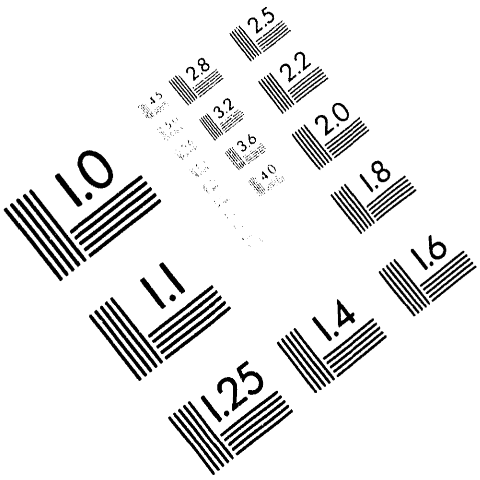

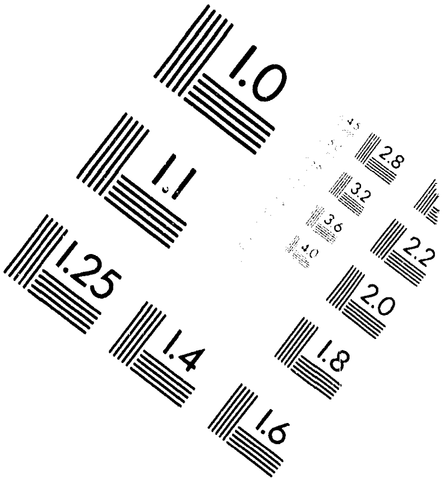

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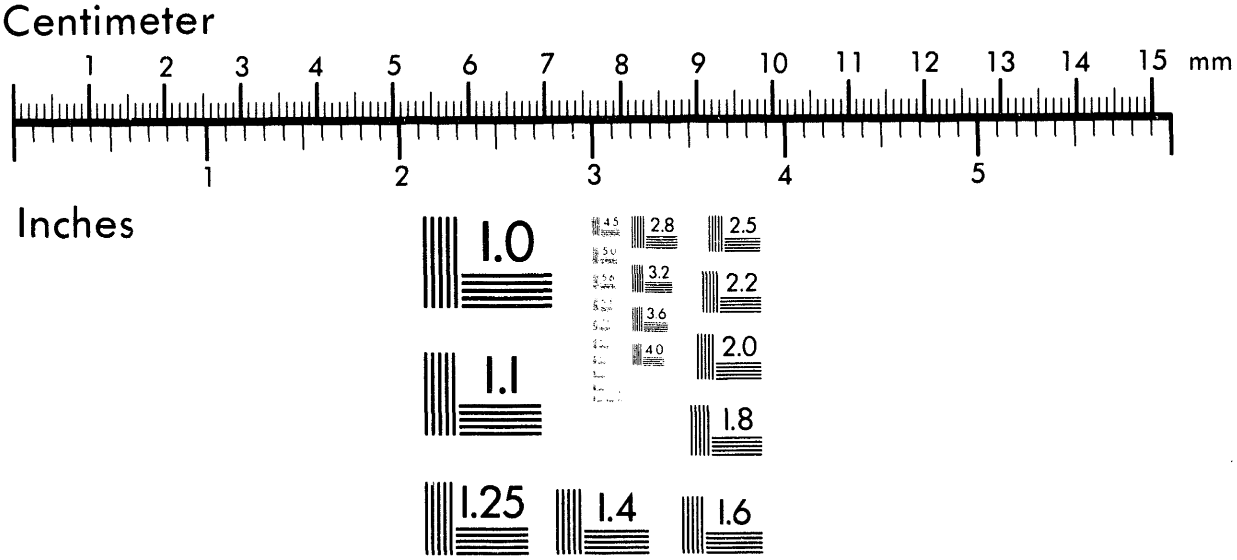

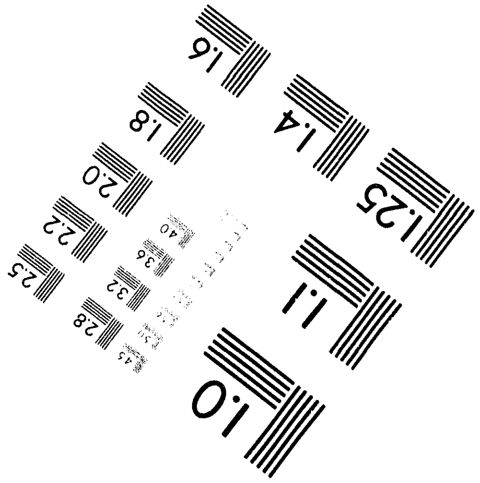

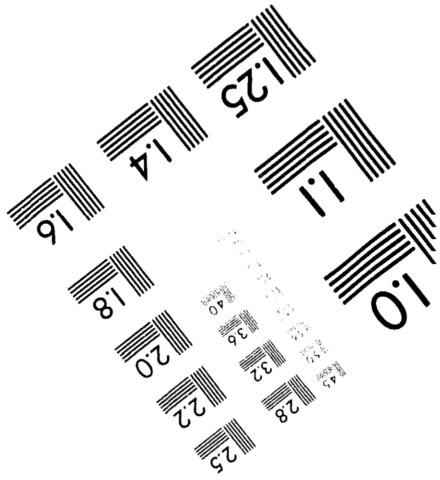

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WSRC-TR-93-214
October 1993

Derivative Classifier

Assessment of Tritium in the Savannah River Site Environment$^{(U)}$

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SRS
SAVANNAH RIVER SITE

Westinghouse Savannah River Company
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PREPARED FOR THE U.S. DEPARTMENT OF ENERGY UNDER CONTRACT NO. DE-AC09-89SR18035

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Chapter 1. Introduction

The Savannah River Site (SRS) was established in 1951 with the mission of producing nuclear materials, primarily tritium and plutonium, for national defense. Manufacture of these materials began in 1954 with the start of the first nuclear reactor. Operation of the SRS has resulted in release of low levels of radioactive materials to the atmosphere and the surface waters leaving the site. From the beginning of the site's operation, the levels of materials were monitored to ensure the safety of the site workers and the surrounding population. The results of the monitoring activities have been released to the public since 1965, when it was felt that this information would no longer compromise the secret nature of some of the defense related functions of the site.

During the 1980s, the operation of the site came under the closer scrutiny of public and environmental regulatory agencies. The past record of monitoring activities has been invaluable in documenting the releases of radioactive materials and in supporting their negligible effect on the public. The frequent use of the information from the monitoring reports and other information from individual research projects suggested that it would be profitable to compile this information in a form that would summarize the important findings and reference the original publications.

This report is the first revision to a series of reports on radionuclides in the SRS environment. Tritium was chosen as the first radionuclide in the series because the calculations used to assess the dose to the offsite population from SRS releases indicate that the dose due to tritium, though of small consequence, is one of the most important of the radionuclides This was recognized early in the site operation, and extensive measurements of tritium in the atmosphere, surface water, and ground water exist due to *the efforts of the Environmental Monitoring Section. In addition, research into the transport and fate of tritium in the environment has been supported at the SRS by both the local Department of Energy (DOE) Office and DOE's Office of Health and Environmental Research.*

This report is divided into sections summarizing the releases of tritium from the site facilities, the transport and concentration of tritium on and in the vicinity of SRS, and the description and results of the assessment of dose to the surrounding public from the releases. A description of the site monitoring network is included. A bibliography of pertinent SRS publications provides a source of further information for individuals who want more details about the information in the report.

This document is intended to show the great effort that has been expended to understand the consequences of the tritium releases from the SRS. It is hoped that the readers will understand that this effort was made to safeguard the safety and health of those who work at the SRS and those who live near its boundaries.

Tritium Releases to the Environment

Introduction

An average member of the public receives an annual dose of about 300 mrem from natural sources of radiation in the vicinity of SRS (WSRC 1989c). Based on national averages, this is about 80% of the total radiation dose received annually by a member of the public from all sources. Medical exposures account for about 15% of the annual dose, and the combined doses from nuclear facilities (other than SRS), consumer products, weapons test fallout, and miscellaneous other sources account for about 4% of the dose. Releases of radioactivity to the environment from the SRS account for about 0.02% of the total environmental radiation dose in the SRS vicinity .

Natural Sources of Radiation

Natural sources include cosmic radiation from outer space, cosmogenic radionuclides formed by the interaction of cosmic radiation with elements in the earth's atmosphere, terrestrial radiation from naturally radioactive materials in the ground, radiation from radionuclides naturally in the body, and inhaled and ingested radionuclides of natural origin.

Enhanced natural sources of radiation are of natural origin but enhanced by man's activities. Examples include air travel at high altitudes, with its attendant increase in cosmic radiation; movement of radionuclides in the ground, as in phosphate mining; and removal of radioactive materials from the ground, such as uranium mining which generates a radon containing waste product (mill tailings).

Cosmic radiation. Cosmic radiation consists of energetic particles of galactic and solar origin. The radiation of solar origin is associated with solar flares, which vary in intensity on an 11-year cycle. Cosmic dose varies with latitude and altitude above the earth's surface. Sea level dose rates range from 30 mrem/yr in Florida to 45 mrem/yr in Alaska; at an altitude of about 2400 m the dose rate increases to 200 mrem/yr (Dukes 1984). An average dose from cosmic radiation in the U.S. is about 26 mrem/yr. An additional dose increment of 1 mrem/yr from cosmic radiation is received by an average individual in the United States due to high altitude air travel.

Cosmic radiation also interacts with materials in the atmosphere and on the surface of the earth to create radioactive nuclides. This source of radiation is called cosmogenic radiation. Many radionuclides are formed by cosmic generation, e.g., tritium, beryllium-7, carbon-14, sodium-22, and many others. Of these, carbon-14 accounts for most of the dose to man, about 1 mrem/yr.

Primordial radionuclides. Natural radioactive materials that have been present since the earth was formed are called primordial radionuclides. These materials have very long radioactive halflives, ranging from hundreds of millions to billions of years. Some of the primordial radionuclides are uranium-235, uranium-238, thorium-232, rubidium-87, and potassium-40. Variations in the distributions of these naturally occurring radionuclides in geologic formations lead to wide variations in dose rates with location. The average unshielded external dose rate from this source is approximately 60 mrem/yr in Georgia and 70 mrem/yr in South Carolina. However, the variation in these states (including the SRS area) ranges from 6 to 350 mrem/yr. An average dose in the United States, corrected for shielding effects, is 28 mrem/yr.

Primordial radionuclides and their radioactive daughter products enter the human body in food, air, and water. An average person receives a radiation dose of about 39 mrem/yr from these natural radioactive materials in the body. Potassium-40, because of the large amount of potassium in the body (about 140 grams), accounts for about 50% of this internal dose.

Radioactive decay products of primordial radionuclides can enter the atmosphere as gases or by resuspension of particles. Such movement can lead to radiation exposure by inhalation. Radon-222, a decay product of natural uranium (^{238}U), has been found to be the largest single source of radiation exposure to man. Radon emanating from the earth is present in the atmosphere we breathe, and is frequently trapped in significant concentrations in structures. It has been determined that an average individual in the United States receives a dose of 200 mrem/yr from radon and its daughter products. This inhalation dose accounts for about 55% of the average annual radiation dose in the United States.

Man Made Sources

Man made sources result from exposures to radiopharmaceuticals and x-rays in medicine, consumer products such as smoke detectors, static eliminators, and x-rays from television receivers.

Medical exposures. Medical radiation is the largest source of manmade radiation exposure in the United States. The average dose to an individual from medical and dental x-rays, prorated over the entire population, is 39 mrem/yr (NCRP 1987b). In addition, radiopharmaceuticals administered for diagnostic purposes account for an annual average dose of 14 mrem/yr when prorated over the population. Thus, the average medical radiation dose in the United States is about 53 mrem/yr.

Occupational exposures. Individuals holding positions in fields such as nuclear medicine or the nuclear industry may be exposed to radiation. The annual average dose when prorated over the population is about 0.9 mrem.

Nuclear facility releases. Nuclear facilities release small amounts of radioactive materials to the environment, resulting in minor radiation doses to the public. When averaged over the United States population, this dose amounts to about 0.05 mrem/yr.

Other manmade sources. A variety of consumer and industrial products yield ionizing radiation or radioactive materials and therefore result in radiation exposure to the general public. Some of these sources are television sets, luminous dial watches, airport x-ray inspection systems, smoke detectors, tobacco products, fossil fuels, and building materials. The estimated dose for the United States population from these sources is 13 mrem/yr.

There have been no atmospheric nuclear weapons tests by the major powers since 1980. However, some radioactive materials from prior weapons tests still remain in the environment. The average annual dose to a member of the United States population from this source is currently about 1 mrem.

Small doses result from miscellaneous radiation sources not previously described. Among these sources are transportation of radioactive materials, the mineral extraction industry, etc. The average annual dose from these sources in the United States is about 0.06 mrem.

Radiation Protection Guidelines

Atmospheric releases. An examination of the dose calculations reported in this document show that the highest hypothetical dose received by a maximally exposed individual from atmospheric release of tritium from the SRS was 1.87 mrem in 1958. The current annual limits on doses to members of the public recommended by the ICRP and the DOE are 500 and 100 mrem, respectively. It is noteworthy that neither the worst case annual dose nor the worst case cumulative dose from SRS tritium releases reported in Table 4-5 exceeded or approached these annual limits. The worst case annual dose was only 19% of the current annual EPA exposure limit of 10 mrem (10 CFR 61).

Liquid releases. As shown in Table 4-7, at no time during site operations has the annual dose from SRS tritium releases to the Savannah River exceeded 1 mrem. Doses from this exposure pathway were calculated under extremely conservative conditions and are without exception much lower than the EPA drinking water standard of 4 mrem/yr.

It is important to note that all of the dose limits described above are meant to be applied to all releases of radioactivity not just tritium. Based on tritium or total releases, the SRS is consistently a minor contributor to radioactivity levels in the offsite environment. More information on the roles of other radionuclides in the SRS releases and doses can be found in the annual environmental reports.

Radiation Levels in the Vicinity of the SRS

A summary of the major sources of exposure for the population within 80 km of the SRS and for the river water consuming populations in Beaufort and Jasper counties in South Carolina and Port Wentworth, Georgia, are illustrated in Figure 1.1.

Many factors, such as the natural background dose and medical dose, are independent of the SRS. The factors that are site dependent are discussed below.

The SRS and surrounding area lie between latitudes 33°N and 34°N, with an altitude variation between sea level and 300 m above sea level. It has been estimated that the total unshielded dose equivalent from cosmic radiation in the vicinity of the SRS (80-km radius) is about 35 mrem/yr, of which 29 mrem/yr results from directly ionizing radiation and 6 mrem/yr is attributable to neutrons (Dukes 1984). Shielding by buildings and the body itself reduces the cosmic dose to about 27 mrem/yr (NCRP 1987b).

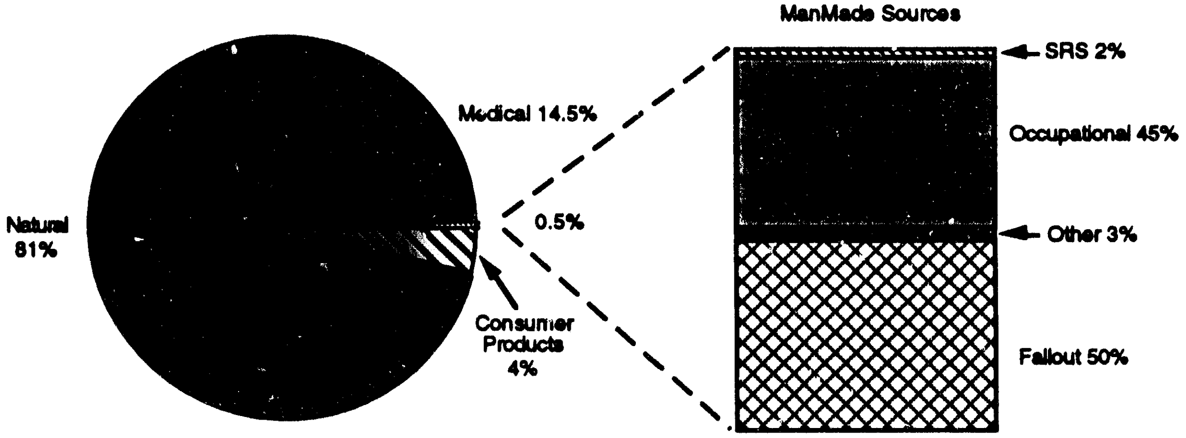

Figure 1.1 Percentage Contributions to Radiation Exposure for the Population in the SRS Vicinity

Comparisons of Tritium Concentrations and Doses On and Near the SRS with Applicable Regulations

Limits on Tritium Concentrations in Air

Tritium is routinely detected in atmospheric samples collected on and near the SRS. Though the levels are above background, they are well below the limits sanctioned by the International Commission on Radiological Protection (ICRP). Comparisons of tritium concentration in air with the EPA Concentration Guideline, as a function of down wind distance, are shown in Table 1-1. Values are reported exclusively for tritium as water vapor, since it provides a higher dose

Table 1-1 Ratios of Average Atmospheric Tritium (HTO) Concentrations On and Near the SRS (pCi/m³)

Distance from Site Center (km)	Calculated Values[a] (pCi/m³)	Ratio to EPA Concentration Guide[b]
0.10	3.60×10^{3}	2.40
1.00	6.00×10^{2}	0.4
10.00	1.00×10^{2}	0.067
100.00	1.50×10^{1}	

[a] Estimated values based on Figure 3.2 of this report.

[b] The applicable 40 CFR 61 concentration guide for tritium is 1.5×10^{-9} Ci/m^3.

Comparisons with the Drinking Water Standard

Onsite groundwater. Although groundwater regions impacted by SRS operations are not used as potable water sources, concentrations of tritium in the monitoring wells located onsite are routinely compared to the U.S. EPA drinking water standard. The current guide for tritium in drinking water is 20,000 pCi/L (20 pCi/mL). The Environmental Monitoring Section at the SRS uses two flagging criteria based on that standard to aid personnel in sample scheduling, interpretation of data, and trend identification. The more restrictive flagging level (Level 2) indicates that the tritium concentration in the sample exceeds 20 pCi/mL.

Of the 25 onsite areas found to have Level 2 tritium samples, 18 are associated with separation and waste management operations conducted near the center of the SRS (WSRC 1989b). The other groundwater systems known to have tritium concentrations greater than the drinking water standard are those shallow formations impacted by reactor operations. Monitoring well samples in the areas around reactor seepage and retention basins frequently reflect tritium levels in excess of the EPA standard. Maximum tritium concentrations observed in monitoring wells on the SRS during 1988 are presented in Table 1-2. The values are grouped by facility and reflect the largest concentrations observed among all the samples collected from the wells in that area. As shown in the table, many of the values exceed the drinking water standard by several orders of magnitude. It must be stressed that these groundwater systems are not used as potable water sources, and any contaminated water outcropping from them is believed to resurface into onsite streams.

Offsite surface and potable waters. The outcropping of contaminated groundwater and the direct discharge of liquid releases to site streams have raised tritium concentrations in onsite streams to levels above background. Since access to these streams is strictly controlled, the impact to human health is negligible. However, once this tritium leaves the site, the potential for contact with downstream populations exists.

Two water treatment plants downstream of the SRS use Savannah River water for domestic and commercial service. The plants are located approximately 160 km below the SRS. The raw and finished drinking water supplies of the Beaufort Jasper, SC, and Port Wentworth, GA, plants are routinely sampled for tritium content. Table 1-4 shows the tritium concentrations at those sites in 1988 and compares them to the EPA drinking water standard. Comparisons of tritium concentrations with the drinking water guide are more meaningful in this case because these data are based on samples collected from public water supplies. As shown in the table, the tritium concentrations at the plants are in the range of 10% to 15% of the drinking water guide. Table 1-3 also confirms that the tritium concentrations just downstream of the SRS are well below (by a factor of 600) the concentration guideline established by the DOE for tritium in surface water discharges.

Table 1-2 Maximum Tritium Concentrations in Selected Wells (pCi/mL).

	Measured Values[a]	Ratio to DWS[b]
Separation Facilities		
Burial Grounds		
Area Perimeter	$2.92x10^{6}$	146000
643-G (Center)	$1.84x10^{6}$	92000
643-G (Center)	$2.81x10^{6}$	140500
643-G (South)	$3.48x10^{6}$	174000
F Area		
Seepage Basins	$6.58x10^{4}$	3290
Canyon Bldg.	$4.52x10^{2}$	22.6
Tank Farm	$2.57x10^{2}$	12.85
H Area		
Seepage Basins	$9.80x10^{4}$	4900
Canyon Bldg.	$1.40x10^{2}$	7
Tank Farm	$7.21x10^{2}$	36.05
S and Z Areas		
S Background	$2.27x10^{1}$	1.135
Z Background	$1.40x10^{1}$	0.7
Tech/Raw Materials Facilities		
A and M Areas		
Metal Burning Pit	ID[c]	
SRTC Seepage Basin	$2.49x10^{1}$	1.245
Misc. Chem. Basin	2.40x10	.012
M-Area Settling Basin	2.91x10	0.1445

	Measured Values[a]	Ratio to DWS[b]
Reactor Facilities		
C Area		
Coal Pile Runoff Basin	$1.08x10^{1}$	0.54
Disassembly Basin	$4.33x10^{2}$	21.65
Burning/Rubble Pit	$2.59x10^{2}$	12.95
Seepage Basins	$8.61x10^{2}$	43.05
K Area		
Acid/Caustic Basin	$9.80x10^{1}$	0.49
Disassembly Basin	$2.43x10^{3}$	121.5
Retention Basin	$1.36x10^{5}$	6800
Seepage Basin	$8.61x10^{2}$	43.05
L Area		
Acid/Caustic Basin	$1.68x10^{1}$	0.84
Disassembly Basin	$2.43x10^{3}$	121.5
Burning/Rubble Pit	ID (c)	
Seepage Basin	$3.19x10^{3}$	159.5
P Area		
Acid/Caustic Basin	$1.34x10^{1}$	0.67
Disassembly Basin	$4.98x10^{2}$	24.9
Burning/Rubble Pit	$3.76x10^{1}$	1.88
Seepage Basin	$2.67x10^{5}$	13350
R Area		
Acid/Caustic basin	ID[c]	
Burning/Rubble Pits	ID[c]	
Seepage Basins	$1.48x10^{1}$	0.74

[a] Measured values are based on data presented in the 1988 SRS Environmental Report.

[b] U.S. EPA drinking water guide for tritium = 20 pCi/mL.

[c] ID indicates insufficient data (n<5).

Table 1-3 Tritium Concentrations in Offsite Surface and Potable Waters

Location	Measured Values[a] pCi/mL	Ratio to DOE DCG[b]	Ratio to DWG[c]
Savannah River just downstream of the SRS	3.40×10^{0}	1.70×10^{-3}	1.70×10^{-1}
Beaufort-Jasper drinking water	2.60×10^{0}	1.30×10^{-3}	1.30×10^{-1}
Port Wentworth drinking water	2.50×10^{0}	1.30×10^{-3}	1.25×10^{-1}
Edisto River[d]	3.30×10^{-1}	2.00×10^{-4}	1.70×10^{-2}

---

[a] Measured values are based on data extracted from the 1988 SRS Environmental Report.

[b] U.S. DOE derived concentration guide for tritium in surface water = 2000 pCi/mL. The DCG is an operational limit applicable to concentrations on the SRS.

[c] U.S. EPA drinking water guide for tritium = 20 pCi/mL.

[d] The Edisto River is not impacted by SRS operations and is sampled to provide estimates of background tritium levels.

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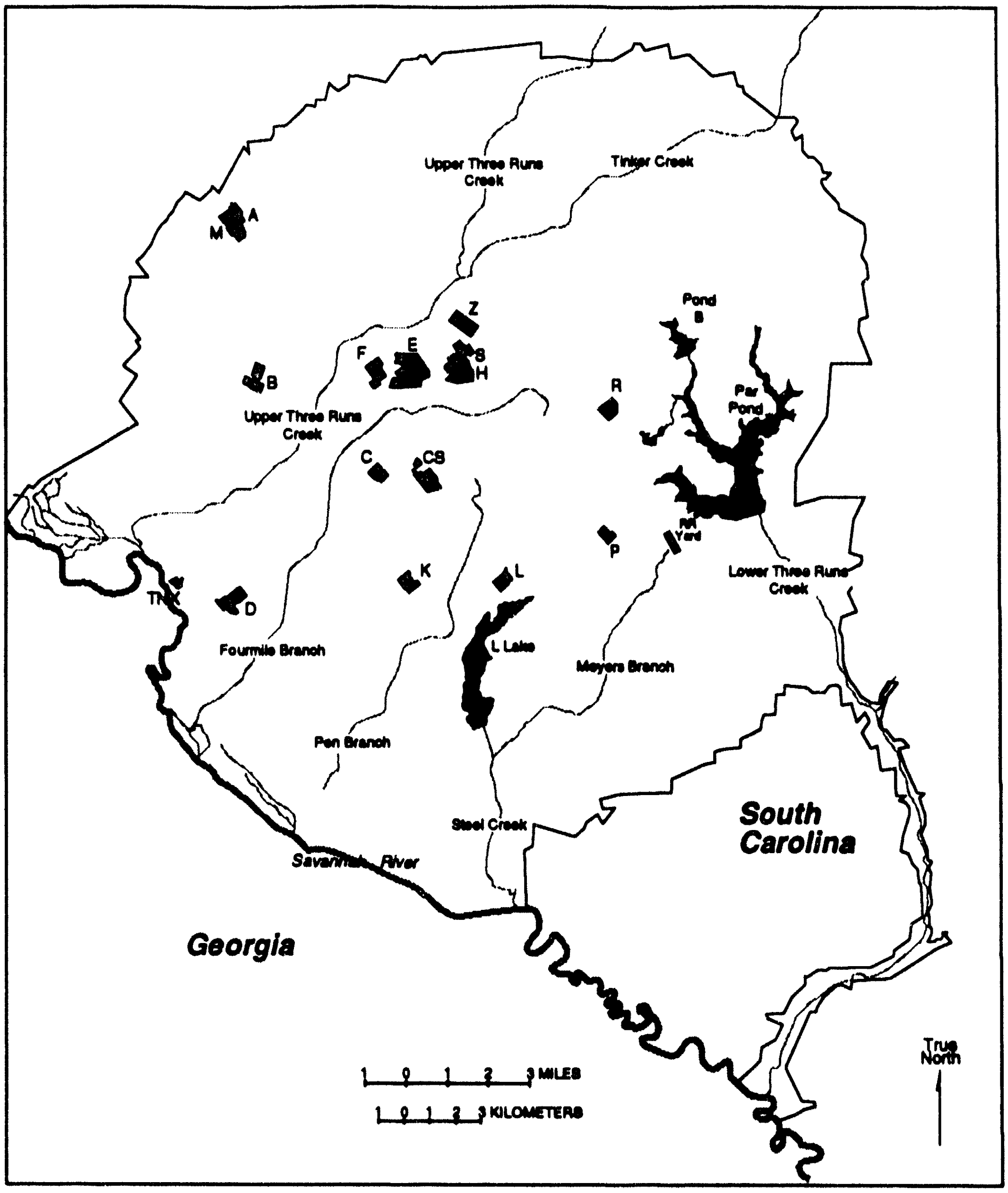

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Figure 2.1 Areas within SRS which may be sources of tritium releases.

Chapter 2. Tritium Releases to the Environment

The nuclear reactions that produce tritium at the Savannah River Site (SRS) are principally the fission of lithium by neutron irradiation of targets, the reaction of neutrons with the heavy water moderator used in reactors, and the ternary fission of transuranic elements in the reactor fuels and targets. Operations involving production and handling of radionuclides at the SRS result in the release of some tritium to the environment.

Tritium is released from reactor operations (reactor facilities), recovery of transuranic elements (separations facilities), recovery of tritium (tritium facilities), laboratory research, and a heavy water rework facility. The receiving media for these releases are the atmosphere, site streams, and the ground (from seepage basins and burial grounds). This section describes the sources of tritium releases and their routes to the environment. Figure 2.1 is a map of the SRS which shows the location of the principal areas within the site, which may be sources of tritium releases.

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Summary of SRS Tritium Releases

Tritium has been released to the environment beyond the site boundaries as:

- tritiated water vapor and gaseous, elemental tritium released to the atmosphere through stacks and evaporation from seepage and retention basins.
- tritiated water released to streams through liquid effluents and through seepage basin and burial ground releases that entered shallow groundwater aquifers and outcropped into site streams.

A summary of releases in these categories is given in Table 2-1. For atmospheric releases, the reactor areas contributed 28%, the separation areas 69%, and "other" facilities <3% of the total. For streams the percentages are 58% from reactors, 31% by migration from seepage basins, and 11% from "other" sources. Tritium released to the atmosphere that reaches the offsite environment is the principal source of the small radiation dose received by the offsite population as a result of SRS production activities. The tritium released by the SRS remaining in the worldwide environment in 1991 is about 35% of the total released, because the rest has decayed to nonradioactive helium.

Only a part of the tritium released to the seepage and retention basins leaves the site. Of the 1,209,000 Ci of tritium released to the basins, 27% evaporated from the basin surfaces, 40% migrated to outcrops and entered surface streams, and 7% remains under the basins after decay.

Of the 4.5 million Ci of tritium buried in the burial grounds 1.5 million Ci remain. Approximately 40,000 Ci have migrated to the groundwater under the burial site. A large part of the tritium buried in the burial ground will decay before reaching surface water. For this reason some of the tritium released to the seepage basins and almost all of the tritium released to the burial grounds do not contribute to the radiation dose to the offsite population.

Table 2-1 shows the distribution of releases throughout the period of site operation, before and after correction for radioactive decay. The releases from the reactor area, the separation areas, and other areas have entered the atmosphere and streams and are dispersed in the worldwide environment. The tritium retained in the seepage basins and the burial ground remains on the site.

Table 2-1 Sources of Tritium from SRS Activities, Curies

Facility	Atmosphere	Stream	Total	Decay Corrected
Reactors	7,022,000	871,000	7,853,000	2,875,000
Separations	17,508,000	9,000	17,517,000	5,811,000
Others				
M-Area	3		3	1
SRTC	18,000	0	18,000	4,000
TNX	32,000	0	32,060	7,000
D-Area	44,000	147,000	191,000	73,000
Total	24,624,000	1,027,000	25,651,000	8,770,000

Basins and Solid Waste Disposal Facility Releases to the Environment

Facility	Input	Evaporation	Streams	Total	Decay Corrected Total	Decay Corrected Remaining on SRS
Basins	1,209,000	408,000	415,000	823,000	403,000	87,000
SWDF	4,463,000		59,000	59,000	44,000	1,497,000

Total SRS Releases to the Environment

	Atmosphere	Streams	Total	Decay Corrected
Total	25,032,000	1,501,000	26,533,000	9,217,000

Reactor Facilities

Most of the tritium released from SRS reactor facilities results from heavy water moderator that becomes exposed to environmental water or air. Liquid releases account for 11% of the approximately 8 million Ci of tritium released from SRS reactor facilities from startup through 1991, and atmospheric releases for 89%.

The tritium concentration in reactor moderator has ranged from 0 to 17 Ci/L during reactor operations. The tritium concentration increases when a reactor is operational and decreases with a half-life of 12 years because of radioactive decay.

Tritium in aqueous solution is transferred to the environment from fuel and target storage (disassembly) basins, direct leakage of moderator from the process heat exchangers to cooling water, and other miscellaneous sources.

