium is concentrated may be large. For example, when tritium is

¹⁹² Harrison, Khursheed and Lambert, 2002, page 305

incorporated into DNA, it does not uniformly irradiate the whole cells, but selectively irradiates the nucleus. The resulting risk to the cell could be greater than if tritium were incorporated more uniformly throughout the cell.¹⁹³ Moreover, organically bound tritium is generally retained in the body longer than tritiated water, because biomolecules have a slower turnover than water.¹⁹⁴ Human studies indicate that tritiated water has a biological half-life of 10 days, and non-exchangeable organically bound tritium has a biological half-life of 21 to 76 days. For tritiated organic molecules with very slow turnover rates, the biological half-life has been found to be 280 to 550 days.¹⁹⁵ This last is comparable to the biological half-life of some metals in insoluble form.

The health impacts on fetuses from exposures to tritium also need further research. Both tritiated water and organically bound tritium can enter the fetus through the placenta. Animal studies have found that tritiated water has a greater average concentration in fetal tissues than maternal tissues, due to the relatively higher water content in a fetus. Organically bound tritium from food ingested by the mother also can be incorporated into the fetal tissues.¹⁹⁶ The health effects on the developing fetus itself (e.g. miscarriages, malformations, and developmental effects other than mental retardation) and on relevant organs at critical periods of fetal development are not well known. Further, the incorporation of tritium into biomolecules of long-lived cells of a fetus, such as neurons or oocytes could result in large doses over the lifetime of the cells.¹⁹⁷ Considering that ova are formed once per lifetime during females' fetal development, the effects of radiation on the reproductive system of female fetuses and the possible effect of such radiation on the children of females irradiated in the womb could be significant.¹⁹⁸ In addition, the combined effects of *in utero* exposure to tritium combined with endocrine disrupting chemicals, such as dioxins or PCBs, need to be studied.

Another issue that needs further research is the transmutation of organically bound tritium into helium-3 during decay. If the tritium is in a biologically important molecule, such as DNA, its decay to helium may result in biological damage that would not be fully accounted for by the emission of a beta ray.¹⁹⁹ Since helium atoms do not bond to carbon, a free helium ion and a reactive carbon ion are left. The carbon ion can lead to single-strand break in the DNA, an interstrand cross-link, or even to a mutation, depending where it happens to be in the DNA.²⁰⁰

¹⁹³ Hill and Johnson, December 1993, page 632

¹⁹⁴ Straume, February 1991, page 4

¹⁹⁵ Hill and Johnson, December 1993, page 638. The International Commission on Radiological Protection (ICRP) assumes a biological half-life of 10 days for tritiated water and 40 days for organically bound tritium in adults. For a 3-month-old child, ICRP assumes a biological half-life of tritiated water and organically bound tritium of 3 and 8 days, respectively. (Harrison, Khursheed and Lambert, 2002, page 300)

¹⁹⁶ Harrison, Khursheed and Lambert, 2002, page 305

¹⁹⁷ Straume, February 1991, page 5

¹⁹⁸ Straume and Carsten, December 1993. These observations are based on experiments with mice. On p. 661-662 they note: "Of particular concern for genetic risk assessment has been the incorporation of tritiated nucleotides into DNA during oogenesis (*in utero*)....It can be inferred from these mouse data that 37kBq/g of body weight of ³H [Tritium]-Tdr administered i.p. [by intraperitoneal injections] will result in ~5 Gray/y.... Because ingestion of ³H [Tritium]-Tdr results in about 1/5 of the dose compared to that from i.p. injections in rodents (NCRP 1979), ingestion of such compounds by women during critical development *in utero* could perhaps result in ~ 20 mGy/y (or 600 mGy in a 30-y-old woman) to oocyte nuclei per 37 MBq (1 mCi) ingested."

¹⁹⁹ Straume, February 1991, page 5

²⁰⁰ Hill and Johnson, December 1993, page 632

This assumption is based on the low number of hydrogen atoms in the DNA for which transmutations have been found. However, there is no threshold dose for the effects of radiation from a non-lethal dose to a single cell. For example, according to Professor David Close, "mutations can be caused by a single tritium replacement of hydrogen in the C5 position of the DNA base cytosine. After the tritium decays, the cytosine is mistaken for thymine. This ... leads to a point mutation with a thymine-adenine pair for the original cytosine-guanine pair in DNA."²⁰¹ The potential health effects of such transmutations need to be further researched. IEER and others have appealed to the National Academy of Sciences Panel on the Biological Effects of Ionizing Radiation (the "BEIR VII" panel) to present an analysis of and some conclusions on this issue²⁰² so that science and public health may both be better served in this regard than they are now.