Tritium is transferred from the reactor to the fuel and target storage basins principally by the adherence of moderator to the surface of the components and entrapment of moderator in the fitting of the components. Transfer also occurs in the hydrated oxide film on the aluminum surfaces of reactor components. The tritium in the moderator exchanges rapidly with hydrogen in the water of the storage basins until equilibrium is reached.

Tritium from the fuel storage basins reaches the environment when the storage basin water is replaced (purged with "clean" water). Purging is necessary to control exposure to operating personnel from tritiated water that evaporates from the storage basins.

When the reactors began operation in 1954 and 1955, a continuous purge of several thousand gallons of water per minute was used to maintain clarity and to cool the fuel and target storage basins. As tritium concentrations in the reactor moderator increased, the resulting increase in tritium releases led to the institution of control measures to reduce the quantity of tritium released to streams.

In the late 1950s, the volume of continuous flow was reduced and some of the overflow weirs were closed. In 1963, the vertical tube storage (VTS) sections of the disassembly basins were modified so that the VTS could be isolated from the other disassembly basins. Provisions were made to circulate VTS water through a portable filter/deionizer system. Heat was removed by heat exchangers that were installed on the roof of the disassembly areas. Water discharged from the VTS was isolated and recirculated through the filter/deionizer system.

After reactor component discharge was complete, the water was routed either to a seepage basin or to the effluent stream until the tritium concentration in the VTS was low enough to allow the isolation gates to be opened to the other basins. A reactor component flushing system was installed to remove a significant quantity of the moderator from the components as they were discharged from the reactors.

In the early 1970s, permanent sand filters were installed to maintain clarity in the disassembly basins and all overflow weirs were closed. The residue collected on the sand filters is transported to 200-F for processing and storage in the waste tanks. The method of purging the VTS, however, is still in use.

Since the late 1950s, tritium released to the environment from fuel and target basin purges has been directed to streams or to seepage basins. When released to streams, the purge water is mixed with the much larger volumes of heat exchanger cooling water resulting in concentrations that are very low and well within the prevailing release limits. When purge water is placed in seepage basins, a significant part of the tritium decays before it migrates to streams and travels offsite. Therefore, the preferred method is to purge to seepage basins.

The process heat exchangers are used to remove heat from the reactors. Heavy water moderator is circulated through the tube side of the heat exchangers and river or pond water through the shell side. Minute leaks allow a small amount of tritium to migrate to the shell side, from which it is discharged to reactor effluents.

Miscellaneous releases include water from the shell side of the fuel and target storage basin heat exchangers, process area sumps, and a variety of other small sources.

Tritium releases from reactor areas to the atmosphere result from moderator evaporation from occasional purges of the blanket gas system. Evaporation of moderator from reactor control rods and guide tubes and from pipe flanges and connections also result in tritium release to the atmosphere. Small quantities of moderator are exposed to the atmosphere during maintenance and fuel discharge operations. Atmospheric tritium is removed from the reactor building through a filtered ventilation system that discharges to a 60-m stack.

Evaporation from reactor fuel and target storage basins and earthen seepage basins are additional minor sources of atmospheric tritium releases.

C-Reactor Area

C Reactor operated from 1954 until it was placed on standby in 1987. Tritium-bearing liquid effluents from the fuel and target storage basin and miscellaneous sources were discharged to either the 904-66G seepage basin or Fourmile Branch. The seepage basin received discharges from 1959 to 1970 and from 1978 to 1985. Between 1955 and 1959, and between 1970 and 1978, discharges were directed to Fourmile Branch. Fourmile Branch also received reactor heat exchanger cooling water effluents which contained small quantities of tritium.

Approximately 99% of the C-Reactor tritium released to the atmosphere was discharged through the 60-m stack on the reactor building, and approximately 1% was released through evaporation from fuel and target storage basins.

The history of the C-Reactor Area tritium discharges is illustrated in Figure 2.2. The figure shows an increase in discharges during the early years of operation as the tritium content of the moderator increased. The discharges approached a steady rate after 1965. The increases in 1984 and 1985 were due to small leaks from the primary reactor vessel to the secondary leak containment cavity. The leaks occurred at inner stress corrosion cracks at several welds in the reactor vessel and led to a reduction in reactor operation in 1986 and a complete shutdown in 1987. Since 1987, small releases have continued related to maintentance and clean-up activities.

In 1991, 7.25 Ci of tritium was detected in Fourmile Branch from C-Area Basin migration.

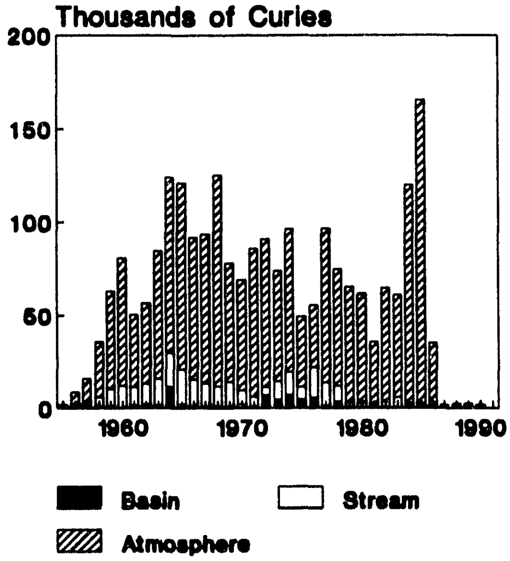

Figure 2.2 C-Reactor Tritium Releases

K-Reactor Area

K Reactor has operated since 1954. Liquid effluents from fuel and target storage basin purges and other miscellaneous sources have been discharged to Pen Branch, the 904-65G seepage basin, and the 904-88G containment basin during the operating history of the reactor.

Prior to 1966, liquid wastewater effluents were discharged to Pen Branch, except for 500 Ci in 1959 and 4700 Ci in 1965, which were discharged to the 904-65G seepage basin. (This basin was not used extensively because of undesirable seepage characteristics.) Since August 1965, a limited portion of the 904-88G containment basin has been used to receive fuel and target storage basin purges and other miscellaneous releases.

The water from the 904-88G containment basin migrates through a shallow groundwater aquifer and outcrops into Indian Grave Branch, a tributary to Pen Branch. Migration of tritium from the containment basin to Pen Branch has been measured since 1969. Pen Branch also receives reactor heat exchanger cooling water from K Reactor which contains small concentrations of tritium.

Approximately 99% of the tritium released to the atmosphere was discharged through the 60-m stack on the reactor building, and approximately

1% was released through evaporation from fuel and target storage basins.

Total atmospheric and liquid releases of tritium from K-Reactor Area increased during the early years of operation as the tritium content of the moderator increased (see Figure 2.3). The discharges reached a peak in 1967 and then showed an overall decrease through 1991. When assessed separately, except for 1983, liquid and atmospheric releases followed a similar pattern throughout the 1955 to 1991 period. The spike in atmospheric tritium releases in 1983 was related to numerous line breaks during an extended outage in June and July.

K Reactor went into stand-by in 1988. Atmosphere tritium release continued at about the same rate after stand-by due to testing and upgrading activities.

K Reactor restart began in 1992 (release data not available at publication of this report).

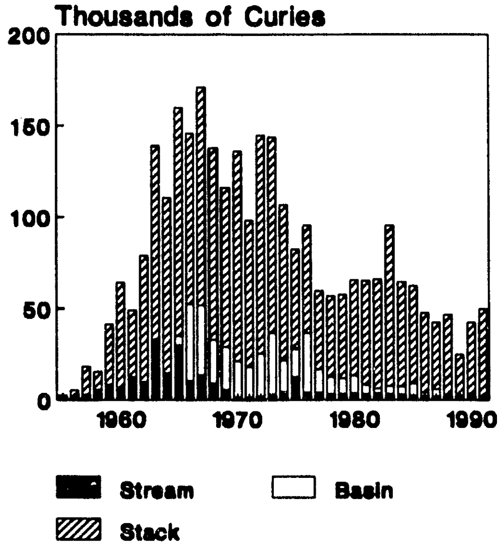

Figure 2.3 K-Reactor Tritium Releases

L-Reactor Area

L Reactor operated from 1955 to 1968, when the reactor was placed on standby. It was refurbished and restarted in 1985. Liquid effluents from fuel and target storage basins and miscellaneous sources were discharged to the 904-64G seepage basin intermittently in 1958 and 1959, 1961 to 1965, and 1967 to 1969. At other times, discharges were released to Steel Creek. When L Reactor was restarted in 1985, liquid wastewater effluents were again directed to the 904-64G seepage basin. Small amounts of tritium were also released directly to L Lake. L Reactor stopped operation in 1988.

Monitoring stations on Steel Creek had not detected any outcropping of tritium from the 904-64G seepage basin prior to construction of L Lake. Any future outcropping to L Lake would be virtually impossible to measure directly because the outcrop would occur at the edge of L Lake. However, as shown in Figure 2.4 tritium in the overflow from L-Lake Dam is greater than direct tritium input, suggesting migration from the seepage basins.

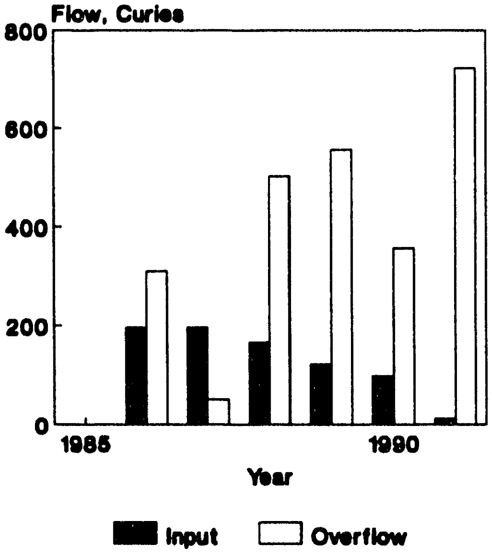

Figure 2.4 Tritium overflow at the L-Lake Dam compared to the effect tritium input to L-Lake.

Heat exchanger cooling water containing small amounts of tritium was discharged to Steel Creek from 1955 to 1968. After the reactor was restarted in 1985, heat exchanger cooling water was discharged to L Lake, which overflows to Steel Creek.

Approximately 99% of the tritium released to the atmosphere was discharged through the 60-m stack on the reactor building, and approximately 1% was released through evaporation from fuel and target storage basins.

The 904-83G oil and chemical basin was used from 1961 to 1979 to receive miscellaneous liquid wastewater containing oil and chemicals from all of the reactor areas (see Figure 2.5). This waste was transported in either tanker trucks or barrels, and the quantity of radioactivity present was measured before the waste was placed in the basin. The 904-83G oil and chemical basin is close to the L-Area seepage basin.

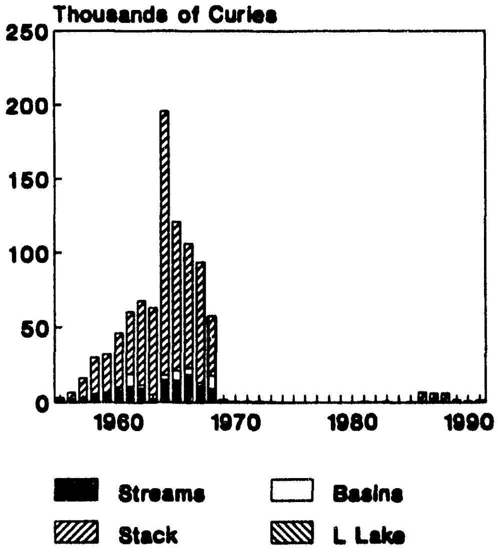

Figure 2.5 L-Reactor Tritium releases

Total liquid and atmospheric releases of tritium from the L-Reactor Area increased from startup until 1964, as the tritium content of the moderator increased (see Figure 2.5). The peak annual release to the atmosphere of 180,000 Ci in 1964 resulted from small moderator leaks at valves and flanges during the first half of the year and extensive maintenance associated with the Phase III containment outage during the second half of the year. Discharges decreased after 1964 and ceased after 1968 when the reactor was placed on standby status.

Releases after restart of the reactor in 1985 were much lower than during the period prior to shutdown because of the low tritium content of the moderator used for restart. Liquid releases followed the same pattern as atmospheric releases except for the peak in 1964 and the continued release of a small amount of tritium to Steel Creek until 1970.

P-Reactor Area

P Reactor was operational from 1954 to 1988. Liquid effluents from fuel and target storage basin purges and other miscellaneous sources have been discharged to Steel Creek, the 904-61G seepage basin, and Par Pond during the operating history of the reactor. Fuel and target storage basin purges containing tritium were discharged to Steel Creek and the 904-61G seepage basin in the years shown below:

Steel Creek	Seepage Basin
1954 to 1956	1957 to 1968
1969	1970
1971 to 1977	1978 to 1991

Reactor heat exchanger cooling water and miscellaneous effluents were discharged to Steel Creek until 1963, when most of the reactor heat exchanger cooling water was diverted to Par Pond. With the construction of L Lake in 1984, the remaining reactor heat exchanger cooling water and all miscellaneous wastewaters were also diverted to Par Pond.

Figure 2.6 shows the measured values of tritium input and transport over the dam from Par Pond. Previous to 1973, the input from P Reactor was not measured. The comparitively large transport of tritium over the Par Pond dam was due to releases from R Reactor. For most of the measurement period the input is much greater than the overflow. Most of the difference must be attributed to evaporation of tritium from the Pond. Averaged over the 18 years when both input and overflow measurements were taken, the difference is 68% of the input. This is much greater than the average of approximately 30%

for the seepage basins. This can be explained by the much greater area of Par Pond. In 1990 and 1991 the overflow is actually less than the input. This suggests that some of the tritium in Par Pond may be stored in the deeper part of the lake or the sediments and have a comparatively long residence time.

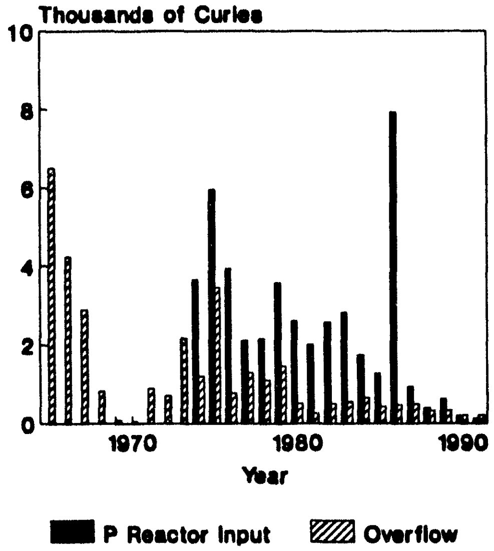

Figure 2.6 Comparison of input and overflow from Par Pond.

When all P-Reactor effluents were diverted to Par Pond, migration of a small amount of tritium from the 904-61G seepage basin to steel Creek was detected (170 Ci in 1985).

In earlier years, migration of this small amount of tritium was obscured by the much larger heat exchanger cooling water flow. The tritium discharge from Par Pond to Lower Three Runs Creek has been measured since 1964.

The majority of the atmospheric tritium (99%) released to the atmosphere was discharged through the 60-m stack on the reactor building, with a small amount (approximately 1%) released through evaporation from the fuel and target storage basin area.

Total discharges of tritium from P Reactor, shown in Figure 2.7, increased from startup until 1964, when 92,000 Ci were discharged due to the increase in the tritium content of the moderator. After 1962 discharges varied widely, with an average of approximately 50,000 Ci/yr. Liquid released followed the same general trends as the atmospheric releases until 1987, when a decrease occurred.

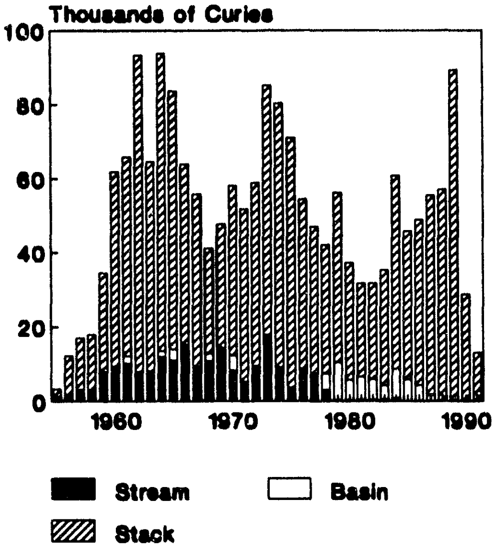

Figure 2.7 P-Reactor Tritium Releases

R-Reactor Area

R Reactor operated from 1954 until 1964, when it was placed on inactive status. Fuel and target storage basin overflow was discharged to Lower Three Runs Creek, Par Pond, and the 904-60G seepage basin. From 1954 to 1958, the overflow was directed to Lower Three Runs Creek. From 1958 to 1964, the release of fuel and target storage basin overflow was alternated between the 904-60G seepage basin and Par Pond.

Heat exchanger cooling water and miscellaneous effluents containing tritium were released to Lower Three Runs Creek from 1954 to 1958. After Par Pond was constructed and placed in operation in January 1959, this water was released directly to Fourmile Branch until a canal and pond system, ultimately emptying into Par Pond, was placed in operation in 1961.

The majority of the atmospheric tritium was released through a 60-m stack on the reactor building.

Total discharges of tritium from R Reactor increased during operation due to the increase in the tritium content of the moderator. Tritium releases peaked at about 70,000 Ci in 1964, the last year of operation (see Figure 2.8). Liquid releases from the fuel storage basins followed the general trends of the atmospheric releases throughout the operational period.

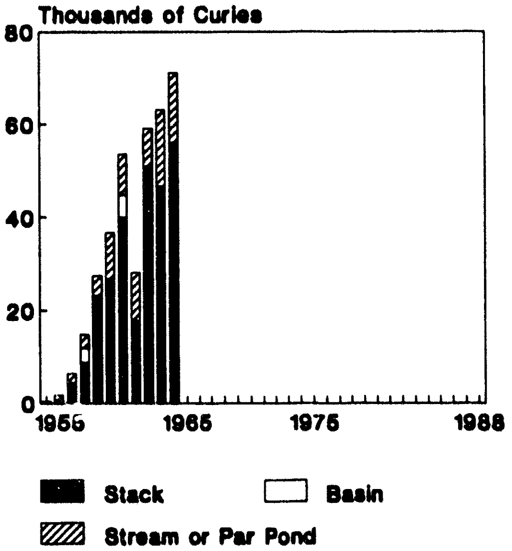

Figure 2.8 R Reactor Tritium Releases

Separation Facilities

Separation facilities that have tritium emissions include

- the fuel and target reprocessing facilities
- the tritium facilities
- the receiving basin for offsite fuel
- the F and H seepage basins
- the waste evaporators and storage tanks

The quantities of tritium released from the fuel and target reprocessing facilities (F and H Canyons), the tritium facilities, and the receiving basin for offsite fuel (RBOF) are combined for reporting purposes to avoid the security classification that applies to tritium from a specific facility.

The F and H Canyons process enriched uranium fuels and depleted uranium targets which are irradiated in SRS reactors. Tritium is released during the reprocessing of this fuel. The tritium facilities process lithium-aluminum targets which are also irradiated in SRS reactors. At RBOF, a small quantity of tritium is released from the cleaning of tritium targets before they are processed in the tritium facilities, from the processing of deionizers used in the reactor areas, and from tritium that escapes from stored fuel.

Except for the F- and H-Canyon processes, releases from these sources are routinely monitored and reported. Releases from the F- and H-Canyon processes are calculated annually based on the processed fuel irradiation history and the fraction that is vaporized.

Small amounts of tritium also evaporate from the F and H seepage basins, from the high-level-waste storage tanks, and from the evaporation of waste at the tank farms. These releases are either estimated or based on periodic measurements.

F and H Canyons

F and H Canyons have been in operation since their respective startup dates of December 1954 and July 1955. In the canyons, ternary fission product tritium follows the process liquid streams, less some fraction that evaporates and exits through canyon stacks. In the liquid streams, some of the tritium is released in overheads from waste reduction evaporators and a small amount remains in the high-level-waste that is directed to the waste storage tanks (tank farms). Another minor source of tritium is wastewater from the reactor areas that is processed in F Area. This waste water originates from sumps, the fuel and target storage basin sandfilters, and other miscellaneous reactor operations.

Prior to 1988 the primary tritium-bearing wastewater from the separations facilities was discharged to the F and H seepage basins. Water from the seepage basins percolates through the soil column to the shallow aquifers and then migrates to an outcrop along Four Mile Creek. The quantity of tritium migrating from F and H seepage basins to Fourmile Branch has been measured since 1959. (The basins were placed in operation in 1955.)

In 1988 a new effluent treatment facility (ETF) was placed in operation to remove particulate and dissolved radioactivity and to remove or neutralize chemicals from the wastewater formerly discharged to the seepage basins. The ETF treatment process is not capable of removing tritium, so the tritium is contained in the discharge from the ETF to Upper Three Runs Creek. Approximately 6,400 Ci of tritium has been discharged to Upper Three Runs Creek between 1988 and 1991.

Closure of the F and H seepage basins has been completed , but migration and outcropping of this tritium in Fourmile Branch will not immediately stop because of the inventory of tritium that exists in groundwater under the seepage basins. After closure, the quantity of tritium reaching Fourmile Branch is expected to decline slowly as the amount of tritium is depleted and tritium decay occurs. Approximately 670,000 Ci of aqueous tritium have been released to the environment from F and H Areas from 1954 through 1991.

A small quantity of tritium from other miscellaneous separation process sources is also released in wastewater that is discharged to Fourmile Branch.

F and H Seepage Basins

F and H seepage basins were used for disposal of wastewater from 1955 until 1988 (see Figure 2.9). Approximately 30% of the tritium released to the seepage basins dissipates by evaporation to the atmosphere. The remaining tritium either percolates through the soil to the upper groundwater aquifers, or it decays to nonradioactive helium. Tritium beneath the basins migrates with the flow of the groundwater and eventually outcrops into Fourmile Branch.

The quantity of tritium migrating from the basins has generally increased since measurements were first made in 1958. Based on 1985-1987 averages, tritium migration has been approximately 2400 Ci/yr from the F-Area seepage basins and approximately 6000 Ci/yr from the H-Area seepage basins and the burial ground.

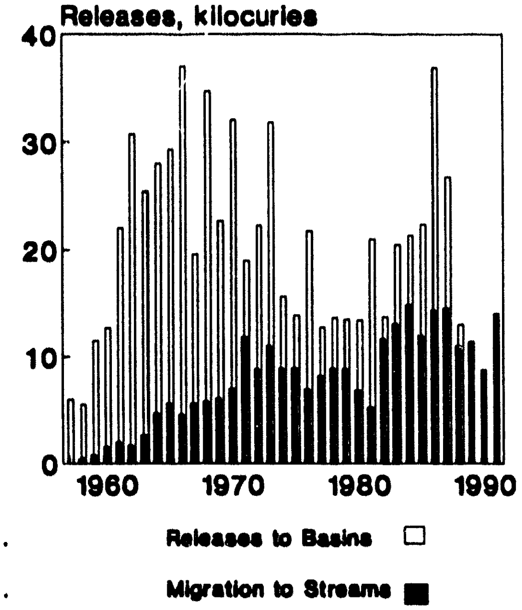

Figure 2.9 Annual Tritium Input into the F and H Seepage Basins and the Total Migration to Streams

Tritium Facilities

The original tritium extraction facility in 232-F operated from 1954 to 1958. It was replaced by the H-Area tritium facilities which extract, separate, purify, and package tritium. The H-Area tritium facilities have operated continuously since startup in 1957.

Tritium is extracted from irradiated lithium-aluminum targets and then processed and packaged for shipment to other DOE facilities for national defense uses. Tritium facility operations are carried out in process cabinets in which air movement sweeps away tritium that escapes from the equipment. The air is exhausted through three 60-m stacks and one 23-m stack.

The tritium facilities are the largest contributor to SRS atmospheric releases, with approximately 17.5 million Ci released from startup through 1991 (see Figure 2.10). These releases typically include both elemental (HT, DT, and T_2) and oxide (HTO, DTO, and T_2O) forms of tritium, with a minor amount (less than 1%) in an organic form (tritiated methane).

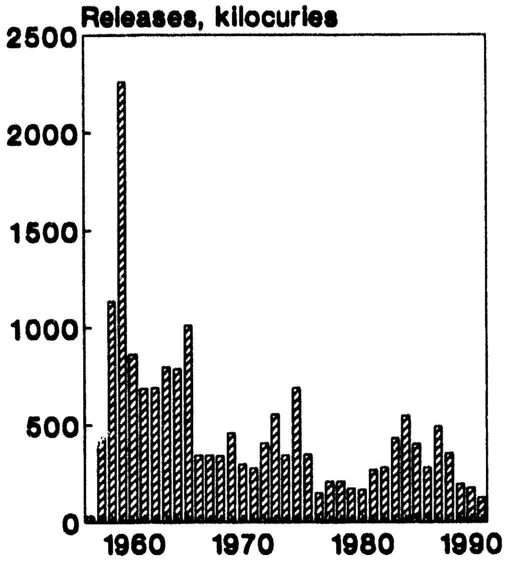

Figure 2.10 Atmospheric Releases of Tritium from the F- and H-Area Tritium Facilities

Forms of Tritium from the Separation Areas

The radiotoxicities of the different forms of tritium vary widely. Elemental tritium is approximately 25,000 times less radiotoxic than the oxide form (NCRP 1979). In cases where the ratio of elemental to oxide tritium was not known, the SRS practice was to be conservative and assume that all of the tritium released was in the oxide form. Studies of HT and HTO release ratios (where HT represents all elemental forms of tritium and HTO represents all oxide forms) from the tritium separations area established that this assumption is excessively conservative.

A study of the HT-to-HTO ratios in atmospheric releases from the area was initiated in 1976. Weekly samples of effluents from the four H-Area tritium facilities stacks were routinely collected for four years. The results of that study (Figure 2.11) indicated that the overall percentages for the 1976-1979 period were 44% HT and 56% HTO (DuPont 1980). However, significant variations in release rates and HT-to-HTO ratios were encountered due to differences in the nature of the work and in the operating periods of the various facilities.

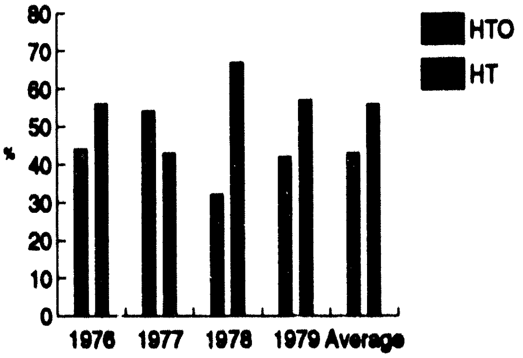

Figure 2.11 HT and HTO as a Percentage of Total Releases from the Tritium Facilities 1976-1979

The elemental and oxide tritium values generated by collecting effluent samples with molecular sieves did not show good agreement with the estimates of total tritium in the stack gases measured with Kanne chambers. (A description of these sampling methodologies can be found in Appendix 1.) It was therefore concluded from the study that insufficient data was available at the time to base tritium doses exclusively on estimates of tritiated water vapor release levels.

In recent years, advances in stack sampling techniques developed at SRS have produced more reliable elemental and oxide tritium measurements. Advanced systems now include computer-controlled in-line, continuous monitors. Sufficient confidence was gained in the monitoring systems to support the use of measured HT and HTO values for calculating offsite doses beginning in 1985. For the period 1985 to 1991, the overall HT and HTO percentages for tritium facilities releases were approximately 36% elemental and 64% oxide, as shown in Figure 2.12.

Tritium releases were highest in the early years of operation with a maximum of 2.3 million Ci in 1958, when both F- and H-Area tritium facilities were in operation. Releases have decreased since 1968 to 200,000 Ci in 1991.

The small quantity of tritium released in miscellaneous liquids is discharged to Fourmile Branch and reported with other H-Area liquids released to streams.

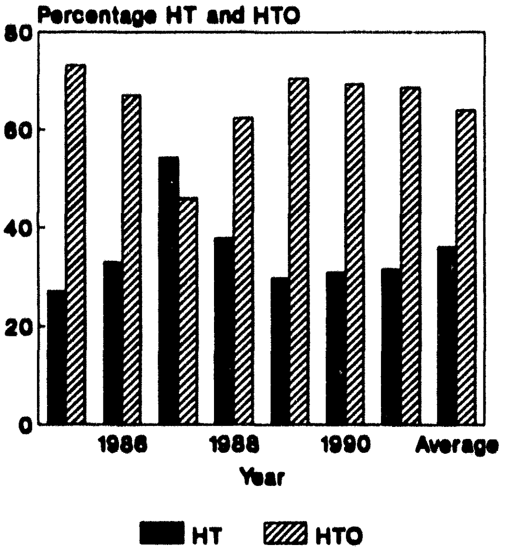

Figure 2.12 HT and HTO as a Percentage of Total Releases from the Tritium Separation Facilities 1985 - 1991.

Receiving Basin for Offsite Fuel

The three major RBOF functions are the storage and packaging of offsite fuel for processing in the canyons, the cleaning of lithium-aluminum targets for processing in the tritium facilities, and the cleaning and recharging of deionizers for use in the reactor areas.

Routine releases of tritium to the atmosphere are very small (on the order of hundreds of curies per year). These releases originate principally from minute leaks from fuel stored in the RBOF basins. Liquid releases to the environment are also very small because tritium from target and deionizer cleaning operations is contained in the liquid waste that is transferred to the waste tank farms (see Figure 2.13). The small quantities of tritium contained in liquid that go to Fourmile Branch are reported with other H-Area liquids released to streams.

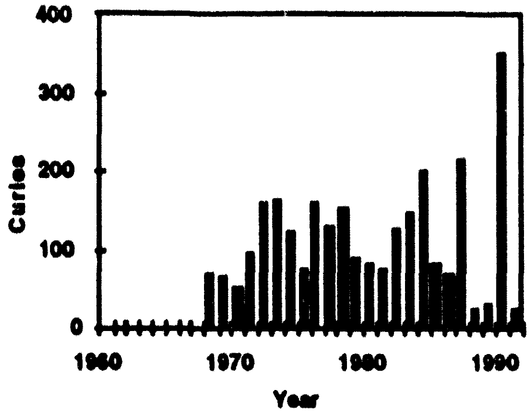

Figure 2.13 Total Liquid Releases of Tritium to Streams from the Separations Areas, including RBOF.

Waste Tank Farms

The high-level liquid radioactive wastes stored in the tank farms generally contain tritium. Some of this tritium evaporates and is vented to the atmosphere from the waste tanks, and some is vaporized in the waste evaporators. Although routine measurements are not made, studies indicate that only a few hundred curies per year are released to the atmosphere from these sources (Harrison 1983).

Solid Waste Disposal Facility

The Solid Waste Disposal Facility (SWDF) is located between the F- and H-Separation Areas. The SWDF is used to store radioactive solid waste produced at the site, as well as occasional shipments from other Department of Energy facilities.

Tritium-bearing wastes at the SWDF include spent lithium-aluminum targets; oil from pumps; contaminated, failed, or obsolete equipment; and a wide variety of incidental process and laboratory waste from the tritium facilities and the reactor areas. Offsite tritium-bearing wastes are principally tritiated waste from Mound Laboratory.

Approximately 4.5 million Ci of tritium have been disposed of in the SWDF between the beginning of operations (1954) and 1991, see Figure 2.14. The inventory (decay-corrected through 1991) was approximately 1.5 million Ci.

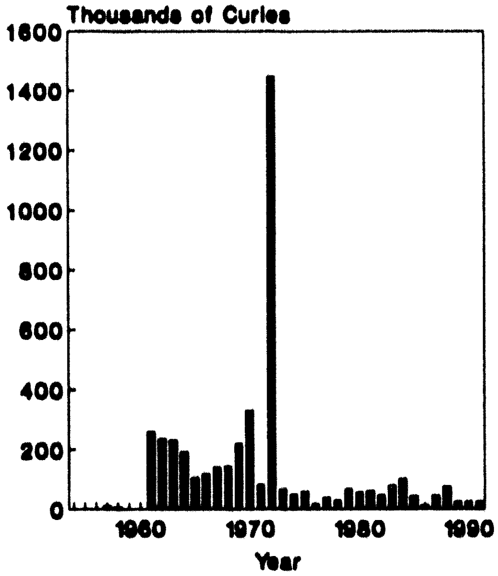

Figure 2.14 Tritium deposition in the SWDF

Tritium has been detected in groundwater beneath five zones in the SWDF. The pattern of tritium in groundwater forms essentially two plumes: one beneath 643-E that is migrating toward Fourmile Branch and one beneath 643-7E which is migrating toward Upper Three Runs Creek (Jaegge et al., 1987).

In 1984, it was estimated from groundwater well measurements that approximately 40,000 Ci of tritium were present in the groundwater below SWDF. Some outcropping of tritium to Fourmile Branch occurs from the plume that is migrating from 643-E.

No outcropping to Upper Three Runs Creek has been detected from the 643-7E plume. Studies indicate that essentially all of this tritium will decay before reaching Upper Three Runs Creek.

Other Areas

Comparatively small releases of tritium to the environment have taken place at five other locations at the SRS: the Heavy Water Rework Facility in D Area, the Savannah River Technology Center (SRTC), the Semi-Works at TNX, the 320-M Laboratory, and the reactor heat exchanger rework facility in Central Shops.

The aqueous and atmospheric releases at the Heavy Water Rework Facility result from cleanup and reconcentration of degraded heavy water from the reactors. Tritium releases from these facilities are generally small (several thousand curies per year).

The releases of tritium from SRTC, TNX, and 320-M are the result of tritium research and development projects, most of which occurred in the early years of site operation. A small amount of tritium was also released during repairs to heat exchangers at Central Shops.

The total releases from these facilities through 1991 was about 240,000 Ci: 39% to the atmosphere and 61% to streams and lakes. Less than 1% was released to the SRTC or Central Shops seepage basins.

Inadvertent Tritium Releases

By definition, an inadvertent release is one which was not planned. Such a release is the result of an unexpected sequence of events, or a failure in a process, which causes a release to the environment. For the purpose of this report, determination of the impact of SRS tritium releases, the identification of significant inadvertent releases is not always consistent with this definition.

In the early days of SRS operation, relatively large releases were expected because of the development work for new facilities and new operating procedures. These releases were not inadvertent and were not documented as such.

This contrasts with the present situation, where very small releases are identified as inadvertent because they are evidence of some malfunction in the process which will require correction. Chapter 3 contains a discussion of the significant, recorded, inadvertent releases of tritium to the environment. Table 2-2 illustrates some of the characteristics of the inadvertent releases to the atmosphere.

For this report, "significant" has been defined as an unplanned event which resulted in a release greater than 0.1% of the average annual releases. This is approximately 700 Ci for an atmospheric release and 70 Ci for an aqueous release.

Certain trends characterize the inadvertent releases. There were no recorded inadvertent releases before 1959. Most inadvertent releases between 1959 and 1974 were related to reactor operations and were atmospheric or aqueous releases of tritiated water resulting from reactor moderator losses (Figure 2.15).

Beginning in 1974 and continuing into 1987, there have been a series of releases from the tritium facilities. These releases have been traced to aging equipment in the facility and are one of the reasons for the construction of a replacement tritium facility at SRS. Both aqueous and atmospheric release after 1988 are primarily associated with reactor area activities.

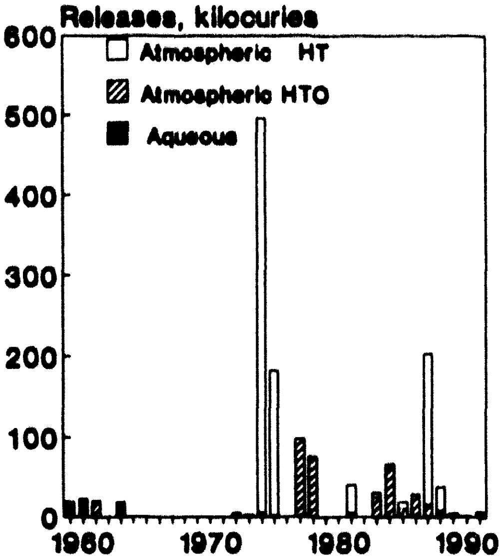

Figure 2.15 Inadvertent tritium releases from SRS facilities showing type of release and chemical form of tritium.

Most of the tritium released was in the form of tritiated hydrogen gas. Although the quantity of tritium released from the tritium processing area over the entire period of operation is much larger than that released from the reactor area the radiotoxicity of tritiated hydrogen gas (tritium facilities) is much less than that of tritiated water (reactor facilities).

These inadvertent releases are included in the release data presented previously.

Table 2-2 Inadvertent Releases of Tritium to the Atmosphere

Date	Time	Release Curies	% HTO	HTO Curies
5/2/74	755	479000	1.0	4790
12/31/75	2000	182000	0.6	1092
3/27/81	845	32934	100.0	32934
7/16/83	2013	56000	1.0	560
3/23/84	440	7500	70.0	5250
9/7/84	1900	43800	100.0	43800
1/31/85	1400	9300	50.0	4650
3/27/85	1353	19422	99.9	19403
7/31/87	855	172000	2.7	4644
3/1/88	616	20000	15.0	3000
6/7/88		3650	4.0	146
10/6/88	730	7086	10.0	700
12/7/88	2248	3082	99.5	3500
1/3/89	NA	500	NA	NA
3/30/89	1015	1100	97.0	1067
10/19/89	NA	800	100.0	800
2/7/90	2330	100	100.0	100

NA - Information not available in written reports.

Comparison of SRS Releases to Other Sources

The major sources of tritium in the environment are natural production from processes in the upper atmosphere, consumer products containing tritium, nuclear power production, and tests of nuclear explosives. Figure 2.16 compares the inventory of environmental tritium from three of these sources with the contribution from SRS operations.

The largest contribution is from nuclear testing, which began in 1945 and peaked in the early 1960s. Tritium production increased greatly with the advent of fusion devices. The next largest contribution is from natural production. Most natural production is the result of cosmic ray reactions with nitrogen gas in the upper atmosphere. Natural production has been calculated to be between 4 million Ci/yr and 8 million Ci/yr, which leads to a standing annual inventory of between 70 million Ci and 140 million Ci.

Tritium in the environment from nuclear power generation has steadily increased from the early 1960s until it is estimated to be approximately 10% of the natural inventory in 1988. These figures are based on the estimates of tritium yield per megawatt electric generation contained in the Report of the United Nations Scientific Committee to the General Assembly on the Effects of Atomic Radiation (UNSCEAR 1982), the estimates of commercial nuclear power production found in the Monthly Energy Review 1988 Annual Summary (EIA 1988), and NCRP Report No. 92 (NCRP 1987c). The estimate assumes that the mix of reactor types and reprocessing facilities during the entire period was the same that was used during the period when the yield was estimated.

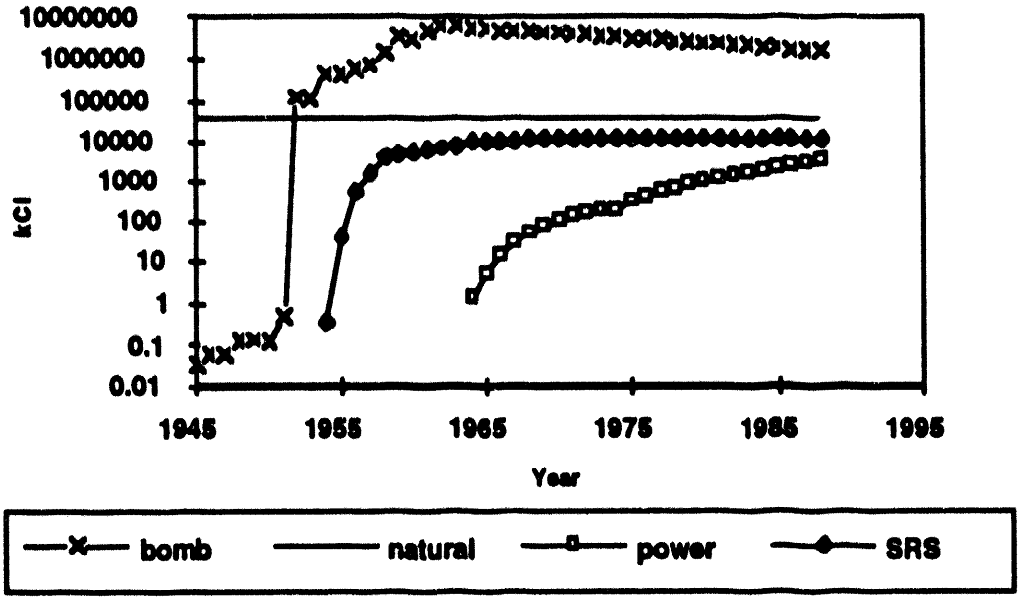

Figure 2.16 A comparison of environmental tritium inventory due to SRS releases and releases from other sources of tritium.

Other commercial uses, such as medical and scientific tracers and luminous products, were estimated to have the potential to release as much tritium to the environment as nuclear power. However, the decrease in the use of tritium for back lighting watches suggests that the releases are not high. The available data does not allow a quantitative estimate of environmental tritium from this source at the present time.

Release data from military production of tritium in other countries are not available. However, it can be assumed that the major weapons producers have facilities that release amounts of tritium approximately similar to those at SRS.

The inventory due to SRS operation never reached the level of the natural inventory and is much less than the inventory due to nuclear device testing. Even though atmospheric testing of nuclear devices has ceased and the tritium from this activity is decaying, the SRS contribution to the global inventory will not approach 1% of the total inventory in the foreseeable future.

Chapter 3. Tritium Concentrations and Transport at the SRS

Atmospheric tritium is associated with water vapor, hydrogen, and volatile hydrocarbons, primarily methane. In the vicinity of SRS, only tritiated water and tritiated hydrogen have high enough concentrations in the atmosphere to be considered important in dosimetric calculations.

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Transport of Tritium from SRS Atmospheric Releases

The transport of tritium in the atmosphere is determined by the processes of advection, turbulent diffusion, and deposition (Slade 1968, Pasquill 1968).

Advection is the movement of gases or particles in the air with the bulk flow of air. Tritiated gases released to the atmosphere are swept along with the wind and thus move with the general speed and in the general direction of the wind at the time of release.

Turbulent diffusion is the process in which the transport of gases takes place through the action of eddy wind currents. Eddies are often visualized as two-dimensional, circular rotating masses of air that slowly exchange their contents with the surrounding air via mixing at their boundaries.

The movement of gases by turbulence can be characterized by the speed with which the eddies mix with their surroundings, the size of the eddies, and the difference in the concentration of the gas between eddies. The mixing depends on the wind speed, the effects of local heating of the air (buoyancy), and the roughness of the surface of the earth. The result of turbulent mixing is spreading, i.e., an increase in volume of air containing the gas, and decrease in concentration of the gas as it is carried downwind from the release point.

The spread of material in the atmosphere is restricted to the volume of air between the ground surface and the height of the surface mixing layer. At the top of this layer, mixing is suppressed by a sudden increase in temperature (an inversion). When the gas has spread to the height of the mixing layer, it is further diluted only by horizontal mixing. The top of the mixing layer is generally much lower at night than during the day. The average daily height of the mixing layer is also lower in the winter than in the summer.

Once the gas has spread through the volume of air in the mixing layer, the gas concentration averaged over circular arcs around the release point will decrease at a rate that is proportional to the inverse of the distance from the release point. In other words, the further the gas moves from the release point the greater the volume of air in which it will mix and the faster its concentration will decrease. As will be demonstrated later, this idea proves useful in analyzing air concentration data collected around release points. Measured concentrations of material released to the atmosphere, if dispersion is occurring in the manner described above, will be distributed along a straight line when plotted against the distance to the sampling station on a logarithmic scale.

Deposition of a gas is the sum of the processes that remove it from the air and deposit it on the soil, vegetation, water, or other surfaces of the earth. Deposition processes are usually classified as wet or dry, depending on whether precipitation is involved in the deposition process. One of the dominant factors determining the deposition rate is the concentration of the gas in the air above the surface. Therefore, the spatial distribution of the deposited material is usually similar to the distribution of the gas concentration in the air.

SRS Annual Average Tritiated Water Concentrations

Measurements of tritium content of atmospheric water vapor have been made since the early 1960s at a network of monitoring stations at SRS. The average annual concentrations resulting from these measurements have been reported in the semiannual and annual reports of the Health Protection Department (see bibliography for complete listing of these titles). These data document the transport of tritiated water vapor at SRS in some detail. The monitoring techniques are described in Appendix 1.

The majority of the monitoring stations are located in two rings around the site. The inner ring is approximately 15 km from the center of SRS, and the outer ring is 40 km from the center. The concentrations around each ring are nearly the same for most years, indicating that there is little preferred direction for tritium transport from SRS. The annual wind direction frequency at SRS is nearly the same from all directions. Figure 3.1 shows isopleths of the average concentration of tritiated water in air and the inverted wind rose for the 5-year period from 1982 through 1986 (points are in the direction which the wind is going rather than the normally reported direction the wind is coming from).

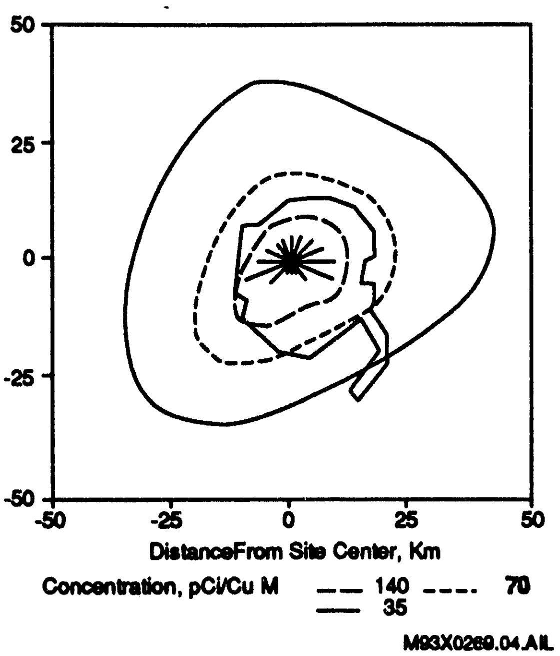


Figure 3.1 The Directional Distribution of Tritiated Water Vapor in the Vicinity of SRS (1982-1986 Data). The Windrose, at the Center, is in Relative Units. The Longest "Petal" is 31.2 km/day

The wind blowing outward from the center of the site is shown as proportional bars (the longest bar represents an average wind speed of 30 km/day in the direction of the bar from the site center). The slightly greater tritium concentration in the east and west directions is mirrored by the increased frequency of wind blowing in these directions. While there is some variation in the wind direction frequency between years and between seasons within years, the annual distribution of tritium transported from SRS is almost equal in each direction.

Figure 3.2 shows the annual average air concentration at each monitoring station during the 5-year period from 1982 to 1986 plotted against the distance from the center of the site. The lower, solid line is drawn through the annual average concentrations while the upper dashed line represents the level at each distance which is calculated to lie above 95% of the measured maximums.

When plotted on logarithmic coordinates, the relationship between distance from the center of SRS and the air concentration is approximately a straight line. The tritium concentration for a set of measurements taken over a specific period of time can be characterized (i.e., approximately reproduced) by the concentration at any arbitrary point on this line and the slope of the line.

The straight line drawn on Figure 3.2 can be characterized by an air concentration of 65.7 pCi/m^3 at 20 km and a slope of -0.76. The 20-km distance is outside, but near, the SRS boundary. The negative slope indicates that the concentration is decreasing as the air is sampled at increasing distances from SRS. The releases for all the years when data were collected can be characterized in this way and compared to each other or to factors which are thought to have an influence on the concentrations measured in a particular year.

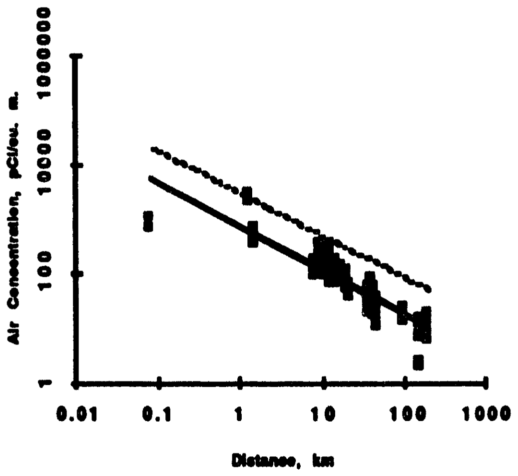


Figure 3.2 The Decrease in Average (1982-1986) and Maximum (All Available Data) Air Tritiated Water Concentration with Distance from the Center of SRS

Figure 3.3 illustrates the variation from 1963 to 1991. The variation in slope is related to variation in the meteorological conditions under which the tritium releases took place. This is not as simple as annual variation caused by differences in wind speed or rainfall. Tritium releases are not uniform throughout the year, and variation can be the result of the coincidence of meteorological conditions and release rates during the year as well as differences in the average meteorological conditions. The slope of the air water vapor tritium concentration with distance relationship calculated with one year's data is probably the best characterization of the tritium decrease with distance for any single year.

longer period of time is more likely to be representative of the average SRS situation and is probably a better indicator of the diffusion climatology of SRS.

As previously described, when a gas, such as tritiated water, moves from a release point and is mixed through a constant height of the atmosphere, the concentration varies inversely with distance from the point, which is the same as the slope of the relationship having the value of -1.0. The average slope of the concentration versus distance relationship for all the tritiated water vapor samples is -0.76. This means that the concentration decreases more slowly than would be expected from simple passive radial diffusion. A factor that could account for the smaller slope is that tritiated water is released from elevated stacks and the center of the plume does not reach the ground for some distance downwind of the source. This counteracts the effect of mixing throughout a larger air mass as the plume moves downwind.

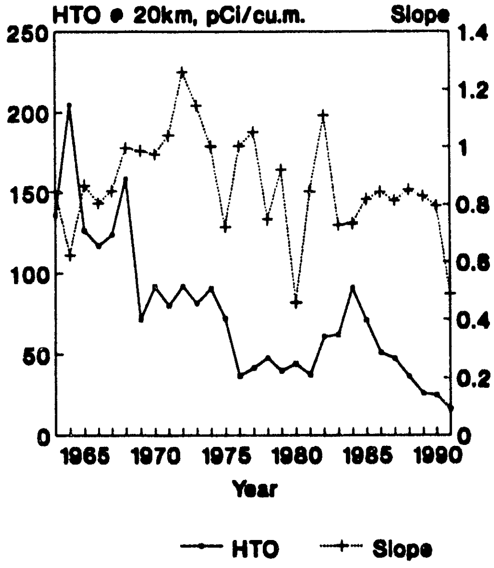


Figure 3.3 The Year-to-Year Variation in Slope and the Characteristic Concentration of Air Water Vapor Tritium at 20 km

The concentration of tritiated water at the reference distance also varies greatly from year to year. Meteorological differences can affect this parameter, but the largest effect is likely due to differences in the amount of tritium released during the particular year. Figure 3.4 shows the variation in air tritiated water concentration plotted against the total tritium released to the atmosphere during the year. It is apparent that the air tritiated water concentration can be better estimated if the tritium released is taken into account.

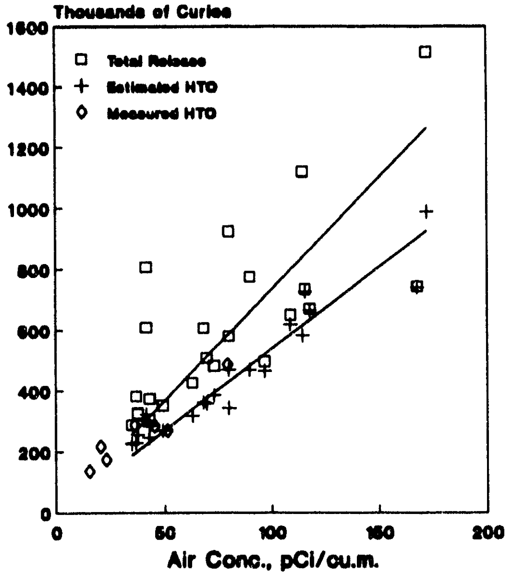


Figure 3.4. The Effect of Releases on the Concentration of Tritiated Air Water Vapor

As documented in the preceding chapter, most of the releases to the atmosphere come from the tritium production area, the chemical separations plant, or the reactor areas. Tritium from the reactor and chemical separation areas is almost entirely in the form of tritiated water vapor. Historically tritium from the tritium production area has been primarily, but not totally, in the form of tritiated hydrogen.

The fact that the air samplers measure only the HTO provides a means of estimating the amount of HTO released for those years when air samples were taken, but the fraction of HTO was not directly measured (1963-1984). One method is to assume that the average percentage release of HTO from the separation areas is the same as during the measured values during the period from 1985 to 1991, approximately 50%. Then the difference in air concentration of HTO from the mean over the estimation period is proportional to the difference from the mean HTO released from the separations area, Figure 3.4 shows the points and a best fit straight line for this analysis. The measured HTO releases, plotted against air HTO concentration are also shown. This analysis predicts that during the period between 1963 and 1984 28% of the total tritium releases from SRS to the atmosphere was in the form of HT. This is somewhat less than the 36% measured from 1985 to 1991.

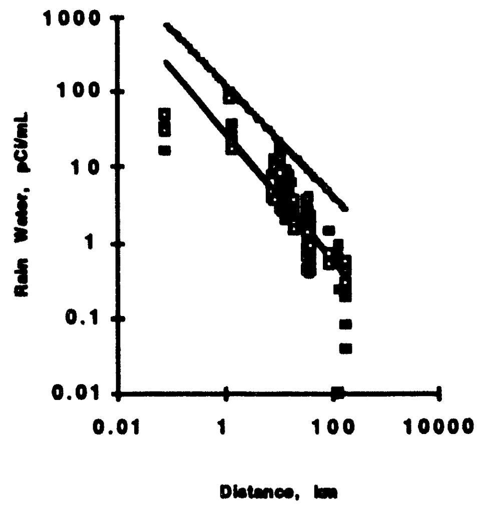


Figure 3.5. Variation of Average (1982-1986) and Maximum (All Available Data) Tritium Concentrations in Rainwater with Distance from the Center of SRST

From this analysis it is evident that the major factors determining the annual average tritiated water vapor concentration of the atmosphere around SRS are the distance from the source, the wind direction, and the amount of tritium released. The height of the atmosphere through which the release is mixed and the wind speed also affect the concentration. Although the variation in the annual average values of these factors is not great, it may explain some of the variation in the measured concentrations not accounted for by distance from the site and the quantity of tritium released in a given year. It appears reasonable to conclude that the transport of tritiated water vapor in the atmosphere is well understood under SRS conditions and estimates made for dose calculations should be more than adequate.

Deposition of Tritium in Rainwater

Deposition of tritium in rainfall can be the result of two processes, rainout and washout. Rainout involves the incorporation of tritium in precipitation as it forms in clouds away from the earth's surface. Washout occurs when precipitation falling from the cloud passes through air containing tritium. Washout of tritium from air that has received tritium from facility stacks or evaporation from seepage basins is the process that is most important in the vicinity of SRS.

Rainfall is collected and analyzed for tritium at most of the air monitoring locations. If rainfall tritium is derived from the washout of air tritiated water vapor, the tritium content of the collected rainwater decreases with distance from the site in the same manner as tritiated water vapor and can be approximated by a straight line when plotted logarithmically (Figure 3.5). The slope of the line for the same 5-year period used in Figure 3.2 is -0.76, which is identical to the slope of the air concentration. As indicated by Figure 3.6, there is generally a close correlation between the air concentration of tritiated water vapor and the rainwater concentration.

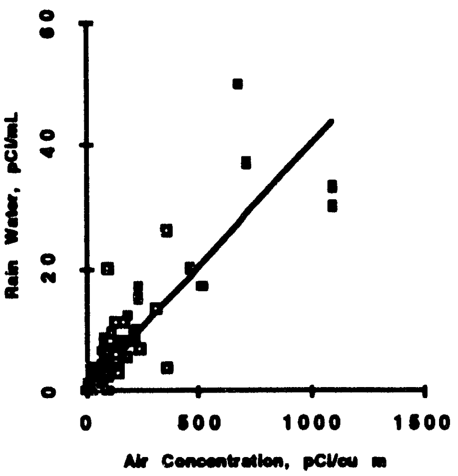


Figure 3.6 The Annual Average Concentration of Tritium in Rainwater Compared to the Concentration in the Air at Each Monitoring Location (1982-1986)

If air water-vapor is the source of rainwater tritium, the tritium content of the rainwater can be no greater than the concentration in the atmospheric water. However, it is possible that the raindrops have not come into equilibrium with the atmospheric water-vapor in the air they are falling through and have a lower concentration. To determine the concentration of tritium in the atmospheric water-vapor, the concentration in the air must be divided by the amount of water in the air. For example, if the concentration of tritium is 10 pCi/m and the humidity is 5 mL/m then the air/water would have a concentration of 2 pCi/mL.

The average equilibrium and its variation from year to year can be determined independently of the variation caused by the decrease in concentration with distance by taking the ratios of the concentrations of air/water, and rainwater at 20 km. Analysis shows that there is considerable variation between years, with the maximum of 56% of equilibrium, a minimum of 20%, and an average of 39%.

Figure 3.7 shows the spatial variation of rainfall deposition around SRS. Like the air tritium concentration, the rainwater concentration is centered around SRS. However, the distribution is not circular; there is a pronounced higher concentration area in the southwest direction. Figure 3.8 illustrates this distribution in another way. The air/water-vapor concentration and rainwater concentration estimated at 20 km from the site center are plotted for 12 locations around the plant where two or more sampling stations are located on a line drawn through them and the center of the site. It is evident from this figure that there is a high correspondence between the two distributions, with a peak in the southwestern direction. However, the relative size of the peak in rainwater is a third larger than the peak concentration of tritiated water-vapor. For this reason, the rainwater distribution appears less circular than the air concentration distribution.

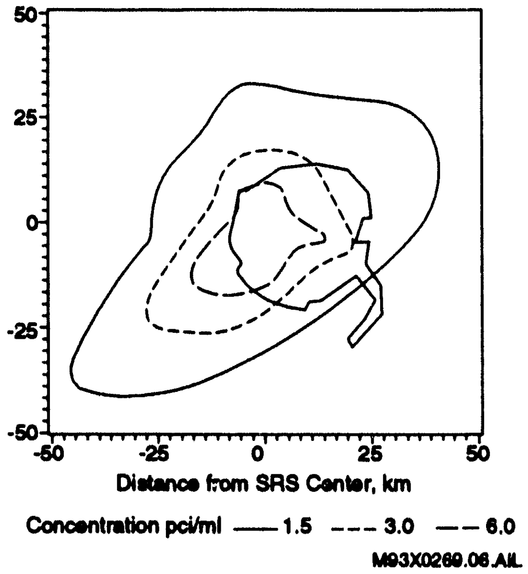


Figure 3.7 The Distribution of Tritium in Rainwater Around SRS (1982-1986)

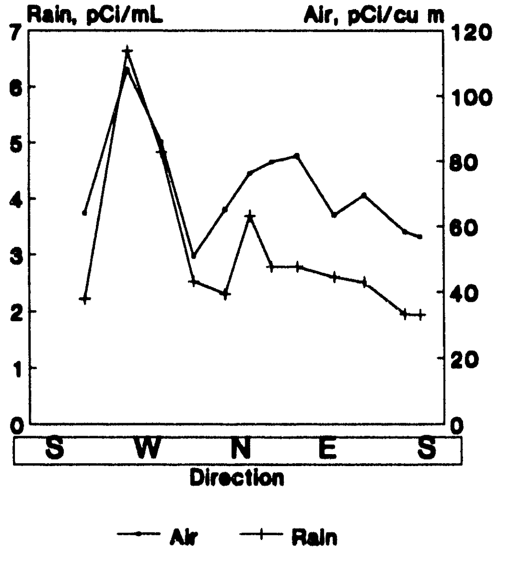


Figure 3.8 A Comparison of the Concentration of Tritium in Air and Rainwater in Different Directions from the Center of SRS

Some of the difference between rainwater and air water-vapor concentrations can be most easily explained by considering the difference in the way the concentrations are measured. Air tritiated water-vapor is reported as an averaged sample collected over a 2-week period. The rainwater is collected over the same period, but rainfall takes place during only a small part of this period. Thus the rainwater concentration is the result of the air concentration during a small part of the measurement period. This is one reason for the difference in the slopes of the decreasing concentration with distance. When rain is falling, tritium is being removed from the air, and the concentration falls more rapidly with distance. The air concentration decrease is most affected by the majority of the time when rainfall is not falling and the concentration is not being decreased by rainout.

It is possible that the differences in the characteristics of storm intensity and type may explain the difference between the distribution of tritium in rainwater and air water-vapor around the plant (Chamberlain and Eggleton 1964). If rainfall coming from a particular direction is characteristically lighter than the rainfall from other directions, the air concentration during the rainfall will decrease less rapidly in that direction and, therefore, so will the tritium concentration in the rainwater. Higher than average air tritium concentrations, and correspondingly higher rainwater concentrations, may also be caused by any combination of higher wind speed and lower lateral spreading of the tritium plume.

A higher concentration in rainwater in a particular direction from the plant center does not necessarily result in a greater deposition of tritium to the ground. If the high concentration is caused by a low rainfall rate, the amount of tritium reaching the surface could actually be less than the deposition in a direction having low concentration but high rainfall.

From this analysis, it is evident that the most important factor affecting the distribution of tritium in precipitation in the vicinity of SRS is the air water-vapor concentration. The average annual rainwater tritium concentration can be estimated to within ±50% by assuming that the rainwater concentration is 39% of the measured air/water concentration. An estimate of the total tritium deposition from rainfall can best be made by averaging the results of the rain gage network, as will be done in a later section describing SRS tritium transport.

Tritium Content of the Soil

The tritium content of the soil is the result of the interaction of a number of processes which transport tritium to or from the soil. (see Figure 3.9) The primary source of tritium, other than in areas such as seepage basins, is the atmosphere. Atmospheric releases reach the soil by rainout of tritiated water, deposition of tritiated water vapor (Garland, and Cox, 1980), and deposition of tritiated hydrogen gas (Murphy, et al., 1976, McFarlane, et al., 1978, Sweet and Murphy, 1981, and Dunstall, et al., 1985).