The Department of Energy has agreed to an action level for tritium in surface water of only 500 picocuries per liter in the context of its clean up at Rocky Flats.²⁰³ This level corresponds to a lifetime risk of cancer for an adult of just under one in a million from drinking two liters of water per day. There is no *a priori* reason why this should not be adopted as an action level for cleanup throughout the nuclear weapons complex. In fact, there is a persuasive case that if such an action level is adopted anywhere, it should be at SRS because of the far larger number of people who use the river and the far larger volume of water involved.

D. Base Cleanup Standards on the Subsistence Farmer Scenario

Long-term cleanup standards for soil and groundwater at SRS should be based on the subsistence farmer exposure scenario, which assumes that a person who grows all his/her own food would unknowingly use contaminated water for drinking and farming. Further, it assumes that such exposure would last a lifetime, and not just a few years. The people in the critical group spend most of their time on the contaminated site. In addition, this scenario assumes that the diets of future populations, as well as the water intake, will be similar to those of today. People are considered protected if their lifetime exposure is less than an assigned limit. The reasoning is that in such a case all other people would be protected since their doses would be lower than that of the hypothetical subsistence farmer. While there is no expectation that such a conservative "worst case" exposure scenario is likely in the foreseeable future, much of the future, especially beyond a few generations, is not foreseeable. Hence, it is prudent to plan for such a land use scenario to be protective. The subsistence farmer scenario complies with the recommendations made by the International Commission on Radiological Protection for exposure, risk estimation procedure, and definition of the critical group.²⁰⁴

²⁰¹ Close, 2001

²⁰² BEIR stands for the Biological Effects of Ionizing Radiation. The National Academy of Sciences and a Committee on this subject issues periodic reports. The current committee is considering the seventh in the series, hence the term BEIR VII. The report is due to be issued in December 2004. The Institute for Energy and Environmental Research and others have asked the BEIR VII panel to consider these aspects of tritium radiation risk, as well as other related issues. See IEER's web site, at <http://www.ieer.org/comments/beir/>

²⁰³ Rocky Flats, 2003. Attachment 5, Table 1, page 5-25

²⁰⁴ Makhijani and Gopal, December 2001

E. Use Cleanup Budget Exclusively For Cleanup Tasks

Although the budget for the Office of Environmental Management (EM) activities at SRS increased by nearly a billion dollars in 1995 (when SRS was transferred to the responsibility of EM), the actual EM activities remain virtually unchanged. Much EM funding is devoted to "cleanup" tasks that are actually just part of "overhead" and "indirect costs" requirements, such as site security, road repair, and administration. In addition, EM funding appears far larger than funds used for clean up especially because of the inclusion of funds for operating the F- and H-canyons.

This funding shift at SRS has been part of a larger pattern: when the Cold War ended, Congress began shifting funding from nuclear weapons to the environmental cleanup and radioactive waste management. Though the funding levels for accounts changed significantly, the change in specific facility operations and individual personnel was much less significant. Consequently, much of DOE's environmental budget has essentially been used to support nuclear weapons facility infrastructure and operations, notably the F- and H-canyons.

The budget from the Environmental Management program should be used to fund only legitimate cleanup related tasks, not general site facility support and infrastructure maintenance. Moreover, cleanup activities that are a result of other national security or materials disposition programs should be included in those budgets. As the cleanup functions are then carried out by EM, the funds can be transferred. This would be a more transparent and accountable way to show the total lifecycle cost of weapons programs.

There is a growing recognition of a serious problem in the direction of the DOE cleanup program that increasingly allows large amounts of waste and contamination to remain onsite. At the same time, there is a lack of confidence in the ability of any institution, especially one with credibility as low as the DOE, to provide effective long-term stewardship for the residual contamination and waste for such long periods of time.

Our conclusion, presented in IEER's 1997 report, *Containing the Cold War Mess*, that DOE is not the right agency for cleanup has, unfortunately, been repeatedly confirmed over the years. We strongly recommend that, instead of abandoning cleanup, policymakers should abandon DOE and move cleanup to an independent agency or to states.²⁰⁵ Congress should create an escrow fund or an entitlement program (see above) for cleanup so states or the independent agency can actually carry out cleanup with confidence. There should be strict national cleanup standards enforced by the Environmental Protection Agency (EPA) to ensure that the funds are properly used.

At the Savannah River Site, it is highly unlikely that the entire site can be returned to background levels of contamination or even very close to that with existing technology. But a great deal more can be done to restore the Savannah River to a better state than it is now and to ensure that programs that are being done in the name of cleanup and waste management do not increase risks to groundwater and surface water in the future. Leaving a million or more curies of waste

²⁰⁵ Fioravanti and Makhijani, October 1997; Makhijani and Gopal, December 2001

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buried in the ground, grouted and covered with a surface cap is incompatible with and even inimical to this goal. Buried waste must be recovered and high-level waste must be vitrified and prepared for deep geologic disposal.

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