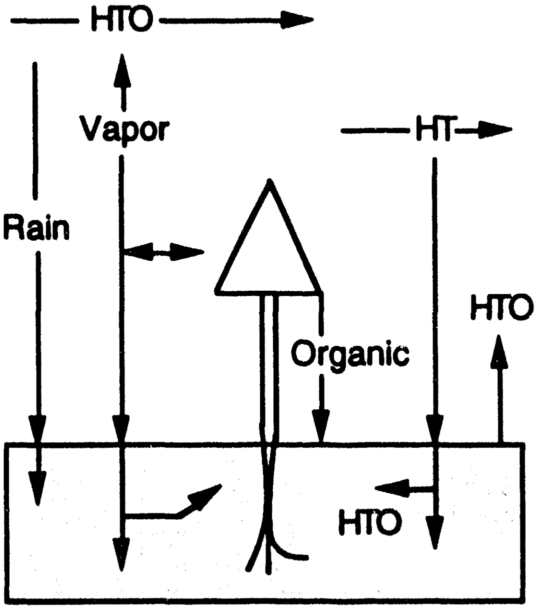


Figure 3.9 The Major Paths of Tritium Transport in the Soil

After deposition, tritiated water vapor is exchanged with the water in the soil and becomes part of the water in the soil pore space. Tritiated hydrogen entering the soil atmosphere is oxidized to tritiated water by microorganisms living in the soil (McFarlane, et al., 1978, Sweet and Murphy, 1981, and Fallon, 1982a and b). The tritiated water deposited by any of these processes moves with the bulk of the soil water by miscible displacement as it infiltrates deeper into the soil. While the soil water tritium will drain from the soil surface under any circumstances, it is most rapidly transported as rainfall infiltrating from above displaces the water below it.

Water is also absorbed by the roots of vegetation and re-enters the atmosphere by transpiration from the plants (Belot, et al., 1988, Foerstel, et al., 1988, and Wiener, et al., 1988). A small fraction of the tritium also becomes incorporated in the soil organic matter. Figure 3.9 illustrates the major paths of tritium movement in SRS soils in those areas not directly exposed to liquid tritium releases.

Routine measurements are not made of soil tritium because the soil tritium content is accounted for in the vegetation tritium concentration, which is measured. The vegetation tritiated water comes from absorption of soil water.

Soil tritium concentrations have been measured as part of special programs to study this part of the tritium cycle. The results of measurements made by Sweet in 1979 and 1980 (Sweet and Murphy, 1981 and 1984) indicated that the tritium content in soil water decreased with distance from the site center. The average concentrations, as shown in Figure 3.10, are similar to those found in rainwater. Each point in this figure is the average of single 60-cm cores of soil taken at different locations.

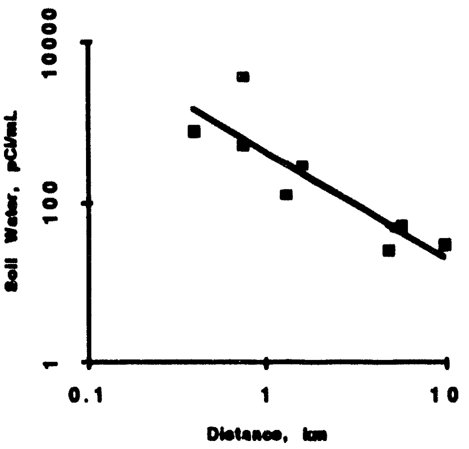


Figure 3.10 Soil Water Tritium Concentrations at Various Distances from the Center of SRS. Grab Samples Taken in 1979.

Depth profiles of soil water tritium concentrations for these same locations show a great deal of variability. In many of the profiles, bands of higher tritium concentration are separated by soil volumes with lower concentrations. Figure 3.11 shows the concentrations for two sites, located about 1 km from the center of SRS. The distribution of tritium is very different at the two locations even though both are near the center of SRS. The differences in these two profiles can be explained by processes that transport tritium to the soil. The concentration of tritium in the rainwater depends on whether the rain falls through the tritium plume as it falls to a particular site. If the site is downwind from a tritium source, the concentration will be higher than if the site is upwind of the same source.

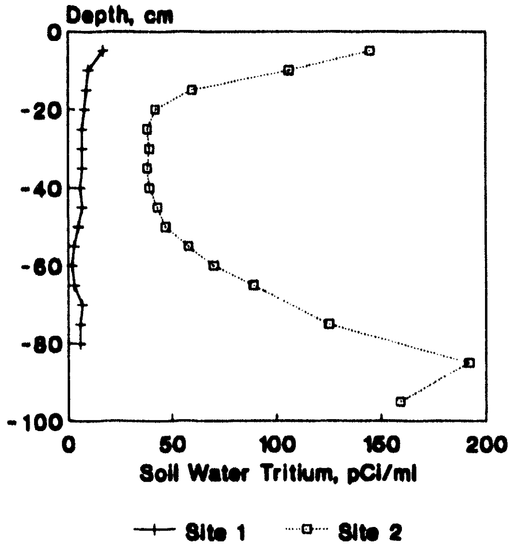


Figure 3.11 Tritiated Water Depth Profiles from Two Locations at the Same Distance from the Center of SRS but with Different Exposure Histories

In addition, between rainfall events, tritium will enter the soil by deposition of tritiated water vapor and hydrogen. The amount of deposition will, as in the case of the rainwater, depend on the direction of the wind and the amount of tritium being released. In this way, soil water that is from rainwater with a higher-than-average tritium concentration, or soil water that has been exposed to deposition when it was near the soil surface, is displaced by later rainfall that has a low tritium concentration.

The pattern found at Site 2, shown in Figure 3.11, could be explained by two periods of higher-than-average exposure separated by rainfall with a lower tritium concentration. The probability that deposition is the source of the higher tritiated water concentration at the surface is confirmed by higher-than-average concentrations in the forest floor litter and the leaves of surrounding trees during sampling of this soil profile. The profile at Site 1 has a much lower soil water tritium content, which can be explained by the site not having been downwind of a source for some time before the sample was taken.

Tritium is also found in the organic component of the soil. As a form of hydrogen, it is a constituent of the organic material. Table 3-1 shows the average tritium content of the water and organic fraction of the soil and forest floor (the layer of organic litter on the soil surface). Estimates of the tritium concentration of atmospheric water and rainwater, discussed earlier in this chapter, are also listed for comparison. The large variation in the values of individual samples is indicated by the comparatively large standard deviations of the sample values shown in parentheses.

Table 3-1 A Comparison of Tritium in the Soil and Forest Floor with the Tritium in Atmospheric Moisture and Rainwater

	Water (pCi/mL)	Organic (pCi/mL)*	Number Samples
Soil (0-60 cm)	32(41)	263(362)	10
Litter Layer	369(958)	353(450)	20
Atmospheric Water	150		
Rainwater	47		

*Activity in water equivalent units from water collected when sample was burned.

The mean soil water concentration is close to the estimated rainwater concentration and below the air vapor concentration, which is consistent with the previous measurements of concentrations in the soil water profiles.

The organic tritium concentration is higher than even the concentration of atmospheric moisture. Since all prior investigations with ecological systems indicate that accumulation or concentration of tritium in any part of the environment is very unlikely, there must be another source for the excess tritium in the soil. The high tritium concentration in the forest floor litter suggests that the source of this tritium is from the vegetation growing above the soil, which is also the source of the organic matter. The reason for the higher-than-expected tritium concentration will be discussed in the following section on tritium in vegetation.

The results of these studies show that the average tritium concentration of the soil water is similar to the tritium content of rainwater and will rarely, if ever, exceed the tritium concentration of the tritiated water vapor in the atmosphere.

Tritium Concentration in Vegetation

The tritium in vegetation is associated with the moisture in the vegetation and with the organic constituents of the dry material. Figure 3.12 shows the spatial pattern of tritium concentration in the vegetation water near SRS. It is clear that the concentration of tritium decreases with distance from the center of SRS. The isopleths are not as circular as the isopleths of tritiated water vapor in the atmosphere. However, they do not show the pronounced higher concentration area in the southwest direction found in the rainwater tritium isopleth. The decrease in concentration in the southeast direction is somewhat greater than for either rainwater or atmospheric moisture.

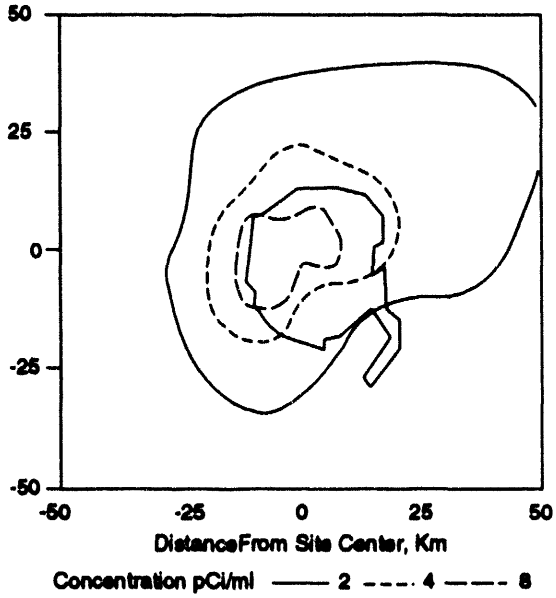


Figure 3.12 The Spatial Distribution of Tritiated Water in Vegetation in the Vicinity of SRS

In spite of the lack of uniformity in the details of the spatial distribution, the general conclusion is that the concentration of tritiated water in the vegetation, like that in the rainwater and air moisture, is nearly the same in all directions. This would be expected from the pattern of annual wind speed and direction at SRS if the source of tritiated water in the vegetation was from the atmosphere. Figure 3.13 illustrates the consistency of the concentration with direction of air flow in another way.

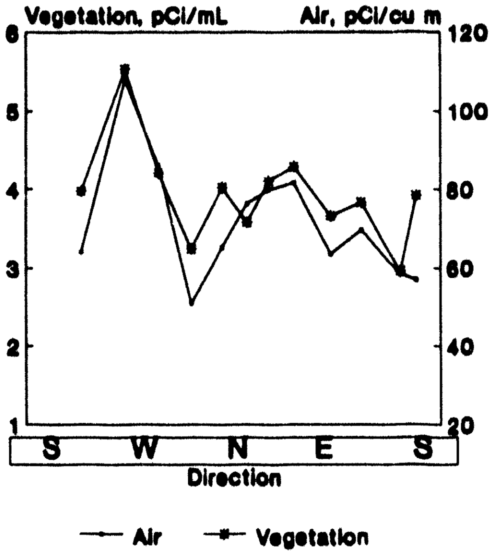


Figure 3.13 A comparison of the Air Water Vapor and Vegetation Tritium Concentration at 20 km for Sampling Transects at Various Directions from the Center of SRS (1982-1986)

Figure 3.14 indicates that the tritiated water content of the vegetation follows the same general pattern of decrease with distance from the center of SRS as air, soil, and rainwater tritiated water. For the 5-year period from 1982 to 1986, the characteristic tritiated water concentration of the vegetation at 20 km is 3.3 pCi/mL and the slope is -1.01. The characteristic concentration is close to that of the air moisture and therefore greater than that of the rainwater. The slope is more negative than the slope of either the air moisture or rainwater, indicating that the concentration of tritium in vegetation drops more rapidly with distance from the center of SRS than the concentration of either the rainwater or atmospheric moisture.

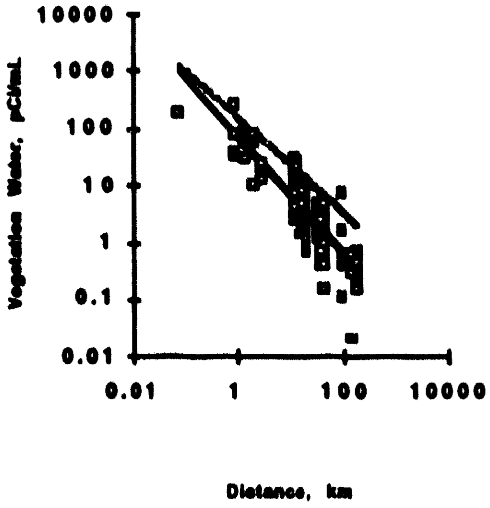


Figure 3.14 The Decrease in Tritiated Water Concentration with Distance from the Center of SRS for Annual Averages (1982-1986) and Maximums (All Available Data)

The tritium concentration of water in the vegetation is the result of a number of processes by which tritiated water enters or leaves vegetation (Raney and Vaadia, 1957, Belot, et al., 1979, Murphy, 1984). Liquid water normally enters the plant from the soil by way of the root and stem systems. Water leaves the plant by evaporation from the leaves. Tritiated water can enter the leaves as vapor and can evaporate from the leaf water.

If the soil water contains tritiated water, the water will enter the roots and move to the leaves at about the same concentration as the soil water. When the tritiated water reaches the leaves, it will evaporate along with the other water from the soil. The rate of evaporation of each type of water, tritiated or normal, depends on the difference in the concentration between the air and the leaf surface for that type of water. The relative rate of evaporation will also depend on the fraction of the water in the leaf of each type of water. If the air has no tritiated water or other water vapor (i.e., the relative humidity of the air is zero), the evaporation of both types of water will be proportional to the fraction of each in the leaves, and the concentration in the leaf will remain the same as that in the soil.

However, if the relative humidity is greater than zero, the difference in the water vapor concentration between the leaf and the air will be less than in the case with zero relative humidity. The evaporation of tritiated water will not change if there is still no tritiated water in the air near the vegetation. In this case the evaporation of tritiated water will be faster, relative to its concentration in the leaf water, than the evaporation of the other water. The higher evaporation of tritiated water will lower the tritiated water concentration in the leaf. The lower concentration will, in turn, lower the evaporation rate of tritiated water. This will continue until a point is reached where the evaporation of tritiated water is equal to the amount of tritiated water being transported from the soil. The result is that the concentration in the leaf will generally be lower than the concentration in the soil water.

The source of tritium in the vegetation can also be tritiated atmospheric water vapor. If the soil water contains no tritiated water, tritium will enter the leaves by diffusion from the air and exchange with the other water in the leaves. If the difference between the water vapor concentration in the atmosphere and the leaf is zero (100% relative humidity inside the leaf) the tritium will enter the leaf until the concentration in the leaf is approximately the same as in the atmospheric moisture. However, if there is a positive difference between the water vapor concentration in the leaves and the air, water will be evaporated from the leaves. When the water evaporates, it will be replaced by soil water pulled up through the roots and the stem. This water will dilute the tritiated water entering from the atmosphere. In time, a steady state tritium concentration will become established in the leaf, which will depend on the rate of entrance of tritiated water and evaporation of other water. The result is that the tritium concentration of the leaf water will generally be less than the tritium concentration of the atmospheric source.

As the previous sections of this report have documented, at the SRS both the soil and the atmospheric water vapor contain tritiated water. If the source of tritiated water in the soil were from rainfall only, the soil water concentration would be less than the atmospheric water vapor concentration, and the vegetation concentration would be expected to be higher than the soil water concentration but lower than the atmospheric moisture concentration.

However, at the SRS there is an additional source of tritiated water in soil. A significant fraction of the tritium releases from the SRS has been in the form of tritiated hydrogen gas. The tritiated hydrogen is oxidized to tritiated water by the action of soil microorganisms. This results in an increase in the tritiated water concentration of the soil and a related increase in the tritiated water concentration of the vegetation relative to the concentration of the air (Murphy and Pendergast, 1979). The magnitude of the relative increase depends on the fraction of the atmospheric tritium that is in the hydrogen gas form. It is possible for this process to cause the concentration of tritiated water in the vegetation to be greater than that in the atmospheric moisture.

Figure 3.15 shows the ratio of vegetation tritiated water to tritiated air moisture. The vegetation is a composite average of all samples taken during a year, including grass, herbs, and tree leaves. During and immediately following years with larger-than-average tritiated hydrogen releases to the atmosphere, the tritium concentration is higher in the vegetation than in the air moisture. There is also some suggestion that during and immediately following years with inadvertent releases of tritiated water, the ratio is decreased relative to years having the mixture of tritiated hydrogen and tritiated water characteristic of years with no inadvertent releases.

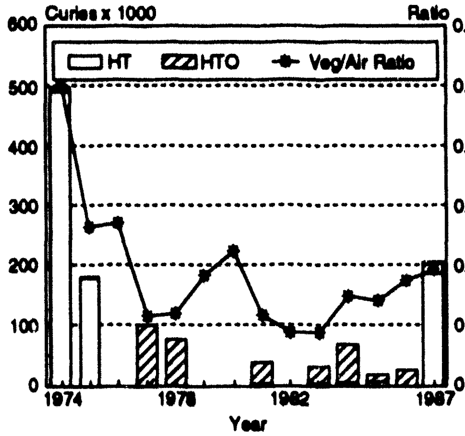


Figure 3.15 The Variation in the Ratio of Vegetation Tritiated Water Concentration to Tritiated Atmospheric Moisture Compared to the Tritium Form and Amount in Inadvertent Releases

Long-term monitoring data of organic tritium concentration in vegetation is not available. A few short-term studies provide some information about the concentration of tritium in the organic form in vegetation. Sanders (1976) measured the tritium content of growth rings in pine trees. He analyzed rings grown before SRS operation and rings grown during 1960, 1965, and 1970. The results of his measurements are illustrated in Figure 3.16. They show the characteristic decrease in concentration with distance from the center of SRS that is found in the vegetation water. This is expected since the organic matter in the tree rings was produced from carbon dioxide and water in the tree leaves by the process of photosynthesis (Moses and Calvin, 1959, Belot, et al., 1983, Guenot and Belot, 1986).

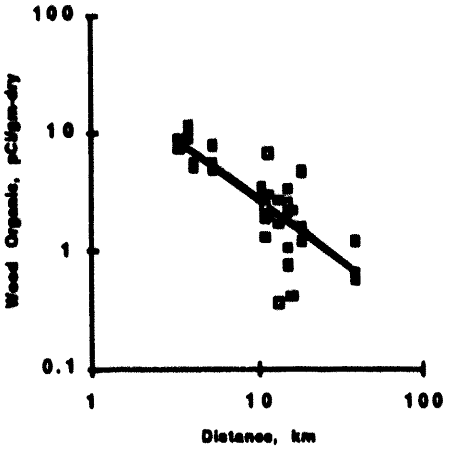


Figure 3.16 The Decrease in the Tritium Concentration of Wood Organic Material with Distance from the Center of SRS

The synthesis of vegetation organic matter from vegetation water is also the reason for the generally greater concentration of tritium in the organic fraction of the soil than in the water fraction of the same soil derived from the forest floor litter. The soil water concentration is derived from the rainfall, which is lower in tritium than the vegetation water.

The mean tritium concentration in the vegetation is the result of the interaction of a number of processes transporting tritium between the environment and the water and organic fractions of the vegetation. Under SRS conditions, the annual average concentration of tritium in the vegetation moisture can vary from 50% to 250% of the annual average concentration of the atmospheric moisture. The average for the 5-year period from 1982 to 1986 is 0.73. This is a larger fraction of the air moisture concentration than is normally used in dose assessment models (Anspaugh, et al., 1973). However, it is consistent with steady-state theoretical calculations (Murphy, 1984).

Tritium Concentration in Wildlife

Annual hunts are conducted at SRS to control the site deer and hog populations and to reduce animal-automobile accidents. Hunt yields average around 1000 deer and 100 hogs a year. These animals are monitored for ^{137}Cs concentration before they are released for consumption by the hunters. The tritium concentration in deer killed in the hunts has been measured on several occasions.

Tritium concentration in deer is similar to that in vegetation in the sense that the concentration is the result of tritium transport to and from the deer through a number of paths. The majority of the water entering the deer is through drinking surface water. A second major source is the water in food eaten by the deer. The water in food is from the moisture in the food and from the water produced by digestion and catabolism (burning for energy) of the food. Water leaves the deer by excretion in urine and feces. Water can also enter or leave the animal in the breathing air and by absorption or excretion from the skin.

The major path by which water leaves the animal is through excretion. The relationship between the volume of water in the deer and the rate of excretion is the major determinant of the turnover time of tritium in the body once the deer has been contaminated. Studies of deer injected with tritiated water indicate that the turnover time is about 6 days. This suggests that deer, like vegetation, respond to the day-to-day changes of tritium in their environment. However, unlike vegetation, deer are mobile and contain water that is the average of the area over which they range.

In 1986 and 1987, a total of 13 deer were monitored for tritiated water concentration of the flesh (Ashley and Zeigler, 1987 and 1988). In addition, 50 deer were monitored in 1966 as part of an intensive study to quantify the tritium in both the water and organic fractions of the flesh (Evans, 1969). Figure 3.17 shows the

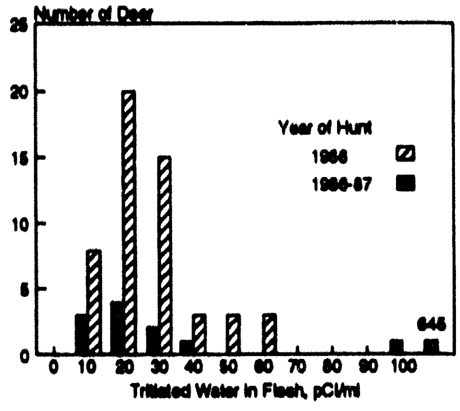


Figure 3.17 The Frequency of Deer Within a Given Range of Tritiated Water Concentration Collected During Intensive Study in 1966 and During Routine Monitoring in 1986-1987

distribution of tritium concentrations in the water of the flesh of deer that were analyzed. In both cases the tritium concentration peaked at about 20 pCi/mL. The two deer with higher concentrations sampled in 1987 probably have no special significance.

In 1966, Evans conducted a detailed study of the relationship of tritiated water to the organic fraction of deer. Samples were taken of various organs, and after the water was removed, the organs were burned and the water of combustion compared to the free water in the deer. He found that the tritium content of the deer organs was always near that of the free water. Figure 3.18 illustrates the results. The comparatively low ratio of tritium in fat to tritium in the body water may be the result of the few exchangeable hydrogen sites in these compounds. It has been shown that fats and oils have almost the same tritium content as the fats and oils in the diet of an animal, while other compounds exchange at least a part of their hydrogen with the surrounding water.

The results of these studies indicate that the tritium content of both the water and organic content of deer at SRS reflect the tritium content of the environment around them. This is probably a good indication of what to expect in other animals, and particularly in other mammals such as man.

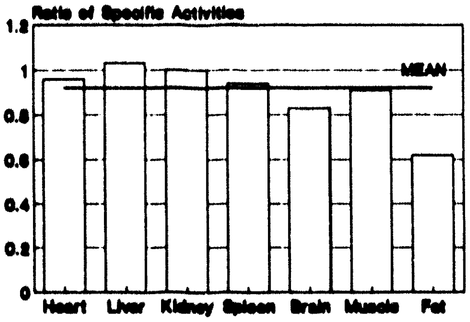


Figure 3.18 The Ratio of Organic Tritium of Tritiated Water in Individual Organs for Deer Collected During 1966 Hunting Season

Tritium Concentration in Fish

Special studies have been made at the SRS to determine the distribution of tritium in fish. About 75% of the weight of a fish is water, and the other 25% is organic material. The water is part of the circulating water in a fish and is in tissue and organs and consists of many organic compounds, including proteins and fats. The source of the tritium in organic material is primarily from photosynthesis (CO_2 + H_2O + sunlight) and secondarily from metabolic reactions. The organic compounds made during photosynthesis are the base of the food chain and undergo many additional transformations before becoming part of the organic matter in a fish. Tritium can also be incorporated by metabolic reactions, since most metabolic reactions involve water.

Special studies at the SRS have been made to establish the general character of the concentration and distribution of tritium in the free water, in the tissue of fish, and in the water from which the fish were caught. Free water tritium (HTO) is part of the circulating water of the fish and can easily be removed by freeze drying. Tissue tritium is organically bound (such as to proteins, fats) and is more difficult to analyze. Organically bound tritium requires the combustion of the tissue at 800 to 1000 C to water before tritium analysis. Special sampling and processing techniques have to be used to ensure that the tritium in the fish is neither lost nor increased during the analytical procedure.

Results from special studies in Par Pond bass at the SRS show that the tritium concentration in the free water is very close to the tritium concentration in the water from which the fish was caught,. This suggests that the tritium concentration was at equilibrium with the water. The tritium tissue is slightly higher than the concentration of the free water tritium in the flesh (Figure 3.19); however, the factor for fish tissue is not large (between 1.1 and 1.75)

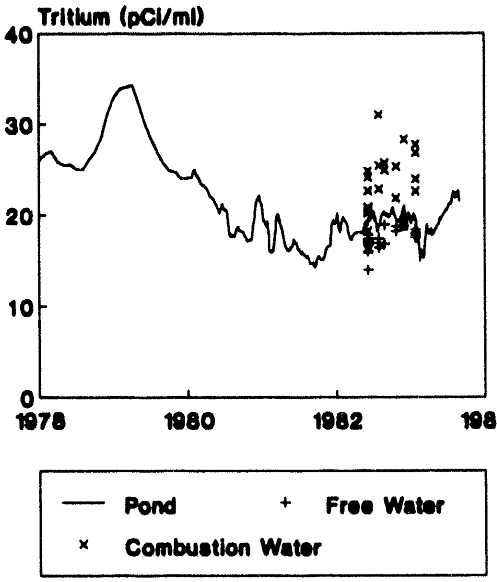


Figure 3.19 Tritium Concentrations in Par Pond Water and Fish

The source of the slightly higher tritium concentration is not known. Candidates are:

fractionation during freeze drying of the samples (Hayes 1982)

transients caused by high tritium concentrations in Par Pond water in the past (slow turnover of organic matter in fish)

assimilation of nonphotosynthetic tritium labeled organics in the food chain

Tritium Concentration in Food

Tritium is measured in a variety of crops and animal food products grown in the vicinity of the SRS. Milk is collected at local farms and from one major milk distributor which gets its milk from the area surrounding SRS. These samples have been taken since the early 1960s when new methods for measuring tritium became available. Before 1971, the sensitivity of the measurement techniques could resolve only a few of the highest tritium concentrations, and most results were reported as below the detectable limit. Since 1971, detection methods have become more sensitive. All but a few of the lowest measurements are above the detection limits and reliable mean values can be determined.

Figure 3.20 shows the results of the mean tritiated water concentration in milk for each dairy or distributor for each year. The average of all sources and the average air concentrations are also shown. The tritium concentration in milk, water, and air vary in similar pattern throughout the period of measurement.

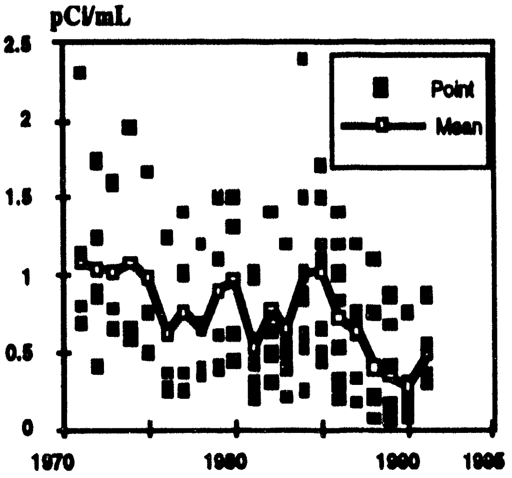


Figure 3.20 The Annual Average Tritium Concentration in Milk Water for Each Dairy or Distributor. The Annual Average of all Distributors and Dairies is Compared to the Annual Average Rainwater Concentration from the Sampling Arc at 40 km from the Center of SRS

Four vegetable food types were measured from 1971-1991: collard greens, fruit (plums, apples, or peaches), grains (wheat, rye, or barley), and corn. As described in an earlier section of this report, the water concentration in the aerial parts of plants is determined by both the atmospheric and soil tritiated water concentration. Figuree 3.21 shows that the average tritiated water concentration of crop plants follows the same temporal pattern as the average concentration of tritium in air. Because of the scatter in these data, it is impossible to differentiate between the ratios of various crop to air moisture tritium concentrations that are found in the literature. A ratio of 0.5 is used in most dose calculations although a ratio of 0.73 is found in other vegetation at SRS, and equilibrium conditions would imply a ratio of ≈ 1.0.

The tritiated water concentration of four animal food types were also measured during the same period: beef, eggs, chicken, and pork. The mean tritium concentration showed a similar pattern to the concentration in the air moisture collected at the ring of sampling stations located 20 km from the center of SRS (Figure 3.22). The results of the measurements of tritium in food in the vicinity of SRS indicate that the concentration in food follows a similar temporal pattern to the concentration in environmental water.

As in the case of vegetable foods, the small sample size and scatter in the data preclude determining a definitive value of the ratio of tritium concentration in animal and air moisture.

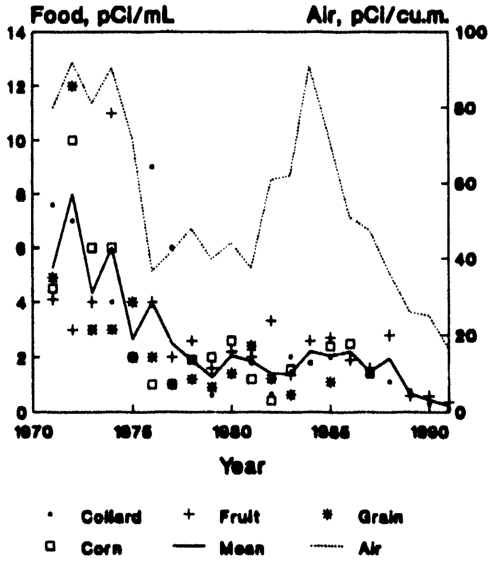


Figure 3.21 Tritium Concentration in the Water of Selected Vegetable Food Grown in the Vicinity of SRS. The Annual Average of All Foods is Compared to the Annual Average Air Moisture Concentration at an Arc 40 km From the Center of SRS

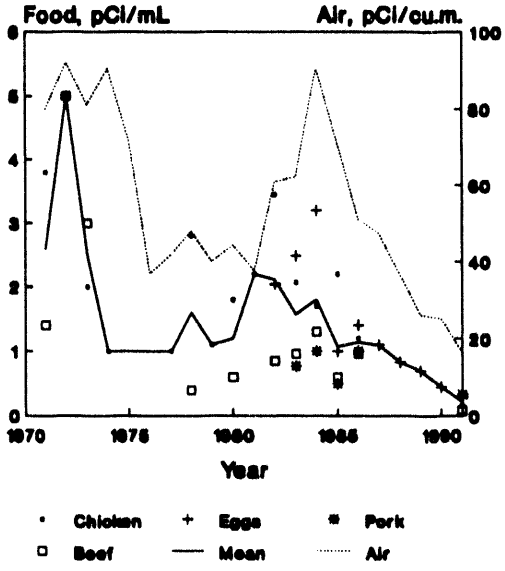


Figure 3.22 The Tritiated Water Concentration of Animal Foods Collected in the Vicinity of SRS Compared to the Annual Average Tritium Concentration of Air Moisture

Transport of Tritium from SRS Surface Water Releases

An accounting of the amount of tritium released from SRS facilities began with SRS startup in 1953. Measurements of the amount in transport in SRS streams and the Savannah River began in the latter half of 1959. Relatively good agreement in the inventory of tritium measured at three locations (the point of release, plant streams before entry into the river, and the river below SRS) has been observed each year since the totals have been compiled, beginning in 1960 (see Figure 3.23 for sampling locations).

Before 1959, low-level measurement techniques needed for routine measurements of tritium concentrations in streams and the river were not available. The lower limit of detection prior to 1959 was 1000 pCi/mL. Liquid scintillation counters, developed in the 1950s, made low-level measurements practical in streams and the Savannah River.

SRS began routine use of liquid scintillation counting in 1959. River and stream measurements began in the last half of that year. During some of the early years (1960-1964), significant differences occurred between releases and the amount of tritium measured in streams and the river (Figure 3.24). These differences led to the addition of effluent monitoring points where small amounts of tritium are released (miscellaneous reactor releases) and the measurement of moderator leakage from the reactor heat exchangers to the cooling water.

Transport data indicate that essentially all tritium released from SRS to flowing surface waters remains in solution, except for minor evaporative losses, and is transported to the Savannah River (Figure 3.24). As shown in Figure 3.24, tritium releases to the Savannah River have decreased significantly since 1964.

Process control improvements have led to the decrease of tritium releases. These improvements include the following:

- change from continuous purges of reactor area disassembly basins to periodic purges in the late 1960s, allowing longer holding time for decay, some evaporation, and a larger inventory of tritium in the basins
- development of equipment and techniques to flush and contain tritium-bearing moderator present on fuel and target housings during discharge from the reactor
- diversion of periodic disassembly basin purges from streams to seepage basins in P and C Areas in 1978, allowing some radioactive decay of tritium before migration to streams via groundwater

SRS Surface Water System

Transport and Dilution

Almost all of the SRS is drained by tributaries of the Savannah River: Upper Three Runs Creek, Beaver Dam Creek, Fourmile Branch, Pen Branch, Steel Creek, and Lower Three Runs Creek (Figure 3.23). Only one small unnamed stream in the northeastern sector of the site drains to the Salkehatchie River to the east. (No SRS facilities discharge to this stream.)

Three large impoundments are located on two of the SRS streams that drain into the Savannah River. The largest of these, Par Pond, has an area of 2640 acres and is located on Lower Three Runs Creek. Pond B, a smaller impoundment consisting of 180 acres, is immediately upstream of Par Pond. L Lake has an area of 1034 acres and is part of the Steel Creek system.

Historically the source of most of the surface water on the site is either rainfall or water pumped from the Savannah River to cool the nuclear reactors. During reactor operation the cooling water is discharged to streams or lakes that flow back to the river. Additional small amounts of water are discharged from other plant processes to streams. Minor additions of water come from natural springs and seepage basin outcrops.

Very little water enters the groundwater through the stream beds. However, water in the large impoundments may enter local porous ground structures and travel short distances. For instance, some of the water in the springs below Par Pond dam has been identified as water from Par Pond (Langley and Marter 1973).

The transport and concentration of tritium as HTO (water that has a protium atom replaced with a tritium atom) in streams and rivers is determined by the processes of volumetric dilution, advection, and turbulent diffusion. ***Volumetric dilution*** of tritiated water occurs when there is an increase in water flow volume.

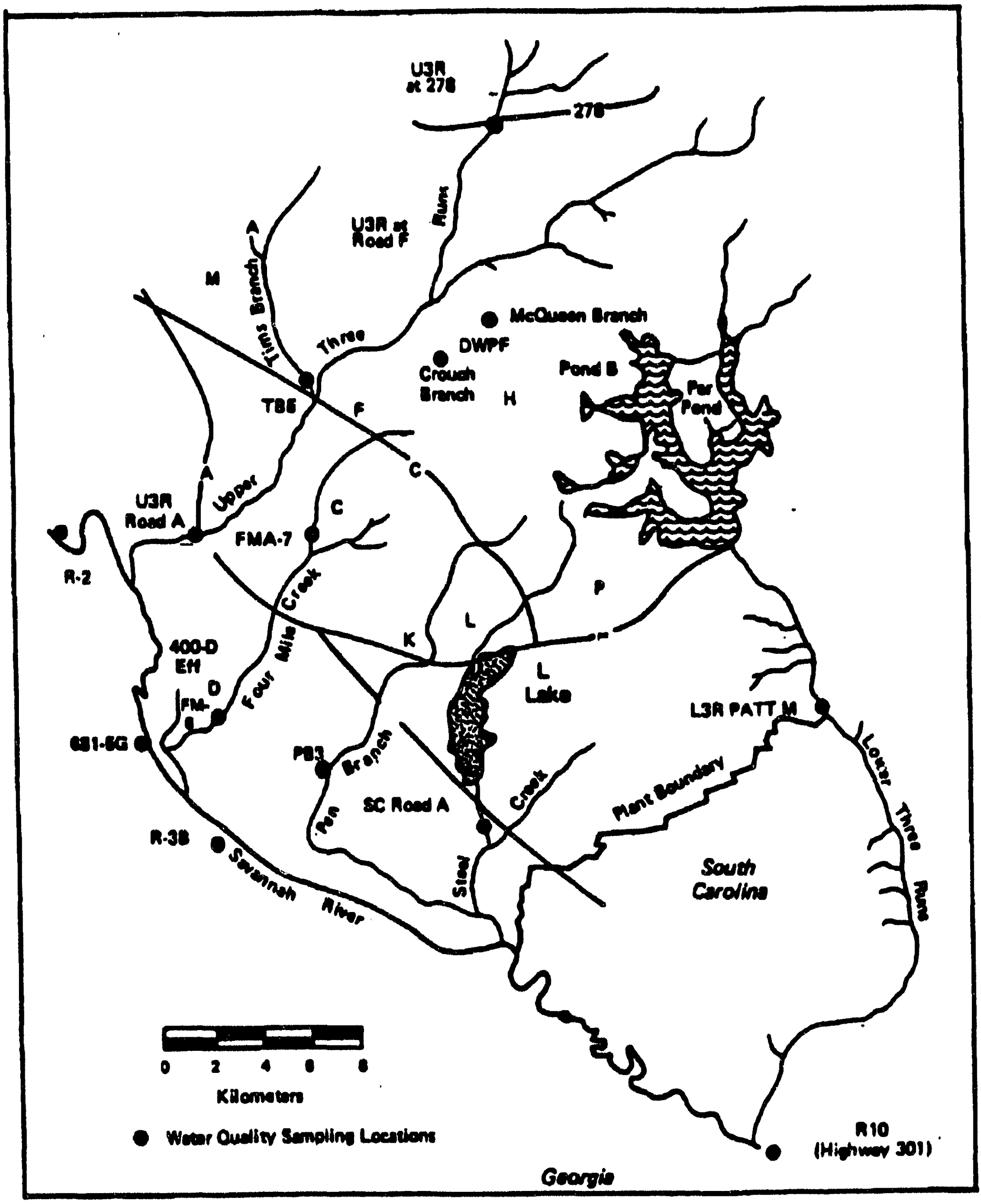


Figure 3.23 Stream Locations Monitored for Tritium Concentration

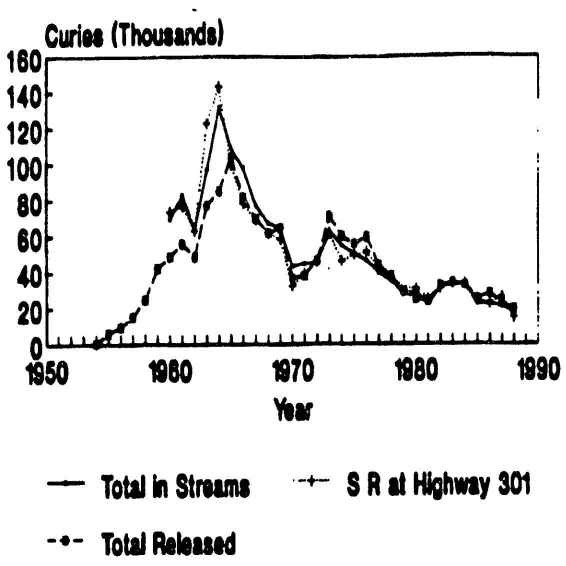


Figure 3.24 A Comparison of Total Tritium Measured in SRS Creeks and the Tritium Measured in the Savannah River at Highway 301 and Downstream from SRS

A decrease in tritium concentration occurs when a stream containing tritium mixes with a river having a lower tritium concentration.

Advection is the movement of tritiated water with the bulk flow of the water. Tritium as HTO is carried along and has the same general speed and direction as the water flow.

Turbulent diffusion or dispersion in surface waters is the process in which dilution of HTO takes place through the action of eddy water currents. This process is important in the initial dilution of short-period releases and is less important as the width of a peak increases. The process is not so important in the dilution of releases that are longer than a day. The concept is similar to atmospheric diffusion except that the process in streams has easily defined boundaries.

Flows

Tritium concentrations in SRS streams and the Savannah River are determined by the tritium release rate and the stream or river flow. An increase in the amount of water flowing in a stream decreases the tritium concentration for a given release. Increases in stream flows occur at SRS due to process and cooling water discharges. SRS discharges can increase natural stream flows by factors of 2 to 15.

Water discharges from a facility are governed by process needs, and the flow variation throughout a year can be greater than in a natural system. Reactor operations have the greatest impact on water flows. For instance, when C Reactor was operating, Fourmile Branch had an average flow of 377 ft^3/s in 1984, and after C Reactor was placed in standby in 1985 and shutdown in 1987, the annual flow dropped to 57 ft^3/s in 1991.

SRS Streams

Tritium is released to SRS streams by direct release from facilities and by migration from seepage basins (Figure 3.25). (The overflows from L Lake and Par Pond, which account for only 2% of the total 1.5 million Ci released, have been included in the direct release values.) A decline in the percent contribution from direct discharge began in the mid 1970s and has continued (Figure 3.26). In 1990, about 81% of the tritium in the streams came from migration and 19% by direct release from facilities. The high percentage of direct release in 1991 (41%) resulted primarily from the inadvertent release of tritium from one of the K-Reactor heat exchangers in December of 1991 (see "Inadvertent Tritium Releases"). These percentages are calculated from the tritium inventory estimates that are made yearly (see Table 3-2) for all site streams and the Savannah River (Davis, et al., 1989). At present only Fourmile Branch and Pen Branch receive a major portion of their tritium content from the migration pathway (13,980 Ci and 2,160 Ci, respectively). Steel Creek receives less than 400 Ci/yr.

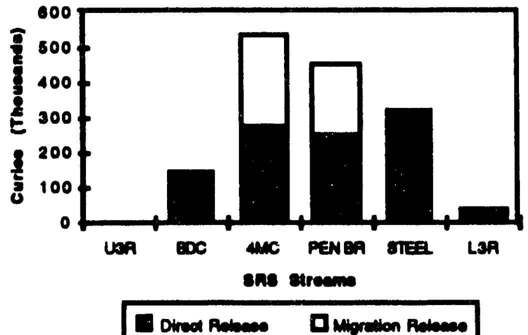


Figure 3.25 Total Releases to SRS Streams by Either Direct Release to the Stream or Seepage from the Groundwater

Table 3-2 Tritium Inventory in SRS Streams and the Savannah River

			Quantity	Curies		% of Total
Area	**Release Point**	**1988**	**1989**	**1990**	**1991**	**To River in 1991**
				Direct Releases		
Reactor						
100 P	Par Pond overflow to Lower Three Runs Creek	327	(321)[a]	207[a]	221	-
	Process sewer to Steel Creek	-	164	67	(43)[a]	-
	Reactor heat exchanger cooling water to Par Pond	-	464	125	(67)[a]	-
100 L	L-Lake overflow to Steel Creek	502	(556)[a]	(358)[a]	723	-
	Process sewer to L Lake	-	24	27	(11)[a]	-
	Reactor heat exchanger cooling water to L Lake	-	98	72	(112)[a]	-
100 K	Process sewer to Pen Branch	264	100	169	74	-
	Reactor HX cooling water to Pen Branch	2,470	112	249	6,470[b]	-
	K-area secondary effluent	-	-	-	6	-
100 C	Process sewer to Fourmile Branch	11	16	1	13	-
	Subtotal	3,570	978	710	7,510	27
Separations						
200 F	Effluent to Fourmile Branch	14	8	327	6	-
	Effluent to Upper Three Runs	-	2	0	0	-
200 H	Effluent to Fourmile Branch	12	20	22	14	-
	Effluent to Upper Three Runs	-	1	4	5	-
200 H	Effluent Treatment Facility	101	2,070	1,200	3,070	-
	Subtotal	127	3,100	1,550	3,090	11
400 D						
400 D	Process sewer to Beaver Dam Creek	1,740	562	358	681	-
	Subtotal	1,740	562	358	681	2
	Total Direct Releases	5,440	3,640	2,620	11,300	41
				Migration		
200 F&H	Solid Waste Disposal Facility and H-Area seepage basin to Fourmile Branch	3,670	3,600	4,280	6,420	-
	200-F seepage basin to Fourmile Branch	3,330	4,440	3,570	5,750	-
	200-H seepage basin to Fourmile Branch	3,980	3,310	1,900	1,810	-
100 C	Seepage basin for Fourmile Branch	-	-	7	-	-
100 K	904-88G to Indian Grave Branch	2,780	2,220	3,560	2,160	-
100 P	Seepage basin to Steel Creek	133	137	224	(364)[a]	-
	Subtotal	13,900	13,700	13,500	16,100	59
	Total Direct Releases and Migration	19,300	17,300	16,100	27,400	100
				Stream Transport		
400 D	Beaver Dam Creek at swamp	2,510	879	756	801	3
200 F&H	Fourmile Branch at Road A13	11,200	11,200	9,370	13,300	50
100 K	Pen Branch at Road A	3,220	2,700	2,510	7,100	27
100 L	Steel Creek at Road A	502	556	358	723	3
100 P	Lower Three Runs at Road B	327	321	207	221	1
ETF	Upper Three Runs at Road A	535	2,160	2,380	4,410	16
	Subtotal	18,300	17,800	15,600	26,600	97
				River Transport		
Tritium measured in the Savannah River below SRS			17,110	16,570	28,700	
Tritium measured in the Savannah River above SRS			1,480	2,080	2,420	
Tritium measured in the Savannah River below SRS (downriver minus upriver)		14,600	15,600	14,490	26,300	96

Note: Because of rounding, the sum of individual columns might not equal totals.

[a] Not used in totals because release has been counted elsewhere.

[b] Includes heat exchanger leak of December 22-25, 1991.

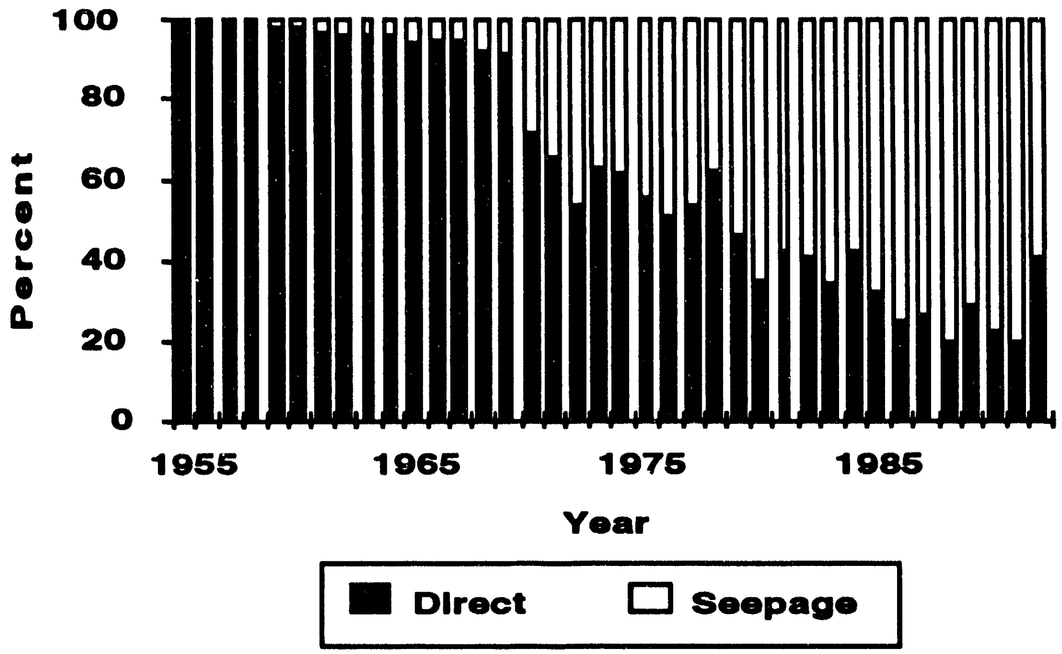


Figure 3.26 Percentage of Tritium in Streams from Direct Release and Seepage Through Groundwater

Since the early 1960s, tritium concentration measurements have been made at a network of monitoring stations on five of the SRS streams and the Savannah River. A summary of these measurements is found in Table 3-3. Beaver Dam Creek tritium concentration measurements were not started until the early 1970s. The tritium measurements are reported in the Health Protection Annual Reports (see Appendix 2, Bibliography) and include the yearly average, the weekly or biweekly maximum, and minimum concentrations for each sampling location. Reporting of the minimum tritium concentration was not started until the early 1970s. Details of the monitoring and measurement techniques are provided in Appendix 1 of this publication. Tritium concentrations from the monitoring location furthest downstream will be used for this discussion so that all SRS facility releases to that stream are included.

Lower Three Runs Creek

P and R Reactors discharged to the Lower Three Runs Creek system. Lower Three Runs Creek has the second largest drainage area (about 490∈ km^2) of the SRS Streams (Wike et al. 1992). Par Pond was constructed to receive cooling waters from P and R Reactors in 1957-1958. It is located near the headwaters of Lower Three Runs Creek. When full, Par Pond covers 2640 acres to an average depth of 6 m. From the dam, Lower Three Runs Creek flows about 39 km before it enters the Savannah River. The narrow strip of land between the dam and the river, which includes the flood plain, is part of the SRS. Several other small ponds were constructed in the headwaters above Par Pond to improve cooling of the reactor effluent. The largest of these is Pond B (about 180 acres).

Table 3-3 Tritium Concentrations in SRS Streams and the Savannah River (1954-1991).

Creek/River System	Avg (pCi/mL)	Standard Deviation (pCi/mL)	Max (pCi/mL)
Upper Three Runs	4.4	2.2 - 17.4	201
Beaver Dam	78	14-420	9274
Fourmile	184	36-800	5300
Pen Branch	85	18-546	14338
Steel	102	3-600	3500
Lower Three Runs	20	2-86	208
Savannah RiverAbove SRS	1.1	0.2-7	29
Savannah River Below SRS	6.5	2.1-14	56

Before construction of Par Pond, effluent cooling water from R Reactor (about 200 ft^3/s) was discharged via Joyce Branch to Lower Three Runs Creek. Since Par Pond was filled in 1958, the overflow to Lower Three Runs Creek has varied, depending on the utilization of the pond cooling water system by P and R Reactors. In 1964, R Reactor was shut down and all P-Reactor cooling water was diverted from Steel Creek to Par Pond. P Reactor was shut down in 1988. An inspection of the Par Pond Dam in March of 1991 led to the discovery of a depression on the downstream face. Although further investigations found no impending potential for dam failure, the pond level was drawn down to minimize the potential for failure. The pond level was drawn down to the 181-foot level, compared with normal elevation of 200 feet above mean sea level.

About 123,297 Ci of tritium have been discharged to the Lower Three Runs Creek system from P and R Reactors (Figure 3.27). Of this total, about 38,875 Ci of tritium have been released to Lower Three Runs Creek. No migration sources of tritium to this system have been identified. Prior to the opening of Par Pond, R Reactor released about 6,423 Ci directly to Lower Three Runs Creek. Thereafter, R Reactor released about 72,430 Ci to Par Pond before being shut down in 1964. P Reactor has released about 44,444 Ci of tritium to Par Pond since 1974. Par Pond has released about 32,452 Ci of tritium to Lower Three Runs Creek since 1964 (Figure 3.28). Between 1964 and 1974, no measurements were made of tritium transport from P Area to Par Pond. Tritium transport measurements made at the Par Pond dam indicate that less than 18,000 Ci would have been released from P Reactor during the years that measurements were not made on P-Reactor releases to Par Pond. Most of the tritium, 14,000 Ci, released from Par Pond between 1964 and 1968 was probably due to R Reactor releases to Par Pond prior to 1965 (Figures 3.27 and 3.28).

Tritium concentrations are measured on composite water samples collected weekly or biweekly from a paddle wheel sampler located below SC State Road 20 (Patterson Mill). Tritium concentrations averaged 20 pCi/mL (ranging from 1.7 to 86 pCi/mL) between 1958 and 1991. The highest weekly concentration was 208 pCi/mL measured in 1964 (Table 3-3 and Figure 3.29). This maximum concentration was probably associated with shutdown activities in R-Reactor Area. The average tritium concentrations have decreased significantly since the mid-1960s due to operation and process improvements. Tritium concentrations now average about 1.7 pCi/mL in Lower Three Runs Creek at Patterson Mill.

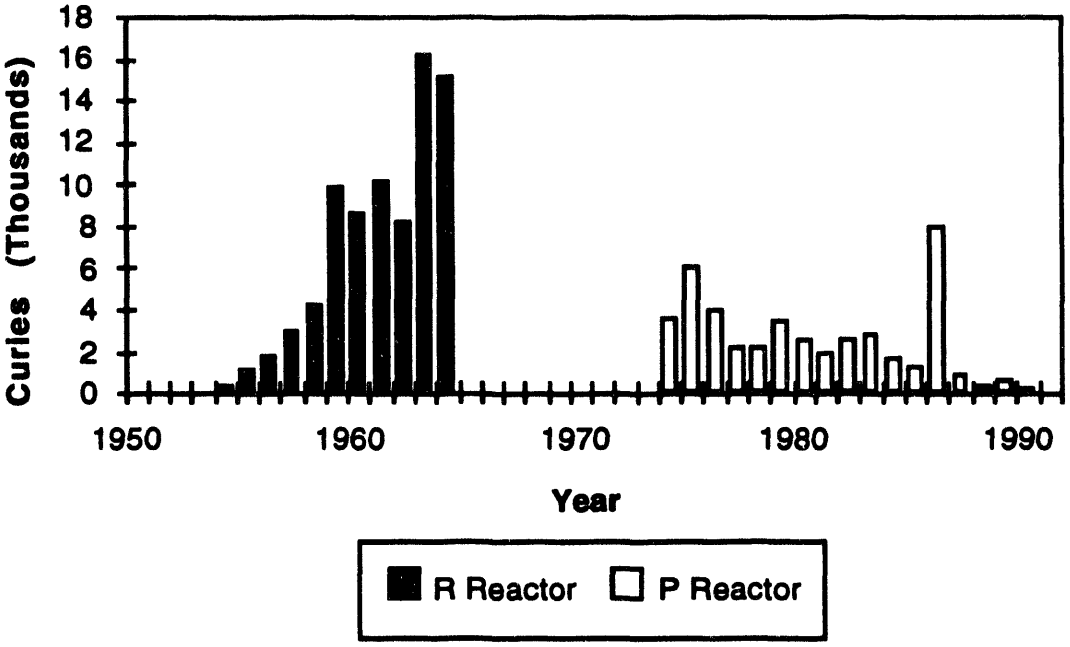


Figure 3.27 Tritium Releases from P- and R-Reactor Areas

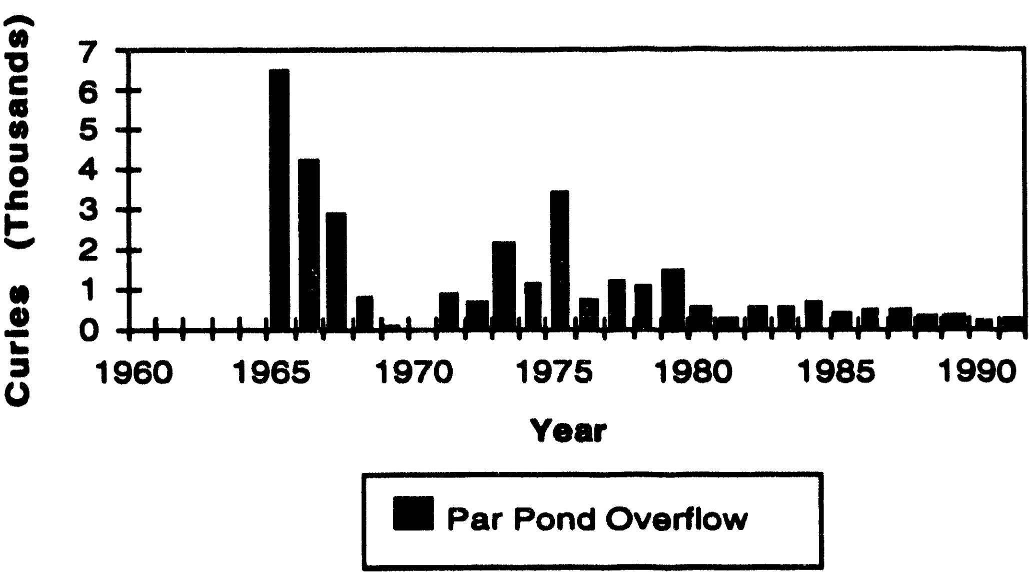


Figure 3.28 Tritium Releases from Par Pond to Lower Three Runs Creek

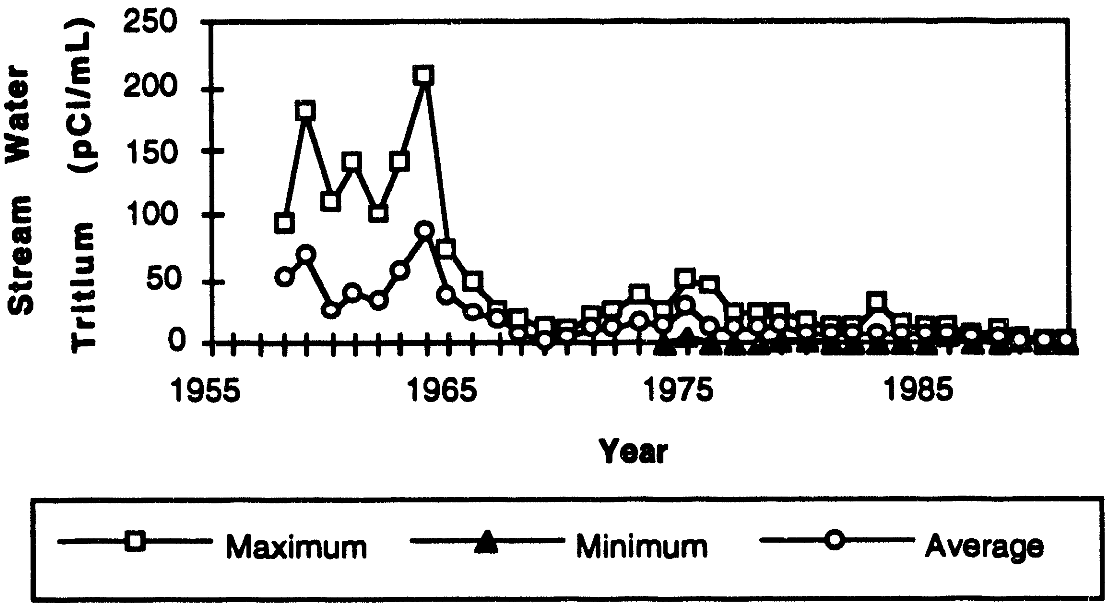


Figure 3.29 Tritium Concentrations in Lower Three Runs Creek at Patterson Mill

Tritium concentrations below Par Pond Dam are decreased by natural flow additions between Par Pond Dam and the river. For instance, the tritium concentration decreased 41% (from 2.9 pCi/mL to 1.7 pCi/mL) between Par Pond Dam and Patterson Mill about 9.7 km downstream. This decrease is primarily accounted for by the increase in flow between the two locations. Further dilution occurs between Patterson Mill and the river about 29 km downstream.

Steel Creek

P and L Reactors discharged effluents to Steel Creek. Steel Creek headwaters are at the P-Area outfall on Steel Creek. The creek flows southwesterly about 3 km before it enters the headwaters of L Lake. L Lake was built in 1985 to provide cooling for L-Reactor thermal discharges. The lake is 6.5 km long and relatively narrow, with an area of 1034 acres. Flow from the outfall of L-Lake Dam travels about 5 km before entering the Savannah River swamp and then another 3 km before entering the Savannah River. The main tributary of Steel Creek is Meyers Branch. Pen Branch enters Steel Creek about 0.4 km from the mouth of Steel Creek on the Savannah River. The Steel Creek watershed has an area of about 91 km^2, not including Pen Branch.

The volume of water discharged from P- and L-Reactor areas to Steel Creek has varied over the years of operation. L Reactor was shut down in 1968, restarted in 1985, and shut down again in 1988. P-Area cooling water was completely diverted from Steel Creek to Par Pond in 1964. These changes in operation have caused a wide variation in the flows and the amount of tritium released to Steel Creek. Flows have varied from 800 ft^3/s in the early 1960s, to 400 ft^3/s in the late 1960s, to 20 to 30 ft^3/s for most of the 1970s and early 1980s. Beginning in 1985 with L-Reactor restart, flows were increased to 400 ft^3/s. In 1991, with L Reactor again inoperable, flows averaged about 140 ft^3/s.

About 323,238 Ci of tritium have been released to Steel Creek from P- and L-Reactor areas. Tritium releases have significantly decreased in Steel Creek, with the shutdown of L Reactor in 1968 and the diversion of P-Reactor process effluents to a seepage basin in 1985 (Figure 3.30). The restart of L Reactor in 1985 did not cause a major increase in the amount of tritium released in Steel Creek. Tritium migration from P-Area seepage basin accounts for less than 400 Ci/yr of tritium in transport in Steel Creek.

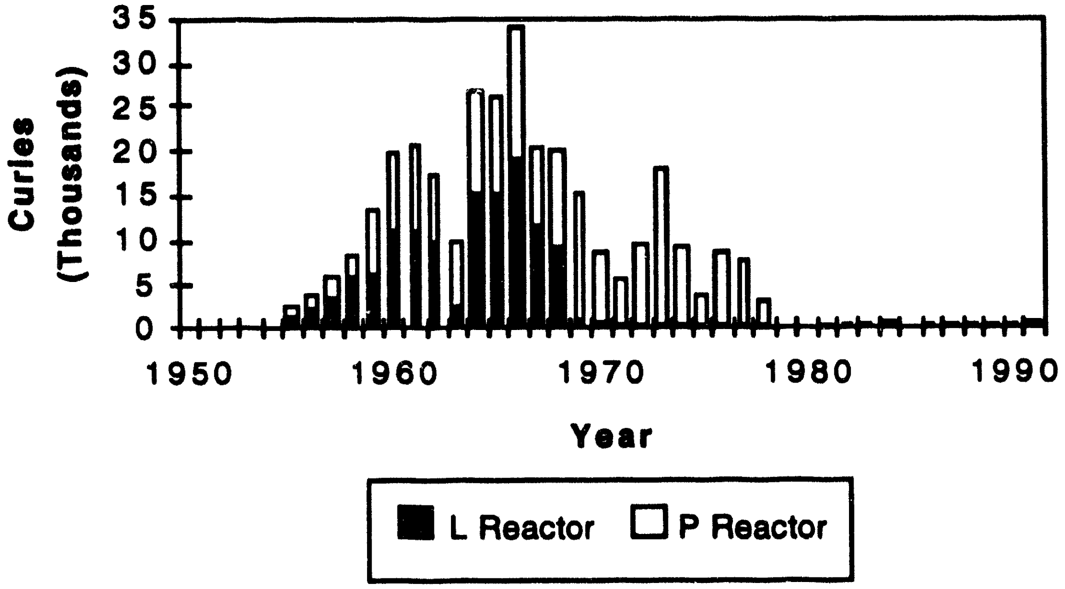


Figure 3.30 P- and L-Reactor Area Releases to Steel Creek

Tritium concentrations are measured on composite water samples collected weekly or biweekly from a paddle wheel sampler located at SC Highway 125 (SRS Road A). The Steel Creek monitoring location was moved to this location from Old Hattiesville Bridge in 1985. Tritium concentrations averaged 102 pCi/mL (ranging from 3 to 600 pCi/mL) between 1958 and 1991. The highest annual concentration was 3500 pCi/mL measured in 1969 (Table 3-3 and Figure 3.31). After L-Reactor shutdown in 1968, the tritium concentrations in Steel Creek increased due to reduced flows. The flow decreased from 400 ft^3/s to 30 ft^3/s, reducing the water available for dilution. Tritium releases from P Reactor to Steel Creek remained the same until all process effluents were diverted to a seepage basin in 1985.

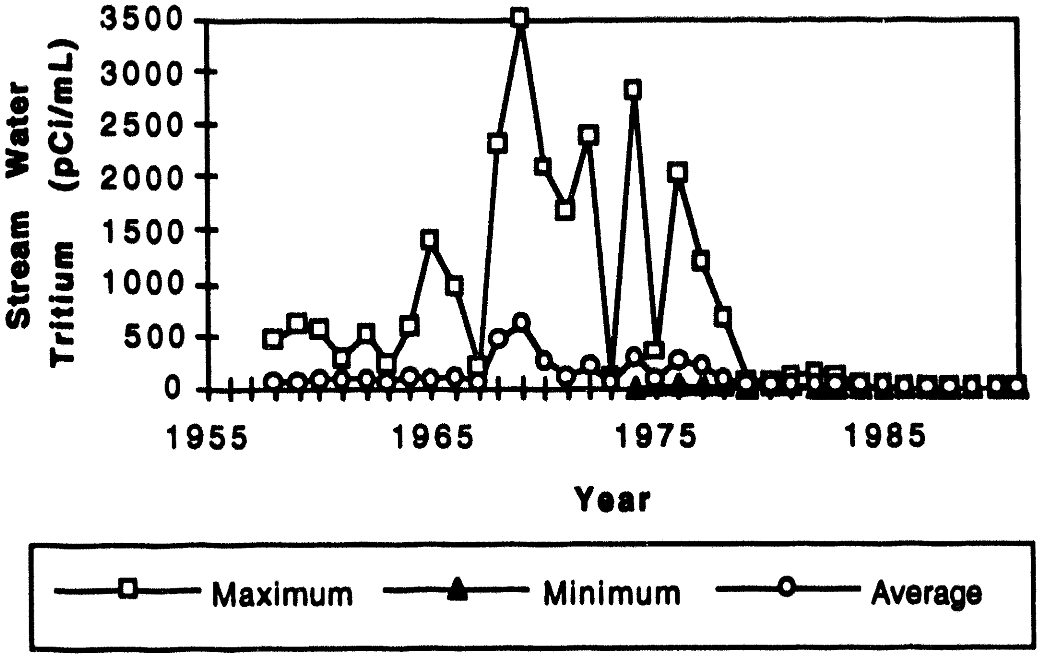


Figure 3.31 Water Tritium Concentration Measured in Steel Creek

Pen Branch

K Area is the only SRS facility that discharges to Pen Branch. Pen Branch lies between Fourmile Branch and Steel Creek, and its flow path is similar to Fourmile Branch. The creek follows a southwesterly path for 24 km, from its headwaters about 3.2 km east of K Area to the Savannah River swamp. After entering the swamp, the creek flows parallel to the Savannah River for about 8 km before it enters and mixes with the waters of Steel Creek about 0.4 km from the mouth of Steel Creek on the Savannah River. Indian Grave Branch is the only significant tributary. It carries cooling water from K Reactor to Pen Branch. The Pen Branch watershed is about 55 km^2. Pen Branch's natural flow is about 5 to 10 ft^3/s, but the flow was increased to about 400 ft^3/s when K Reactor discharged directly to the creek. Under operating conditions of the new K-Reactor recirculating cooling tower, Pen Branch flow would be approximately 55 ft^3/s (45 ft^3/s cooling tower blowdown) (Paller et al., 1989).

Of the 448,526 Ci of tritium released to Pen Branch from K-Area operations, about 54% has been released directly and about 46% has been released through migration (Figure 3.32). Migration of tritium from the K-Area seepage basin has been the major source of tritium in Pen Branch since 1969 (Cummins et al., 1991).

Tritium concentrations are measured on composite water samples collected weekly or biweekly from a paddle wheel sampler located below SC Highway 125 (SRS Road A). Tritium concentrations averaged 85 pCi/mL (ranging from 18 to 546 pCi/mL) between 1958 and 1991. The highest weekly concentration was 14,338 pCi/mL measured in 1964 (Table 3-3 and Figure 3.33). The average tritium concentrations have decreased significantly since the mid-1960s due to operation and process improvements. Tritium concentrations now average about 50 pCi/mL in Pen Branch, and further decreases are expected as tritium releases from seepage basin sources continue to decrease.

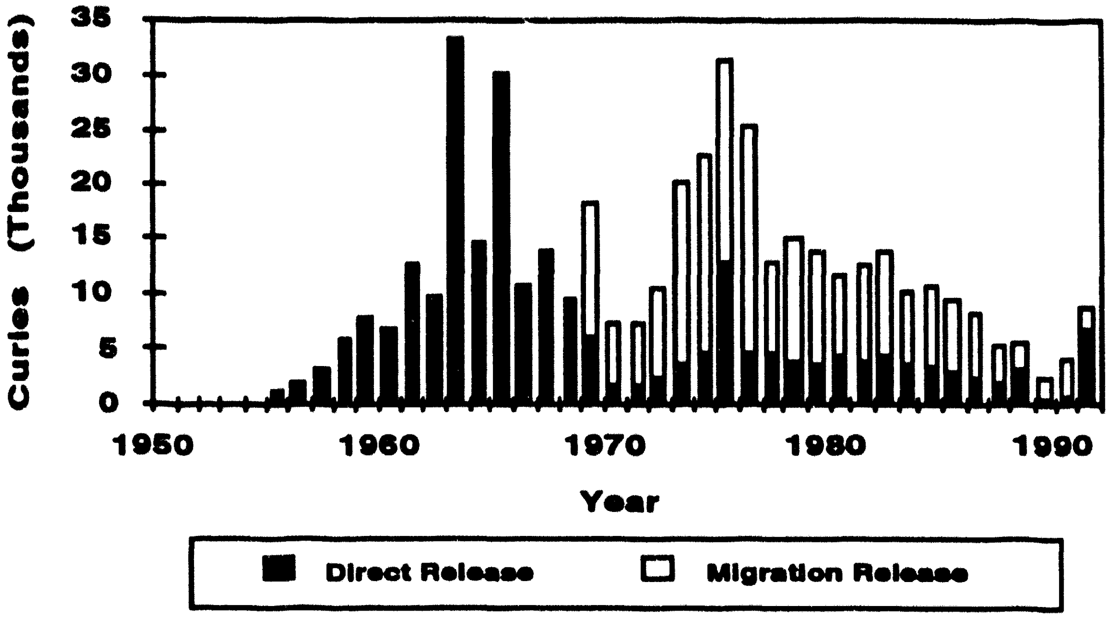


Figure 3.32 K-Reactor Area Releases to Pen Branch

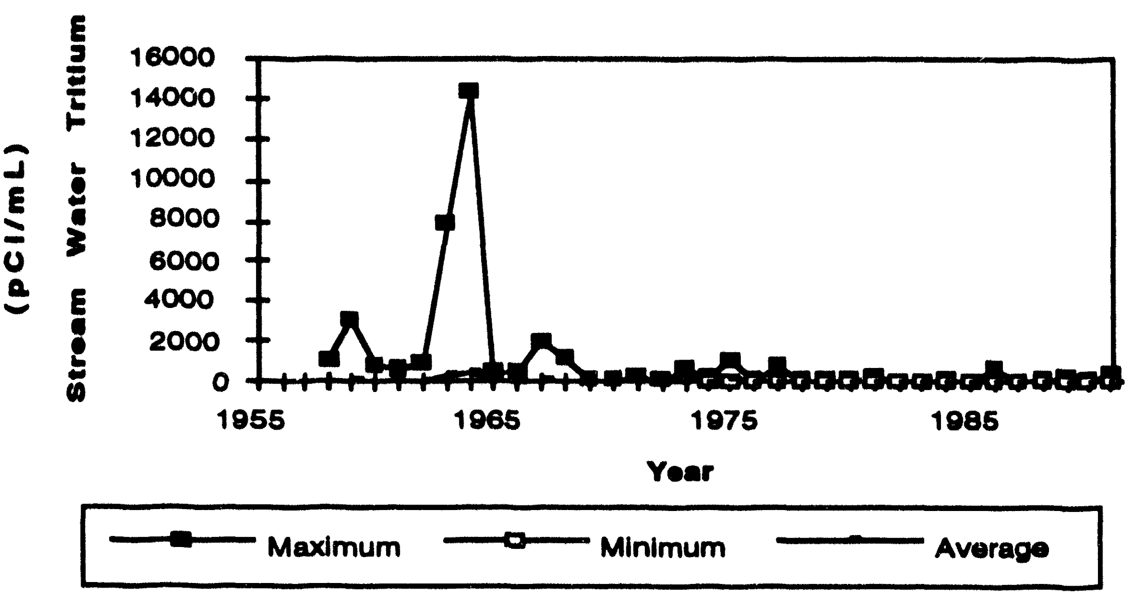


Figure 3.33 Tritium Concentration in Pen Branch

Fourmile Branch

Fourmile Branch begins near the center of the SRS and follows a generally southwesterly path for about 24 km to the river. The total watershed is onsite and drains about 57 km^2 to the river. The watershed includes several SRS facilities: F- and H-separation areas, C-Reactor Area, the Solid Waste Disposal Facility, and F- and H-Area seepage basins.

The natural flow of about 5 ft^3/s is increased by F- and H-Area process effluents and drainage to about 20 ft^3/s, just above the C-Area discharge stream. The flow is increased further by flow from C-Reactor Area. C Reactor has not operated since 1985, and the flow contribution from

C Area to Fourmile Branch is now about 10 ft^3/s. The average flow in Fourmile Branch in 1991 was about 57 ft^3/s.

Of the 536,394 Ci of tritium that has been released to Fourmile Branch, approximately 50% has come from direct sources, and approximately 50% has come from migration (Figure 3.34). As facility releases have decreased, migration has represented a larger fraction of the tritium in Fourmile Branch. In 1991, greater than 99% of the 14,005 Ci of tritium in transport in Fourmile Branch was from migration from F- and H-Area seepage basins and the Solid Waste Disposal Facility (Table 3-2 and Figure 3.34).

The F- and H-Area seepage basins received low-level radioactive waste from the chemical separation processes in the General Separation Areas (GSA). The basins served the function of delaying the release of the effluent to the environment. The seepage basins stopped receiving effluents in 1988 and were capped and sealed in 1990 to reduce the leaching of contaminants.

In 1988 and 1989, an extensive study was performed to determine the character of groundwater outcropping into Four Mile Creek and its associated seepline (Haselow, et al., 1990). Tritium values along the seepline, elevated conductivity, and low pH values corroborated the determination that the contaminated leachate from the F- and H-Area seepage basins were impacting the areas.

In 1992 a quarterly sampling program was established to evaluate the hypothesis that rainfall and natural groundwater flow would dilute and flush out the contaminant plume over time, (Dixon and Rogers, 1992). The program measures conductivity and pH in addition to tritium.

Results from the First Quarter 1992 Tritium Survey of the F- and H-Area seeplines, completed in May of 1992, indicate that rainfall is diluting the contaminant plume and washing the plume from the receiving wetland systems. The May survey produced tritium concentrations in the F- and H-Area seeplines that were significantly lower than the original tritium concentrations measured by Haselow et al. (1990).

Tritium concentrations are measured on composite water samples collected weekly or biweekly from a paddle wheel sampler located below SC Highway 125 (SRS Road A). Tritium concentrations averaged 184 pCi/mL (ranging from 36 to 800 pCi/mL) between 1958 and 1991. The highest weekly concentration measured was 5300 pCi/mL in 1958 (Table 3-3 and Figure 3.35).

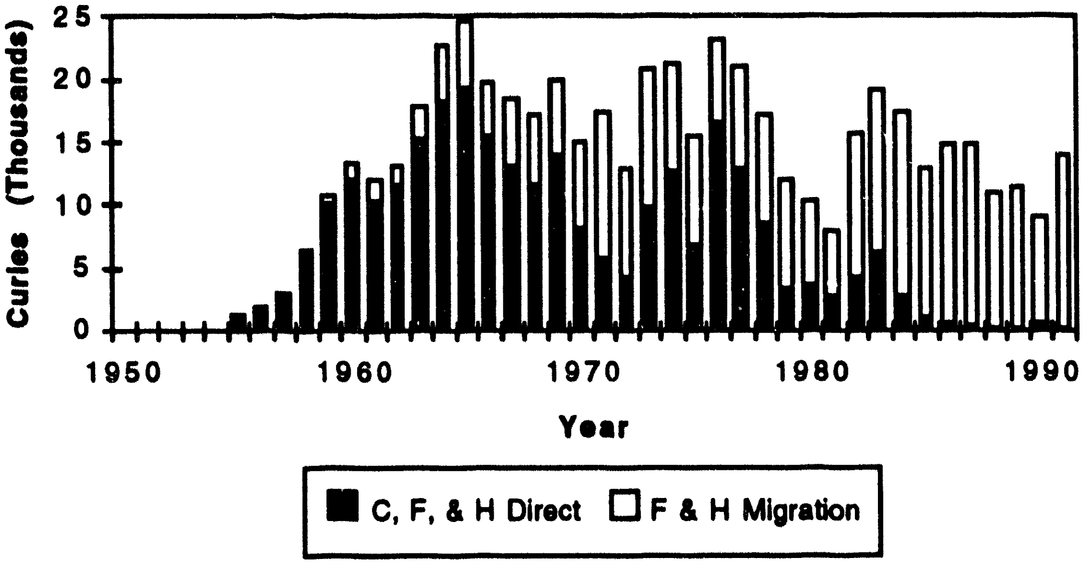


Figure 3.34 F-, H-, and C-Area Releases to Fourmile Branch

The average tritium concentrations in Fourmile Branch have increased since 1985 because of the reduction in flow from the shutdown of C Reactor. Tritium from migration sources to Fourmile Branch has remained relatively constant since 1985, but the flow was reduced about a factor of 10 with the shutdown of C Reactor (Figure 3.35). The highest concentration reflects releases to Fourmile Branch from C-Reactor fuel storage basin operations and the low flows during reactor shutdown.

Beaver Dam Creek

Beaver Dam Creek receives tritium releases near its headwaters from the 400-Area operations. Beaver Dam Creek is the smallest of the SRS streams that discharge into the river. It is 5 km long with a watershed of about 2.2 km^2 (Wike et al. 1992). The 400-Area operations that release tritium include the heavy water rework units, the drum wash facility, and the laboratories. These facilities have released about 146,815 Ci of tritium to Beaver Dam Creek since operations began in the early 1950s (Figure 3.36).The released tritium is diluted with process water from the area and travels about 6.5 km before it mixes with the Savannah River. About 100 ft^3/s of process water is discharged from the 400 Area (primarily from power plant operations), and this water dilutes the tritium that is released from the other 400-Area facilities. Beaver Dam Creek flow was further increased to about 200 ft^3/s when C Reactor was operating. (C Reactor was shut down in 1985.) About 100 ft^3/s of water from C Reactor would flow through the swamp and combine with Beaver Dam Creek flow about 0.4 km above the mouth. Travel time for tritium released from the 400 Area to reach the Savannah River is about 10 hr.

Composite tritium samples are collected weekly from a paddle wheel sampler located at the 400-D effluent and analyzed for tritium. A summary of the tritium concentrations in Beaver Dam Creek is shown in Table 3-3 and Figure 3.37. The average tritium concentration in Beaver Dam Creek at the 400 Area between 1972 and 1991 is 78 pCi/mL (Ranging from 14 to 420 pCi/mL). The highest annual average concentrations occurred in the first 3 years of measurement (1972, 1973, and 1974). Since 1974, the average has decreased to 39 pCi/mL (±17 pCi/mL) due to process operations improvements.

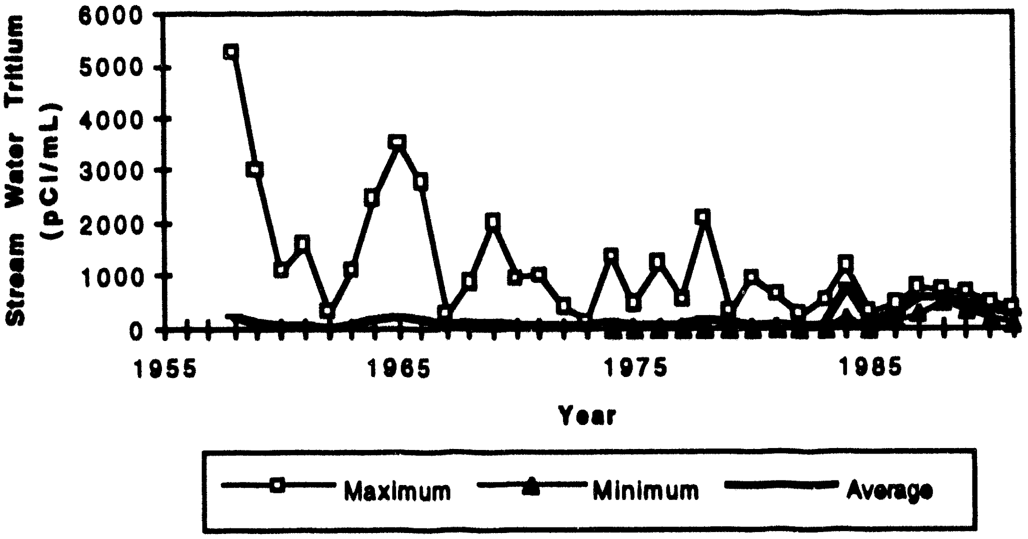


Figure 3.35 Tritium Concentrations Measured in Fourmile Branch

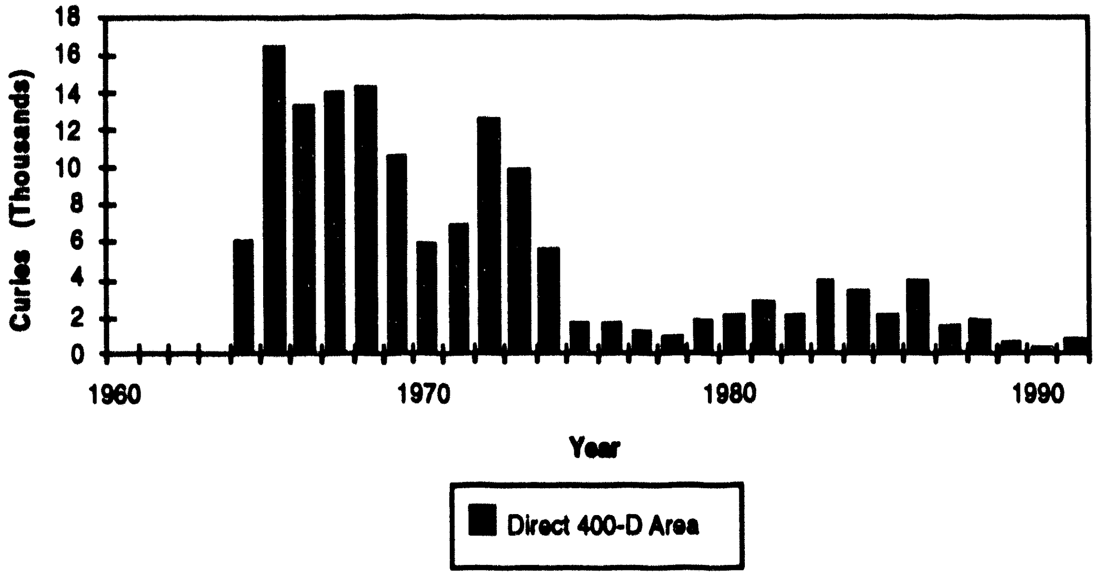


Figure 3.36 Tritium Releases from 400-D Area

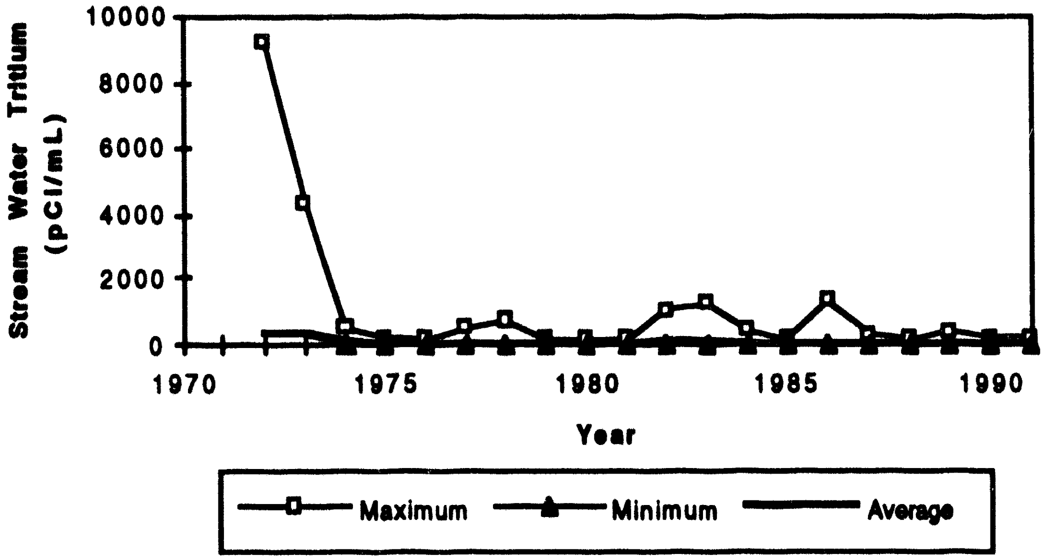


Figure 3.37 Tritium Concentrations in Beaver Dam Creek

Upper Three Runs Creek

Upper Three Runs Creek is the only SRS stream with headwaters arising off the site. The stream is 40 km long and drains an area of about 545 km^2. Its main tributaries are Tinker Creek and Tims Branch. Upper Three Runs Creek has the largest natural flow of any site stream. The average flow during 1991 was approximately 280 ft^3/s.

SRS facilities that drain into Upper Three Runs Creek include M Area, the Savannah River Technology Center (SRTC), and storm drain and ash basin flows from F Area. Until 1988, no tritium was released directly to the surface water draining these areas. Beginning in 1988, the Effluent Treatment Facility (ETF) in H Area began releasing tritium to Upper Three Runs Creek. The ETF released about 3,070 Ci of tritium to Upper Three Runs Creek in 1991. The release of 243 Ci of tritium from SRTC to the A-Area seepage basin is not expected to impact tritium concentrations in Upper Three Runs Creek.

Tritium concentrations are measured on composite water samples collected weekly or biweekly from a paddle wheel sampler located below SC Highway 125 (SRS Road A). Tritium concentrations averaged 4.4 pCi/mL (ranging from 2.2 to 17.4 pCi/mL) between 1961 and 1991. The highest concentration was 201 pCi/mL in 1964 (Table 3-3). The average tritium concentration is higher than in streams or rivers at a distance from SRS, or which have tritium concentrations of less than 0.3 pCi/mL, providing no nuclear facility is discharging tritium into them.

The higher tritium concentrations in Upper Three Runs Creek, as compared to background regions, are probably a result of the local washout/deposition of released SRS atmospheric tritium released onto the Upper Three Runs Creek watershed. Even though Upper Three Runs Creek did not receive SRS water discharges of tritium until ETF began discharging in 1988, about 24 million Curies of tritium were released to the atmosphere. About half of the 545 km^2 of the Upper Three Runs Creek watershed is on the SRS and the other half is adjacent to the boundary. Tritium atmospheric transport and cycling processes are discussed earlier in this chapter.

Until 1988, a general decrease in both atmospheric releases and tritium concentrations in the creek had been occurring since 1959, indicating that washout/deposition may have been the source of tritium in Upper Three Runs Creek (Figure 3.38) prior to ETF discharges. Prior to ETF discharge, an estimate of the percent of atmospheric release that was transported by Upper Three Runs can be made by comparing creek transport to SRS releases. Creek transport (29,000 Ci) between 1954 and 1991 is approximately the average flow (257 ft^3/s before ETF) multiplied by the average tritium concentration (3.7 pCi/mL before ETF). Only about 0.1% of the SRS atmospheric tritium releases have been transported in Upper Three Runs Creek, indicating that very little of the tritium released to the atmosphere is in the local surface waters.

Savannah River

The Savannah River is the principal surface water system near the SRS. All SRS facilities discharge into one of the six tributaries that drain to the Savannah River. The river adjoins the SRS along its southwestern boundary for a distance of about 32 km and is 225 river km from the Atlantic Ocean. The Savannah River drainage basin has a total area of 27,388 km^2.

SRS has three pump stations on the river. Two of these pump stations were used to supply water to cool the nuclear reactors. The smaller third pump station supplies cooling and process water for the 400 Area. Except for evaporative losses, all of the water pumped by SRS is returned to the Savannah River.

The flow of the Savannah River increases down river of SRS. Upstream of SRS at Augusta, GA, the average flow is 10,280 ft^3/s. The average flow at Augusta, GA has remained nearly the same, 9570 ft^3/s, since the filling of Thurmond Lake (formerly Clarks Hill Reservoir). Flows increase to about 14,460 ft^3/s near Clyo, GA, about 161 km down river of SRS.

Tritium accounts for greater than 98% of the radioactivity in the Savannah River. From 1953 to 1991, about 1.5 million Ci of tritium of SRS origin were in transport in the Savannah River at Highway 301 (Table 3-4). Tritium concentrations are measured on composite water samples collected weekly from paddle wheel samplers above SRS and below SRS (see Figure 3.23). The samplers above SRS are used to determine contributions upriver of SRS.

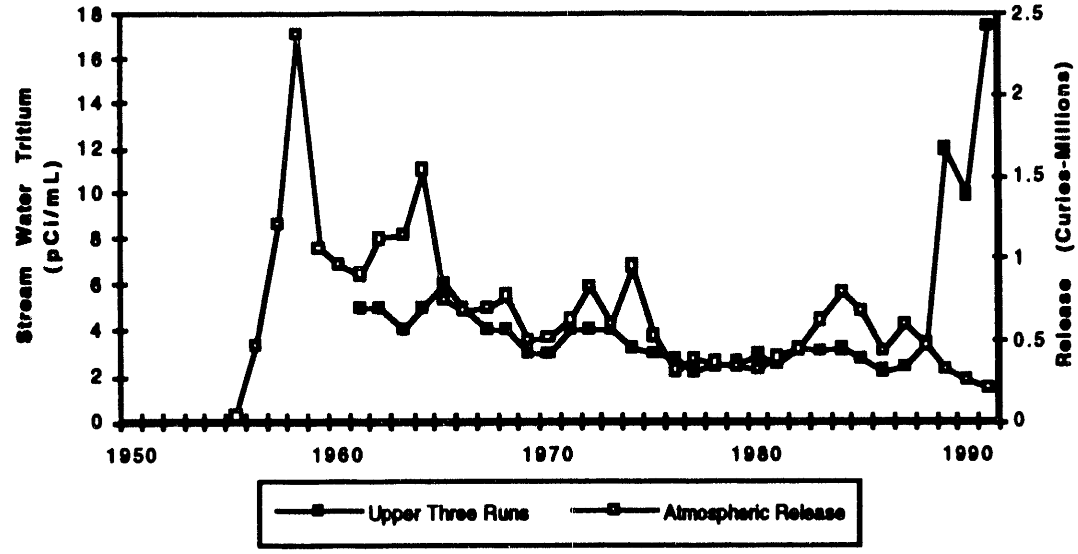


Figure 3.38 Tritium Concentrations Measured in Upper Three Runs Creek Compared to Atmospheric Releases from SRS Facilities

Above SRS, the river averaged 1.1 pCi/mL (ranging from 0.2 to 7 pCi/mL) between 1958 and 1991. The highest weekly concentration of 29 pCi/mL occurred in 1960 (Table 3-3 and Figure 3.39). Historically, most of the tritium in the river above SRS was due to fallout from nuclear weapons testing. Tritium concentrations in the river above SRS now average <0.4 pCi/mL.

Below SRS, at Highway 301, SRS releases increased tritium concentrations to an average of 6.5 pCi/mL (ranging from 2.1 to 14 pCi/mL) between 1958 and 1991. The average tritium concentrations have decreased significantly since the mid-1960s due to operation and process improvements (Figure 3.40). The highest weekly concentration of 56 pCi/mL was measured in 1960 (Table 3-3 and Figure 3.40). This high concentration reflects additions from both nuclear weapons test fallout and SRS releases. The highest tritium concentration, 280 pCi/mL, was measured in a grab sample taken in the river following a tritium release from 400 Area in 1972 (see Inadvertant Releases). The grab sample was one of many taken over several days and not composited.

As previously discussed, relatively good agreement in the inventory of tritium measured at the point of release and the river below SRS has been observed each year since the totals have been compiled (Figure 3.41). This transport data indicates that essentially all tritium released from SRS to flowing surface waters remains soluble, except for minor evaporative losses, and is transported to the Savannah River. Comparison of measured to calculated tritium concentrations (release/flow), shows that the annual average tritium concentrations at Highway 301 can be calculated from annual releases and average flow data (Figure 3.41).

Each year SRS projects the maximum amount of tritium to be released to the Savannah River. Maximum individual and population doses are estimated for these projected releases by using appropriate dose models. The dose models calculate doses by estimating the tritium concentration based on release and average annual flow rate data. Since no reliable method exists for estimating future river flows, a minimum flow of 6000 ft^3/s (maximum individual dose) and an average of 10,000 ft^3/s (population dose) are used to estimate the tritium concentrations in the Savannah River to be used for dose calculations. (See Chapter 4 for further elaboration of dose calculations.)

Table 3-4. Liquid Tritium Releases (1954-1991)

Overflows year	River Flow Rate (cfs)	Direct Release & Pond to Streams (Ci)	Seepage to Streams (Ci)	Original Total Release (Ci)	Decay-Corrected Total (Ci)*
1954	7,382	366	0	366	46
1955	5,974	5,870	0	5,870	778
1956	6,309	9,390	0	9,390	1,317
1957	8,312	15,025	0	15,025	2,229
1958	11,038	19,849	400	20,249	3,177
1959	9,748	31,269	800	32,069	5,322
1960	13,112	38,265	1,600	39,865	6,998
1961	10,909	43,640	2,000	45,640	8,474
1962	10,580	38,522	1,700	40,222	7,899
1963	11,138	58,464	2,700	61,164	12,706
1964	20,497	65,583	4,700	70,283	15,443
1965	12,785	98,460	5,600	104,060	24,185
1966	11,175	77,265	4,600	81,865	20,125
1967	10,573	64,017	5,600	69,617	18,102
1968	9,624	55,791	5,790	61,581	16,937
1969	10,945	45,454	18,789	64,243	18,689
1970	8,208	23,935	12,887	36,822	11,330
1971	10,687	20,111	17,843	37,954	12,353
1972	11,235	28,764	17,247	46,011	15,839
1973	14,428	42,996	27,786	70,782	25,774
1974	11,101	32,854	27,126	59,980	23,101
1975	15,405	28,151	27,480	55,631	22,663
1976	13,912	31,784	27,856	59,640	25,699
1977	11,646	27,179	16,583	43,762	19,946
1978	10,523	17,148	20,412	37,560	18,107
1979	13,251	10,182	19,250	29,432	15,008
1980	13,200	10,267	14,402	24,669	13,305
1981	6,604	9,664	14,183	23,847	13,605
1982	7,169	10,927	21,530	32,457	19,586
1983	12,348	14,217	19,785	34,002	21,702
1984	12,759	10,470	22,320	32,790	22,137
1985	7,167	6,108	18,910	25,018	17,865
1986	5,516	7,341	20,480	27,821	21,014
1987	8,955	4,315	18,271	22,586	18,044
1988	5,232	5,444	13,894	19,338	16,341
1989	7,832	3,768	13,747	17,515	15,655
1990	12,064	2,895	12,534	15,429	14,587
1991	11,598	8,243	16,511	24,754	24,754
Totals		1,023,993	475,316	1,499,309	570,842

Note *Annual releases have been decay-corrected to 1-1-91.

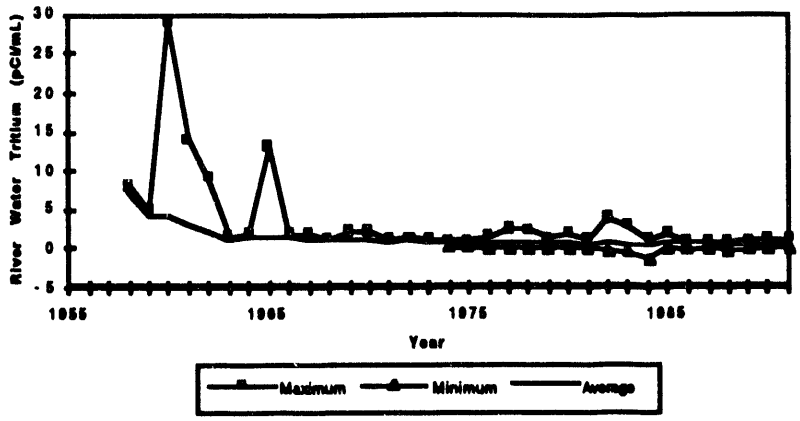


Figure 3.39 Tritium Concentrations in the Savannah River Above SRS

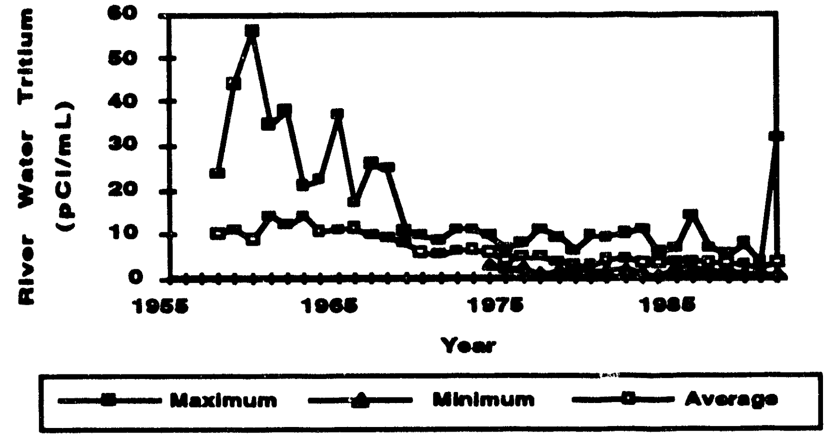


Figure 3.40 Tritium Concentrations in the Savannah River Below SRS

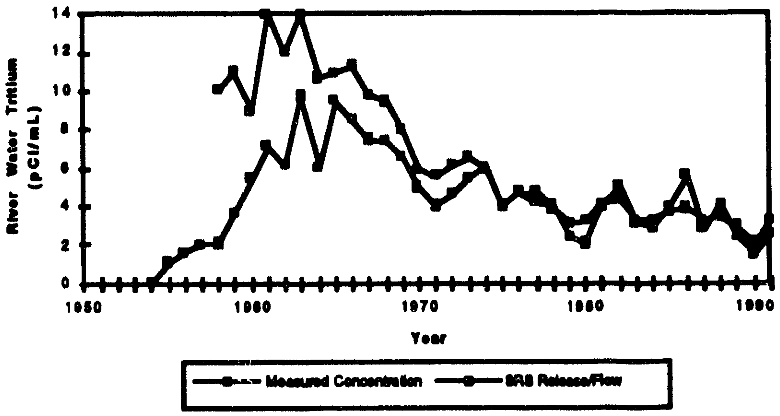


Figure 3.41 Measured Versus Calculated Tritium Concentrations in the Savannah River Below SRS

A comparison of the tritium concentrations measured at Highway 301 to calculated tritium concentrations (actual SRS releases divided by the minimum or average flow) for past years shows that the dose model projection method can be used reliably for tritium dose projections (Figure 3.42). Between 1958 and 1991, the minimum flow projection (6000 ft^3/s) over estimates the measured concentration by an average of about 40% (8.9 ± 4.9 pCi/mL projected vs. 6.5 ± 3.5 pCi/mL measured). Between 1958 and 1991, the average flow projection (10,000 ft^3/s) produces a closer estimate of the actual concentration at Highway 301 (5.4 ± 2.9 pCi/mL projected vs. 6.5 ± 3.5 pCi/mL measured). On a year-to-year basis, variation around the average would be expected due to flow variation.

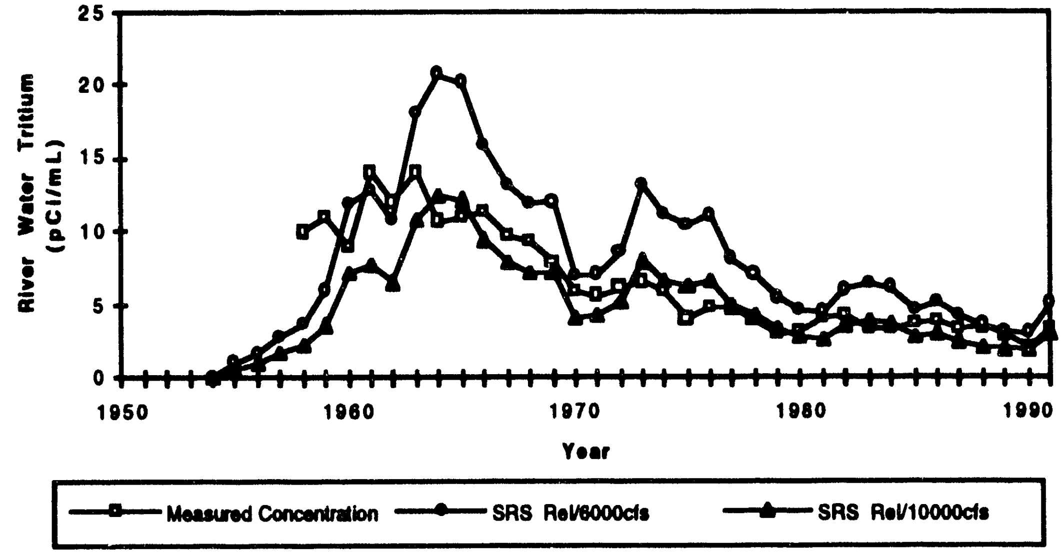


Figure 3.42 Comparison of Measured Versus Projected Tritium Concentrations in the Savannah River Below SRS

From Highway 301, the river water travels about 129 km before it is used by the Beaufort-Jasper and Port Wentworth (City of Savannah) water treatment plants.

Water Treatment Plants

Two water treatment plants down river from SRS supply treated Savannah River water to customers in Beaufort and Jasper Counties, SC, and Port Wentworth (parts of Chatham County), GA (Figure 3.43). The Beaufort-Jasper intake canal is 16.4 km upstream (River Mile 39) of the Port Wentworth intake. Pumps at the Beaufort-Jasper pump station lift water into a supply canal that flows by gravity for about 29 km to the water treatment plant. Operation of the plant began in 1965 with a treatment capacity of about 10 million gallons per day. The Port Wentworth river water intake is located on Abercorn Creek, about 3 km from the river, at River Mile 29. From this intake, water travels about 11 km through a pipeline to the plant. The plant was in operation prior to SRS startup, and its present capacity is about 45 million gallons per day.

Tritium concentrations are measured once a month in the raw water at Beaufort-Jasper and Port Wentworth water treatment plants. Each monthly sample represents a composite of daily water samples collected by the water treatment plant operating personnel. Since 1971, average tritium concentrations for both treatment plants have been reported in the annual environmental report. Beginning in 1974, the maximum and minimum concentrations were also included in the annual environmental report.

Water from the Beaufort-Jasper plant averaged 2.2 pCi/mL (± 0.8 pCi/mL) between 1971 and 1991. The highest concentration of 7.1 pCi/mL was measured in 1977 (Figure 3.44).

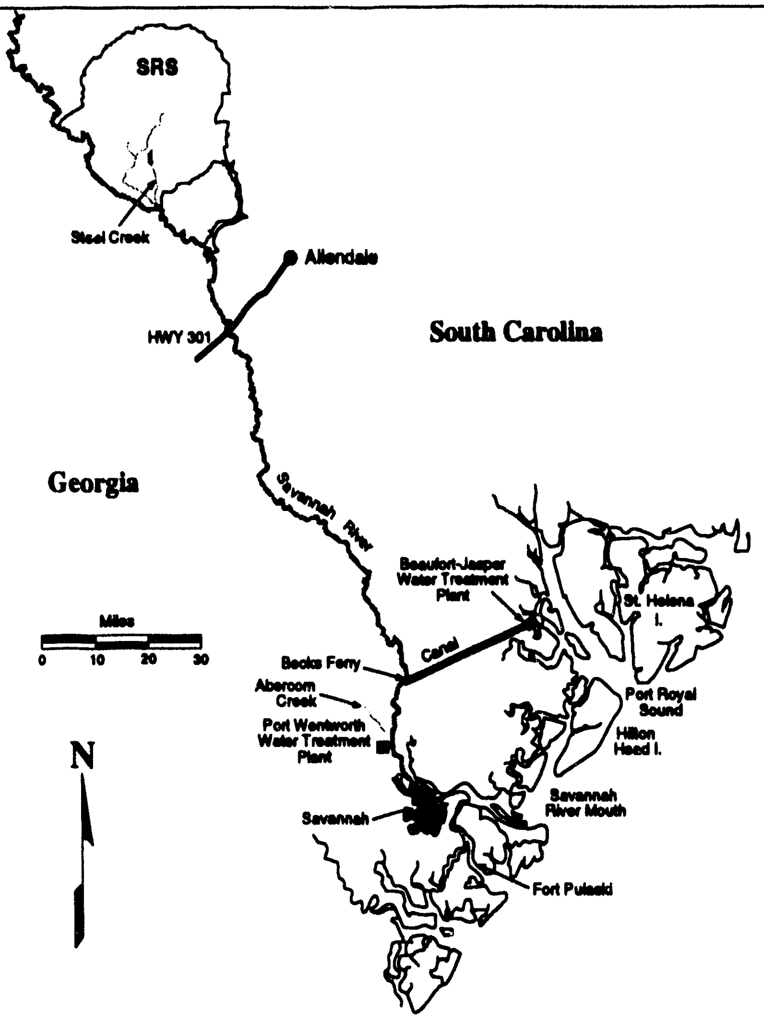


Figure 3.43 Location of Beaufort/Jasper and Port Wentworth Water Treatment Plant

At the Port Wentworth plant, the average between 1971 and 1991 is slightly higher (3.2 ± 1.0 pCi/mL) with a maximum concentration of 11 pCi/mL measured in 1978 (Figure 3.45).

Tritium concentrations decrease over the 80-mi distance between Highway 301 and the downriver water treatment plants (Figure 3.43). Dilution is a result of surface water and groundwater inflow into the river or supply canal and direct rainfall on the river or canal. The flow in the river increases about 20% between Highway 301 and the water treatment plants, decreasing the tritium concentrations (Hayes 1983). Most of the 23% tritium concentration decrease at Port Wentworth can be accounted for by this flow increase. Local water inflow from the small Abercorn Creek watershed may account for additional dilution of Savannah River water before it is pumped by the Port Wentworth pump station.

Prior to 1985, the tritium concentration decrease was much greater for Beaufort-Jasper (54%) raw water than for Port Wentworth (23%) raw water. Entrainment of local surface waters in the Beaufort-Jasper pump station is located about 3 km from the Savannah River.

Water flows to the pump station through a canal that connects with the Savannah River. Prior to 1985, a small surface stream and other local surface waters flowed into the canal and diluted the Savannah River water before it was pumped into the canal. Special water treatment problems were caused by the high organic and low

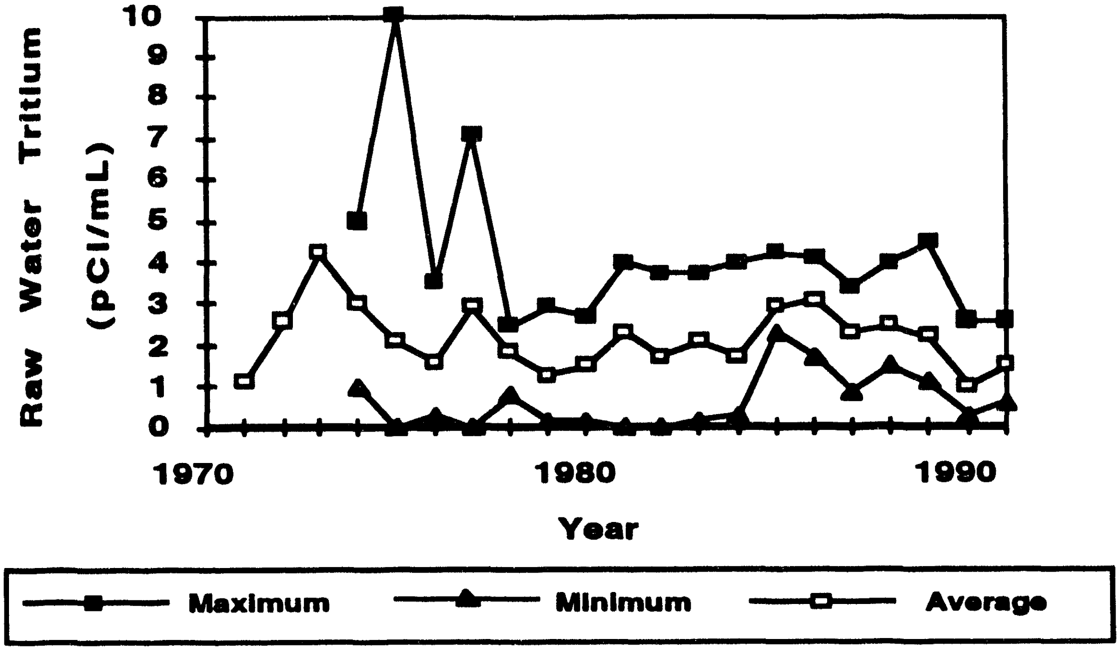


Figure 3.44 Tritium Concentrations at the Beaufort/Jasper Water Treatment Plant

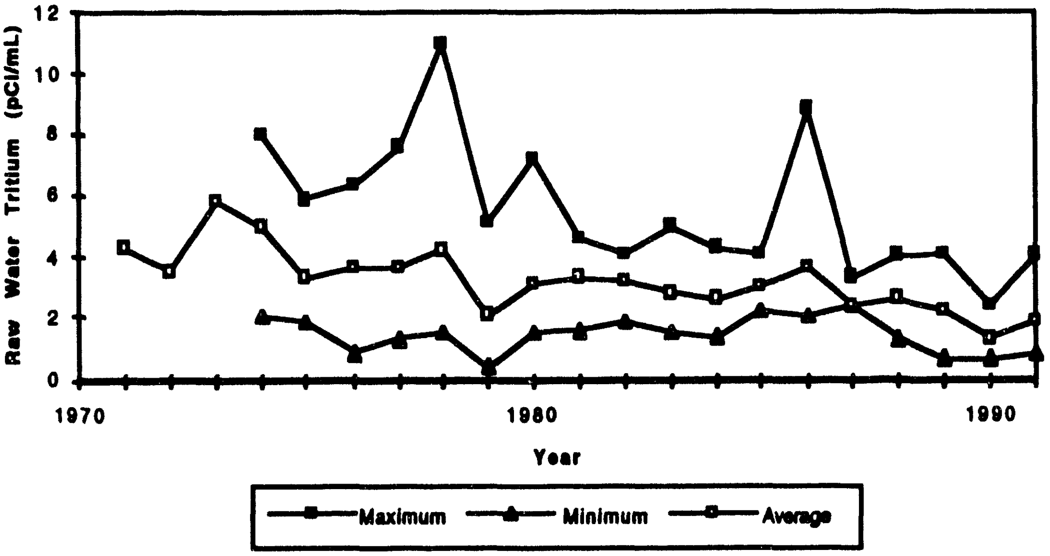


Figure 3.45 Tritium Concentrations at the Port Wentworth Treatment Plant

suspended sediment concentrations of local coastal plain surface waters. To reduce treatment problems, the canal was rerouted in 1985 to avoid and reduce the entrainment of the local surface waters. Since 1985, tritium concentration at the two water treatment plants has been nearly the same.

Tritium concentration at Highway 301 can provide a conservative and reliable estimate of concentration downstream at the water treatment plants (Figure 3.46).

Savannah River Estuary and Coastal Waters

Special studies have been made on the transport and dilution of tritium in the Savannah River estuary and local coastal waters.

An estuary begins where sea water is measurably diluted with river water. In the Savannah River estuary, this process begins about 35 km upriver from the mouth. This mixing process, which dilutes the tritium concentration of Savannah River water, is more or less continuous through the length of the estuary (Figure 3.47). The linear mixing process of tritiated Savannah River water and ocean water is illustrated by the straight line in Figure 3.48. The line was constructed from the measured tritium concentration and salinity of surface water samples from the Savannah River estuary during a period of steady SRS tritium releases (Hayes 1975).

The linear relationship between the salinity and tritium content of the Savannah River water in the estuary indicates that the tritium from the river water and the dissolved salts from the ocean water are mixing at the same rate, and presumably by the mixing processes, in the estuary. This observation provides insight into the processes which dilute tritium with ocean water in the estuary. The linear relationship between tritium content and salinity also means the tritium content at any point in the estuary an be estimated on the basis of much less expensive salinity measurements.

Other characteristics of the Savannah River estuary that affect tritium concentration includes tidal effects and vertical stratification. The tritium concentration at any location in the estuary varies with the tide. At low tide, the salinity is the lowest and tritium concentration would be the highest, and the converse would be true for high tide. Vertical stratification is a result of density difference between the lighter river water and the denser ocean water. This vertical stratification results in higher tritium concentration and lower salinity at or near the surface. At the mouth of the Savannah River estuary, tritium concentration from the river has been reduced an average of about 50% by steady mixing with sea water as the river water is flushed from the estuary.

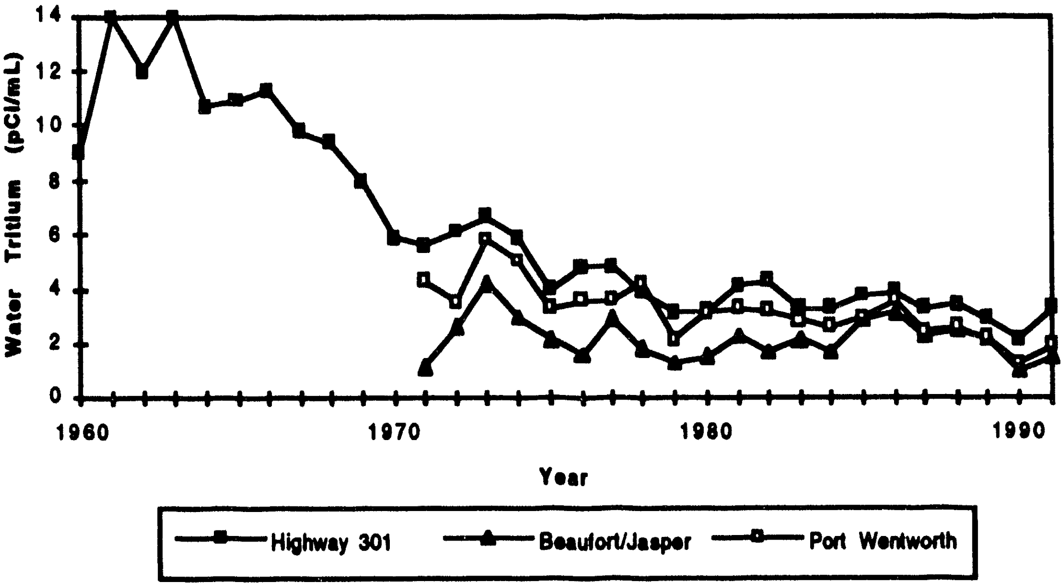


Figure 3.46 Tritium Concentrations at Highway 301 and Downriver Water Treatment Plants

The amount of time it takes a pollutant, in this case tritium, to leave a surface water system is referred to as a flushing time. The flushing time of an estuary is a crude estimate of how long a conservative pollutant, such as tritium, would remain in an estuary. Flushing time of 2 to 3 days has been calculated for the Savannah River estuary using three different methods (Hayes 1979). The calculational methods usually underestimate the flushing time. Several simplifying assumptions are made, such as the estuary is not stratified and constant source and flow conditions exist (Dyer 1973). If simplifying assumptions are not used to reduce the computational complexity, the calculations are extremely laborious.

Coastal Waters transport and mixing of the Savannah River-seawater mixture is governed by wind, tidal action, interconnecting creeks, coastal currents, fresh water flow, and Gulf Stream meanders. Depending on the local conditions, Savannah River water may be transported up or down the coast or straight out to sea. In the transport process, the Savannah River water is mixed with more coastal water. Eventually it is flushed out to the Gulf Stream.

The mixing of Savannah River water in the local inland marine region around the Savannah River was investigated (Figure 3.47). Surface water samples were collected in the inland marine region around the Savannah River estuary and two surrounding rivers (Coosawhatchie and Ogeechee) to determine the distribution of Savannah River water. (Samples were taken in the same week as the estuarine samples discussed earlier.) The samples were measured for tritium concentration and salt content.

Results from these measurements show the presence of tritium throughout the local coastal waters. The tritium concentration in a sample can be from any combination of three sources: Savannah River, ocean water, or another local river. This analysis technique is limited because fresh water sources with nearly identical tritium concentrations cannot be distinguished from one another. However, the Savannah River water and ocean water components are clearly discernible, and the fact that other fresh water sources are present can be stated. Identification of the source(s) of the tritium in the water samples required an extension of the tritium-salinity graph that was used for the estuary. The graph in Figure 3.48 was extended to include the additional data from the inland marine waters and other rivers (Figure 3.49). Tritium concentrations are lower in the other two rivers, and the mixing of these river waters with sea water would fall along a mixing line different from the Savannah River line. If only two sources of water were mixing (e.g. a river and ocean), then dilution would follow along that river-ocean water straight line relationship. Tritium-salinity concentration points lying between the two lines represent mixtures from the Savannah River, the other river, and ocean water.

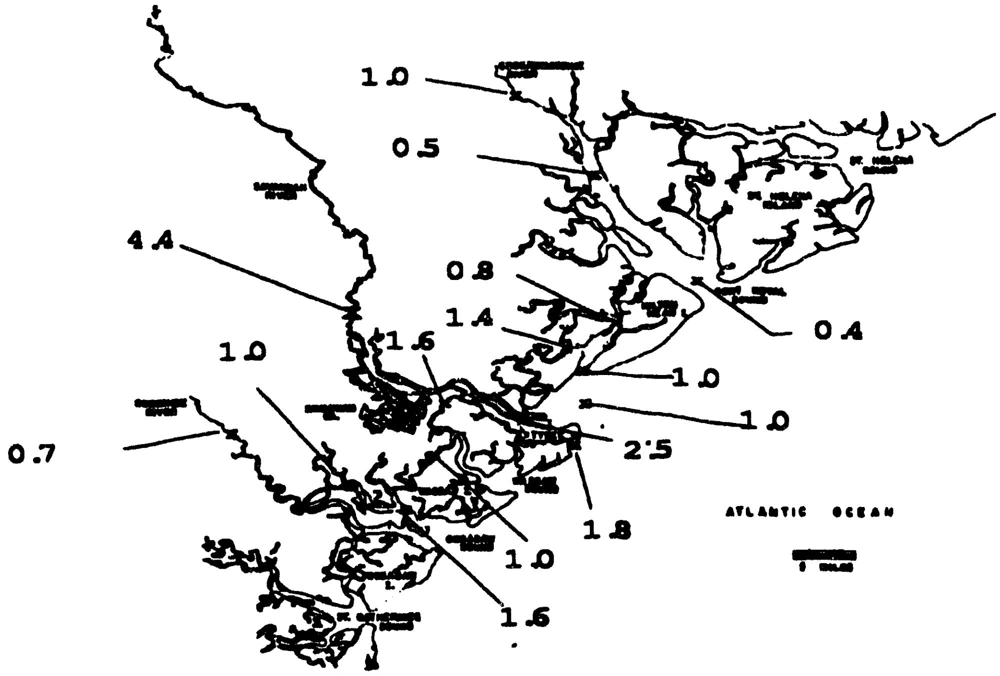


Figure 3.47 Tritium Concentrations in the Savannah River Estuary

Nearly all of the samples represented water from only two sources: one of the rivers and ocean water. Four samples appear to be mixtures of all three sources (identified as AS, BS, AN, BN in the figure). A more detailed analysis using tritium-salinity relationships showed that the two samples north of the Savannah River had nearly the same composition, and the results were averaged: estuary 74% ocean water, 12% Savannah River, and 14% other river water (this analysis method cannot distinguish the difference between the Ogeechee and Coosawhatchie River sources). The samples to the south had two different compositions. The AS sample was 29% ocean water, 14% Savannah River water, and 57% Little Ogeechee River water. The other sample, taken about 3 km seaward, was 64% ocean water, 26% Savannah River water, and 10% Little Ogeechee water. These results show that Savannah River water spreads into the local region and undergoes considerably more dilution in its transport to the coastal waters.

Savannah River water is eventually flushed to the Gulf Stream and transported out of the southeast coastal region. Estimates of the flushing time from the coastal waters vary from 2 to 3 months, depending on the calculation method used (Atkinson, Blanton, and Haines 1978). The flushing time calculated using river input and coastal freshwater volume is 2.7 months. The fresh water volume along the coast is estimated from salinities and total coastal water volume. A second method involving Gulf Stream meander frequency and typical coastal water entrainment dimensions produced an estimate of 2 to 3 months (Atkinson, Blanton, and Haines 1978). These estimates show that freshwater in the coastal area is moved out to the Gulf Stream where it is entrained by the large flow of the Gulf Stream (about 1 billion ft^3/s).

After the coastal water is entrained by the Gulf Stream waters, the tritium is further diluted as it becomes part of the complex North Atlantic Ocean circulation system. Probably all of the tritium will decay while it is in the North Atlantic circulation system.

SRS Surface Water Tritium Releases and Transport

Tritium accounts for more than 98% of the radioactivity in the Savannah River. From 1954 to 1991, about 1.5 million Ci of tritium of SRS origin were released to the Savannah River (Table 3-4). Of this original release, about 59% has decayed to helium and most of the other 41% is in the North Atlantic Ocean circulation system.The sources of tritium in SRS surface waters include direct releases from SRS facilities and migration of tritium primarily from the F- and H-Area seepage basins, the Burial Ground, and the K-Area containment basin. Migration occurs when tritium that has been released to these earthen basins in previous years reaches onsite streams via shallow groundwater that crops out into the streams. Since the mid-1970s, migration has accounted for most of SRS tritium releases to surface waters. A detailed discussion on the migration of tritium from various facilities is presented in the following sections.

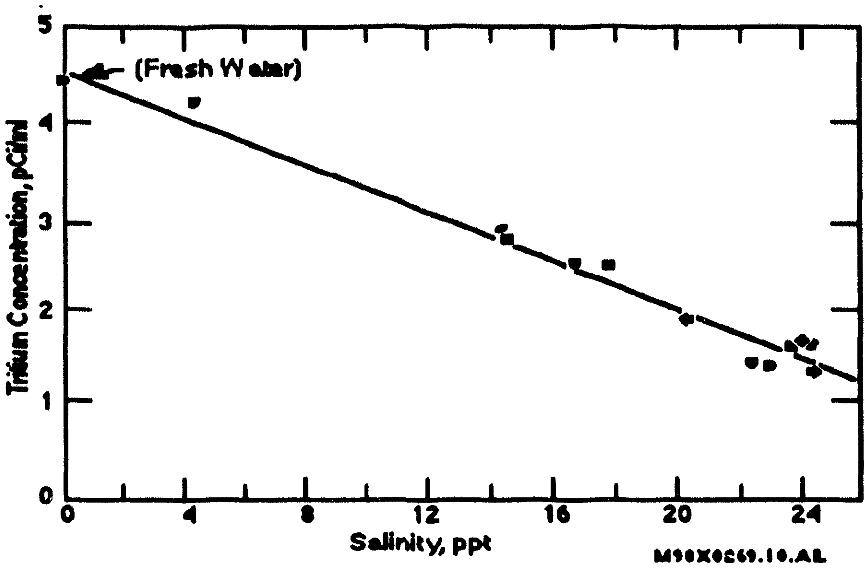


Figure 3.48 Tritium-Salinity Relationship in the Savannah River Estuary

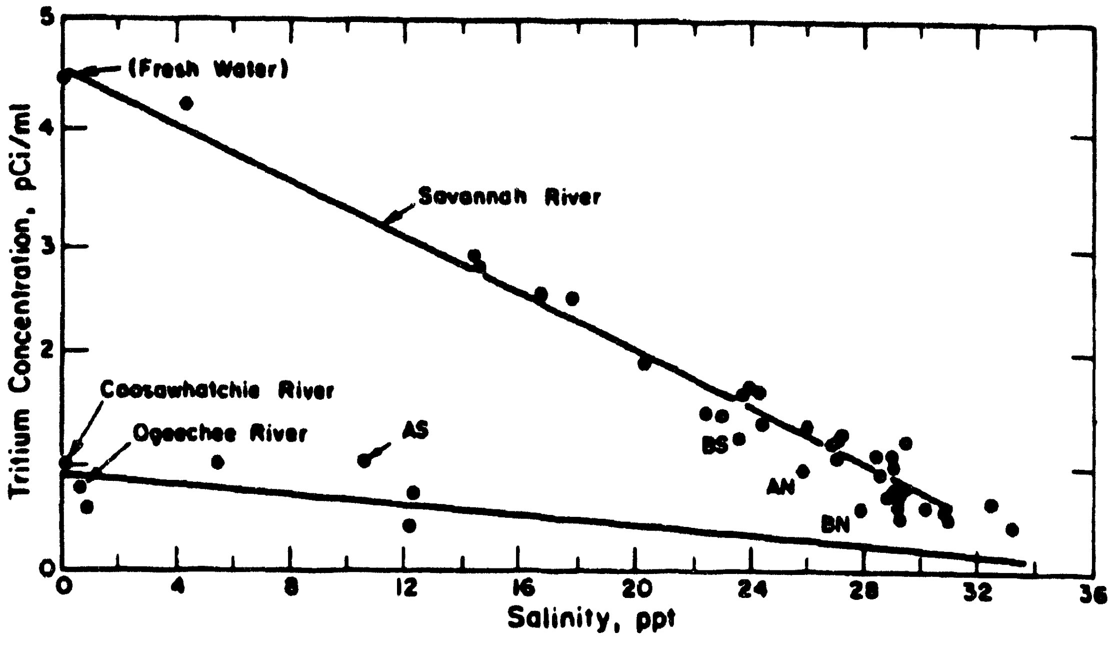


Figure 3.49 Tritium Salinity Relationships in Coastal Waters

Impact of Tritium on the SRS Groundwater System

Introduction

There is no indication that the tritium contamination in shallow groundwater aquifers at SRS has reached the public zone. The tritium in groundwater is generally confined to specific locations under waste management operating areas from which it travels toward surface streams with the normal flow of groundwater.

Primary factors in the confinement of the tritium in groundwater are the size of the site and the local hydrological conditions. Because the contaminated areas are located near the center of the 753-km^2 site, there is a buffer zone of sufficient size to contain the tritium within the site boundaries until it crops out into a site stream or decays to stable helium.

Tritium in groundwater results from past waste disposal practices that were consistent with general industry methods from the 1950s to the early 1980s. Sources of tritium in groundwater are principally wastewater released to earthen seepage basins, buried solid wastes, and residues and leachates that have percolated through the soil to the upper groundwater aquifers. SRS waste disposal practices significantly improved in the late 1980s with the phaseout of seepage basin usage in all nonreactor facilities and with the enhanced packaging of tritium-containing wastes that are buried.

Tritium entering the groundwater system is transported downgradient, forming a plume within the groundwater. This type of movement within the groundwater flow system is referred to as ***advection (or convection)***. Other mechanisms also influence the movement of tritium through the flow system. One example is ***hydrodynamic dispersion***, which is a combination of mechanical mixing and molecular diffusion. These two dispersive processes cause a spreading of the tritium in groundwater over a larger area than advection alone could produce, resulting in a dilution of the tritium concentration. The ***mechanical mixing*** results from velocity differences produced by heterogeneities in the physical system through which the groundwater moves and the amount of winding and twisting in the path traveled. ***Molecular diffusion*** occurs as the result of the kinetic activity and is usually much less important than the effect of mechanical mixing. Essentially, tritium moves as a nonreactive constituent within the groundwater system while decaying with time.

A comprehensive assessment of hydrological conditions and the status of groundwater contamination was recently completed for each SRS environmental site containing radioactivity. These assessments are contained in a series of environmental information documents that were completed from 1985 to 1986. A brief summary of the data contained in these documents plus additional relevant information from the annual SRS Environmental Reports will be provided in this section. The referenced environmental documents contain additional information.

The sources of groundwater tritium, measurements of tritium in groundwater, transport of groundwater tritium, modeling efforts, and ultimate fate of the tritium will be discussed in the following sections for each groundwater tritium source at SRS. Unresolved issues will also be addressed where relevant.

The SRS Groundwater System

The Coastal Plain groundwater system at SRS is very complex. The geology at the site indicates a past environment where many interbedded clay, silt, and sand layers were deposited in an intricate three-dimensional flow system. The groundwater system can be divided into six main units, which are composed of several separate geologic layers (Figure 3.50 and 3.51).

At the base of the groundwater system is a dense clay which retards the movement of water (an aquitard). Overlying this layer is the region of loosely packed sediments laid down during the Cretaceous period (formerly referred to as the Tuscaloosa). The Cretaceous unit is an excellent source of water and can sustain yields of 63 L/sec.

The upper 6-m section of the Steel Creek layer and the entire Ellenton layer are composed of thick silty clay material that forms a 30-m leaky aquitard unit above the Cretaceous aquifer. Overlying this aquitard is a tertiary-age aquifer. This unit is approximately 30-m thick,

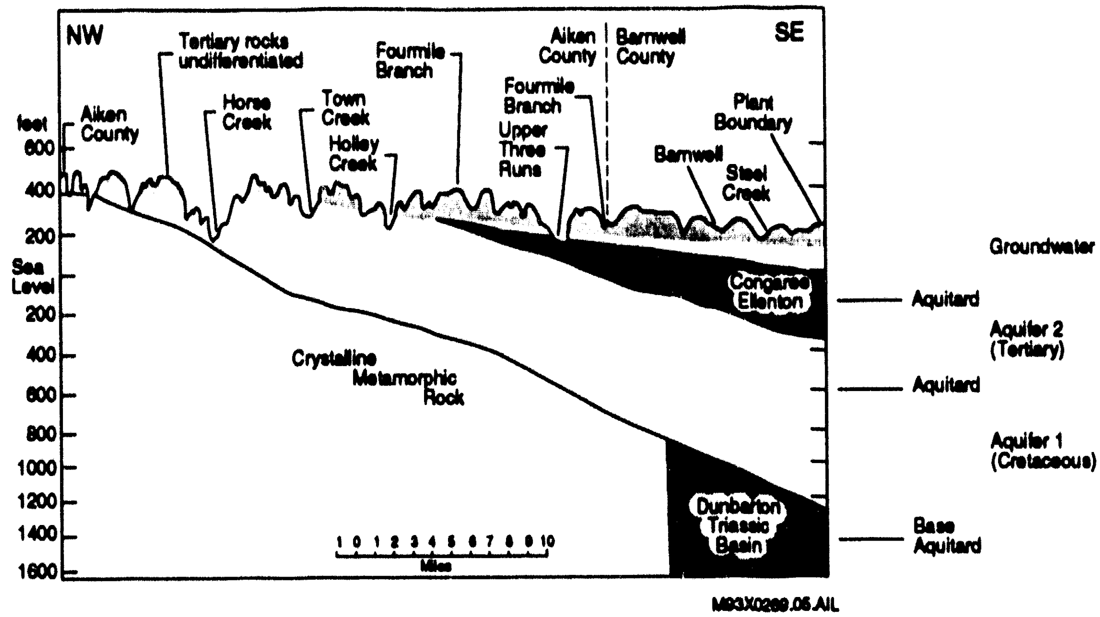


Figure 3.50 Geologic Cross-Section Showing the Main Aquifers

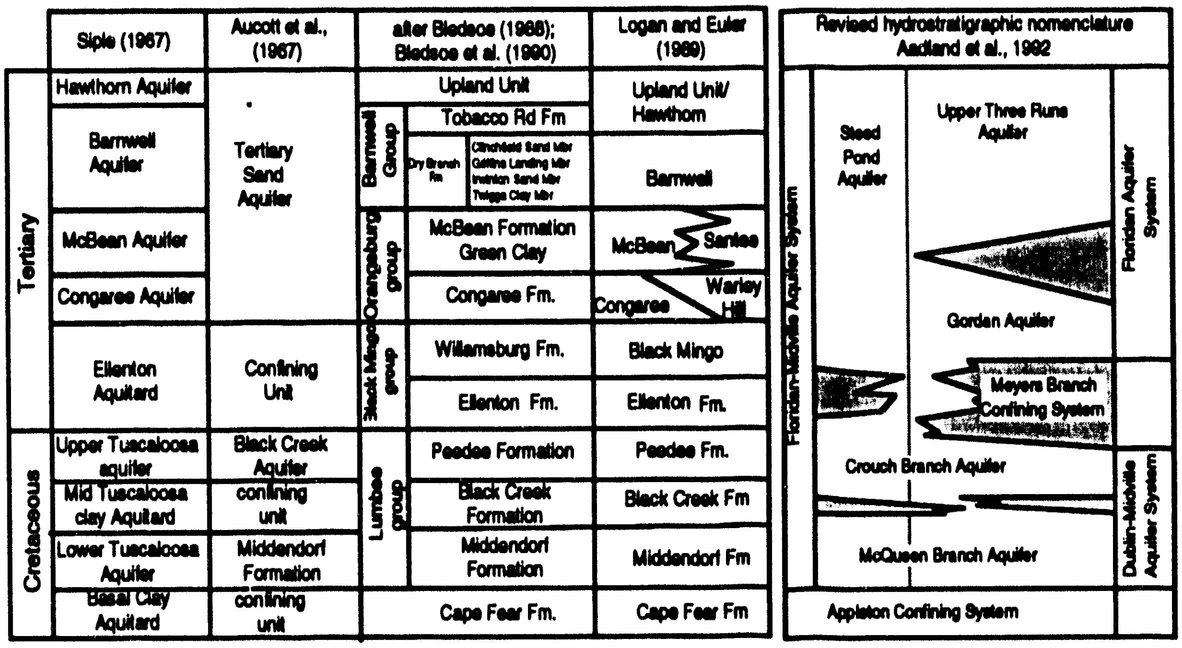


Figure 3.51 Geologic Cross-Section Showing the Stratigraphic Formations as used at SRS

consisting predominantly of fine-to-medium and medium-to-coarse well-sorted sands. The Tertiary aquifer is not nearly as prolific as the Cretaceous aquifer below it but can sustain yields up to 6.3 L/sec in water supply wells.

Overlying the Tertiary aquifer is a 15-m depositional layer which acts as a leaky aquitard unit. This unit is often referred to as the "green clay", a local designation in early documents because of the color of the glauconite interbedded in this layer. Overlying this unit is the water table unit which extends to the surface. The water table unit is not an aquifer by strict definition because of its low water-producing capabilities. Several wells in the water table at SRS cannot produce 0.06 L/s for a substantial period of time. Nevertheless, it is a distinct and important groundwater unit because any aquifer contamination from tritium or other materials entering at the surface must flow through the water table unit before entering other groundwater units or discharging to surface waters. The thickness of the water table varies greatly across the site due to the changing topography. It can be as low as zero where soil has been eroded away by a stream or as deep as 61 m.

In some areas it is necessary to modify the units defined above because of local features. For example, to effectively describe the groundwater system in the northern part of the SRS, it is necessary to divide the water table unit into three units consisting of an aquitard (referred to locally as the "tan clay") between two units with groundwater characteristics like the single water table unit. At K-, L-, and P-Reactor areas, in the southern portion of the site, evidence from core descriptions and geophysical logs indicate that the tan clay is very sporadic and thin in these areas and is, therefore, not a consistent unit.

F-Area Seepage Basins

The F-Area seepage basins are located in the central portion of SRS, west of Road C and opposite Road E (Figure 3.52), approximately 8 km from the nearest site boundary. The basins are at an elevation of about 85 m and approximately 610-m northwest of Fourmile Branch and 1830-m southwest of Upper Three Runs Creek. The bottom surface of the three F-Area basins covers approximately 22,000 m^2. The three F-Area basins have a combined capacity of about 109,000 m^3 at overflow conditions. From 1955 to 1988, the F-Area seepage basins routinely received wastewater containing some tritium from the F-Area separations facilities. The purpose of these basins was to delay the release of tritium to surface streams by using the soil column and groundwater pathways. The wastewater entered the basins through a single underground pipeline into Basin 1. Wastewater then flowed from Basin 1 to Basin 2 and Basin 3 through underground pipelines. The average daily flow to the F-Area seepage basins, measured upstream of the basins in 1985, was 411 m^3/day. The basins were taken out of service in December 1988 and no longer receive wastewater.

Groundwater has been monitored for tritium since basin startup in 1955. Tritium accounts for 99% of the radioactivity in the basins. The cumulative original release of tritium is estimated to be 300,000 Ci, and the decay-corrected release through 1991 is 120,000 Ci. Monitoring programs have defined the plume of tritium emanating from the F-Area seepage basins in the water table (Figure 3.53). This plume was investigated to determine its horizontal and vertical extent. Figure 3.54 shows the results of this investigation. Recharge from rainfall drives the maximum concentrations below the water table in the area between the basins and Fourmile Branch. Discharge to the creek then permits the maximum concentrations to rise again to the water table in the vicinity of the stream. This explains the outcrop concentration of 40,000 pCi/L of tritium within the area between the 1000 and 10,000 pCi/L contours shown in Figure 3.54. The average tritium concentrations from wells located around the seepage basins for the years 1982 to 1991 are given in Table 3-5. Water flow at the basins is generally downward through the unsaturated zone to the water table. When this vertical flow from the seepage basin reaches the water table, the flow path is generally downward and horizontal toward Fourmile Branch. The average gradient between Basin 3 and Fourmile Branch is approximately 0.014 m/m.

Most of the flow from the F-Area basins to Fourmile Branch is from Basin 3. The first wells, in what was later defined as the main flow path, were installed during 1962. One of these, well F19 (Figure 3.55), had very low concentrations of tritium until July 1963. The concentration increased from 74 pCi/mL in June 1963 to 6600 pCi/mL in July 1963 and continued to rise until it reached 18,600 pCi/mL during November 1963. No tritium was released to the basins between March 1957 and March 1959. If the increase represents tritium releases that began in March 1959, the travel time of 52 months over a distance of 240 m results in 55 m/yr velocity.

Tritium was detected in Fourmile Branch, 490 m from Basin 3, in April 1967. If this tritium is assumed to have left the basin during 1959, the flow velocity is 61 m/yr. The tritium measured in Fourmile Branch remained constant during 1968, 1969, and 1970, increasing the likelihood that the detected tritium left the basin following the shutdown between 1957 and 1959. However, since tritium had been released to the basin during 1955 when the basins were placed in operation, the detected tritium may represent this plume. This approach would result in a flow rate of 41 m/yr, which is more in line with the results of calibrated flow modeling that suggests a flow rate of about 20 m/yr.

Modeling the transport of tritium by groundwater from the F-Area seepage basins to the surface streams and then the Savannah River results in a predicted peak tritium concentration of 0.081 pCi/mL at the time of basin closure.

Measurements of migration from the F-Area Seepage Basins to Fourmile Branch indicate the release rate has not decreased between closing of the basins in 1988 and 1991. This is consistent with the previously calculated velocities of the groundwater. Modeling studies of the transport of tritium by groundwater from the F-Area Seepage Basins to Fourmile Branch suggest that releases to the stream should decrease to less than 1000 Ci/yr (20% of 1991 releases) by the year 2000.

Table 3-5. Tritium Activity in F-Area Seepage Basins Wells

	Annual Average Concentration(pCi/mL)									
Well	**1982**	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**
F-9	280	910	2,300	6,800	-	4,830	-	-	-	-
F-10	-	-	36,000	39,000	44,000	60,500	32,500	1,257	-	-
F-14	16,000	15,000	27,000	41,000	12,000	6,430	-			114
F-15	1,900	940	3,200	1.300	6,400	1,730	3,130	2,654	471	490
F-16	13,000	12,000	23,000	32,000	26,000	7,160	6,545	-	128	247
F-17	220	390	61	730	2,000	1,260	2,910	1462	1200	547
F-18	33	32	48	5,100	42,000	-	-	-	-	-
F-18A	-	-	-	-	-		7,368	19,858	2,887	-
F-19	-	130	36	190	-	13,100	-	-	-	-
F-23	3,200	64	260	-	-	-	-	-	-	-
F-24	28	25	44	44	41	40	45	20	10	-
F-25	1,700	1,100	140	79	37	42	67	25	12	35

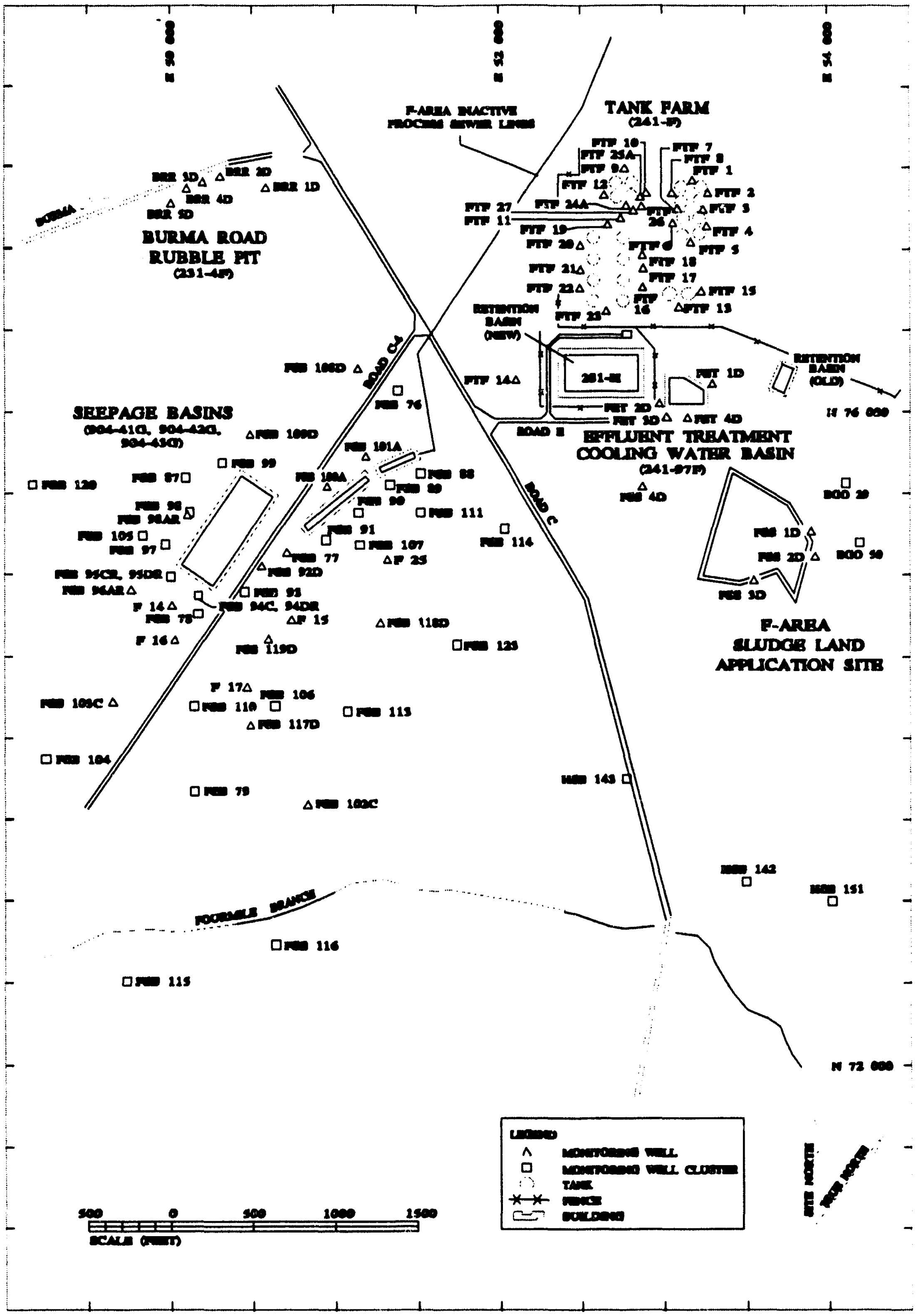


Figure 3.52 Location of and Placement of Wells Around the F-Area Seepage Basins

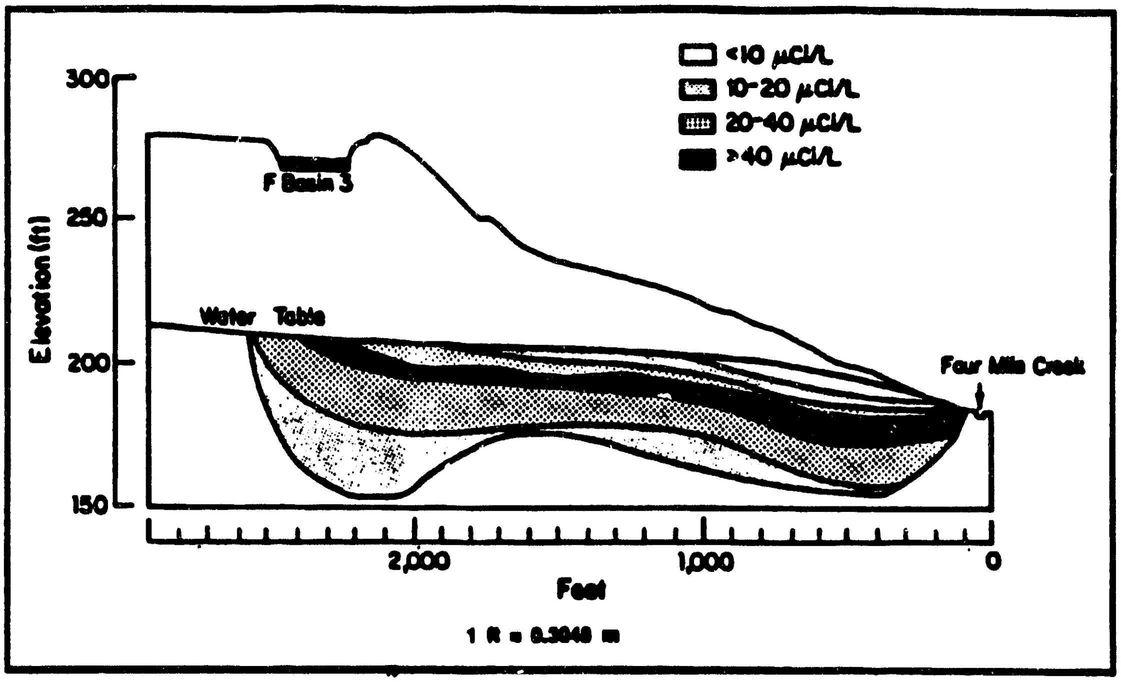


Figure 3.53 Vertical Distribution of Tritium in Groundwater along a North-South Cross Section under F-Area Seepage Basin 3

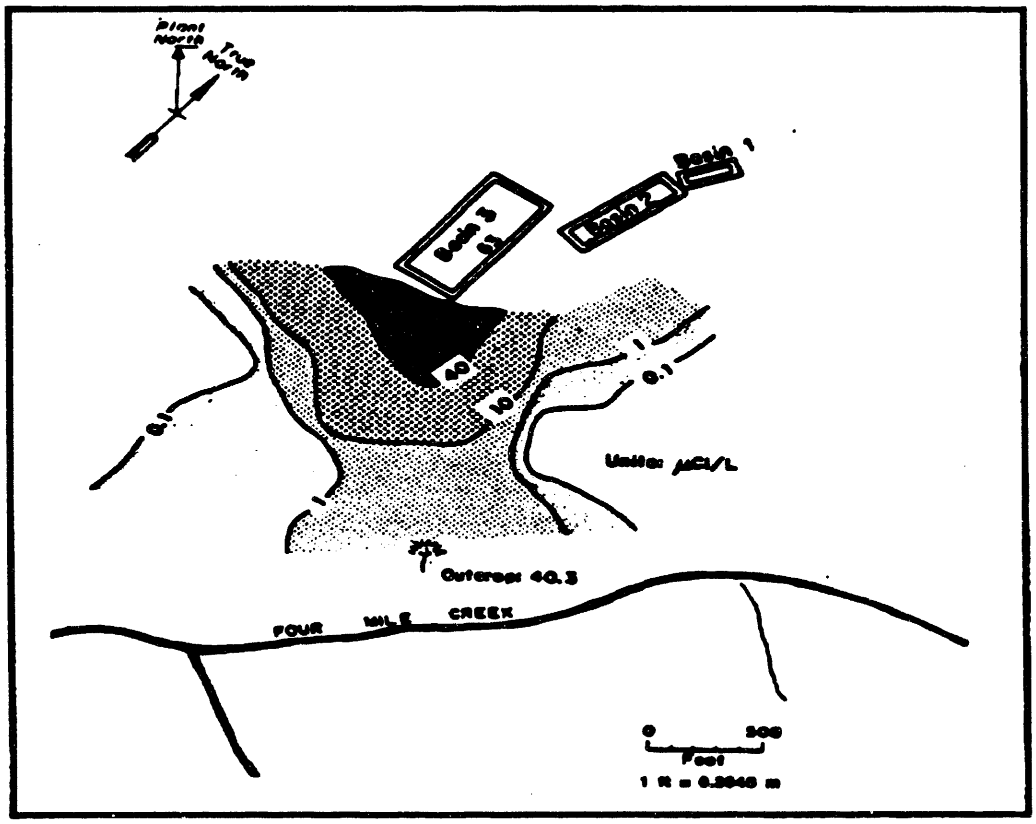


Figure 3.54 Horizontal Spread of Tritium Plume Downgradient from the F-Area Seepage Basin 3

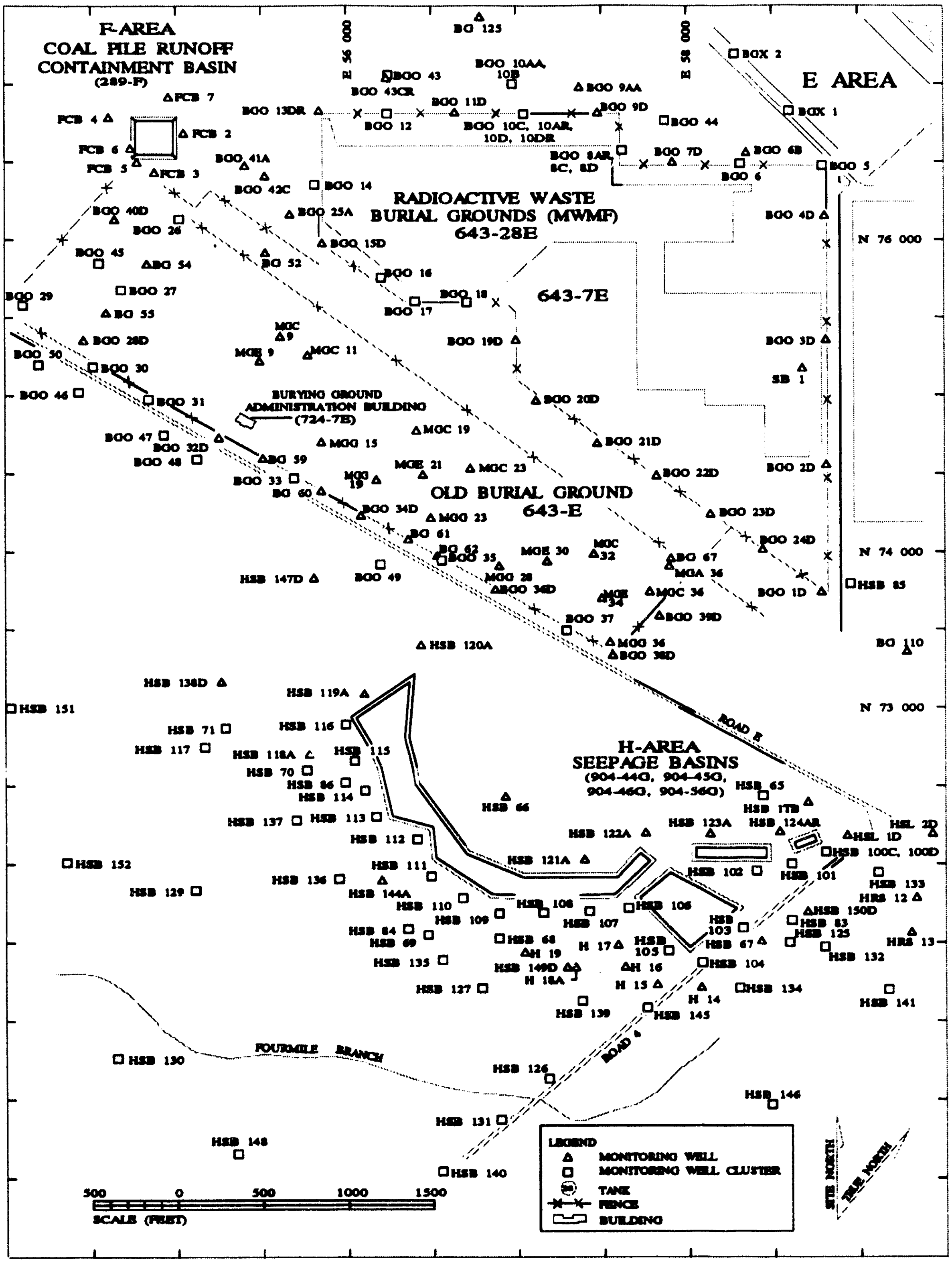


Figure 3.55 Locations of H-Area Seepage Basin and Wells Field

H-Area Seepage Basins

The H-Area seepage basins are located in the center of SRS, southwest of Road E and north of Road 4 (Figure 3.55), approximately 10 km from the nearest plant boundary. Basin 3 has been inactive since 1962. Basins 1, 2, and 4 became inactive in December 1988. The four basins had a combined floor area of approximately 42,700 m^2. The three basins that operated until 1988 had a combined capacity of approximately 140,000 m^3 at overflow conditions. Wastewater to these basins entered through a single underground pipeline into Basin 1, then traveled from Basin 1 through four pipelines into Basin 2 and then to Basin 4. The purpose of these basins was to use the soil column and groundwater pathways to delay the release of tritium to surface streams.

Since 1955, the H-Area seepage basins have received wastewater containing cooling water from the tritium facilities, other H-Area operations, retention basin transfers, the receiving basins for offsite fuel, and two tank farm waste evaporators. The average daily flow into the basins for 1985 was 577 m^3/day. Radioactive releases to the seepage basins, as monitored by the Environmental Monitoring Section, are greater than 99% tritium. First measurements were made in 1955 and the cumulative original release was approximately 330,000 Ci through 1988. The decay corrected release is 150,000 Ci.

Flow out of the seepage basins is downward (approximately vertical) through the unsaturated zone to the water table. This vertical flow through the unsaturated zone resulted in a groundwater mound beneath Basin 4. The horizontal component of groundwater flow from beneath the H-Area seepage basins is toward Fourmile Branch or the H-Area effluent stream, a tributary to Fourmile Branch. The gradient between Basin 4 and Fourmile Branch ranges between 0.02 and 0.033 m/m, but this rate includes an increased gradient as the stream is approached. The gradient toward Fourmile Branch in the immediate vicinity of the basins themselves is approximately 0.010 to 0.018 m/m.

The water table at H-Area seepage basins is 4.6 to 7.6 m below ground level and outcrops at Fourmile Branch from 122 to 427 m south of the basins. Groundwater monitoring has been performed since the basins were placed in operation. The annual average tritium concentration in the groundwater at the H-Area seepage basins from 1982 to 1991 is shown in Table 3-6. The locations of the wells sampled are shown in Figure 3.55. Investigations using monitoring wells have defined plumes of tritium emanating from the H-Area seepage basins in the water table. These plumes are in the form of fingers moving from the basins toward Fourmile Branch, as shown in Figure 3.56. Aquitards below the basins delay, but do not prevent, the vertical movement of groundwater. Tritium has been found in wells HSB 68A and 84B downgradient from the seepage basins. This tritium is beneath the aquitards in the McBean Formation. Tritium that enters the Gordon Aquifer will discharge to Upper Three Runs Creek; however, the travel time is about three times the rate to Fourmile Branch. The aquitard below the Gordon Aquifer prevents vertical movement, and the hydraulic conductivity of the aquifer is such that the predominant flow direction is horizontal toward Upper Three Runs Creek.

The result of this hydrogeology is that tritium moves downward through the unsaturated zone to the water table. Once in the water table, tritium moves horizontally to Fourmile Branch and vertically into lower aquifers where it moves to Fourmile Branch and Upper Three Runs Creek and ultimately to the Savannah River. Groundwater travel time from the seepage basins ranges from approximately 2 years to greater than 50 years, depending upon the exact pathway followed. Tritium presently reaching Fourmile Branch appears to be dominated by preferential flow through the shorter travel time pathways. The amount of tritium released to Fourmile Branch in 1991 was less than the release at the time of closure in 1988 (0.015 pLi/yr). Models of the groundwater system predict that the releases will be less than 15% of the 1988 release rate by the year 2000.

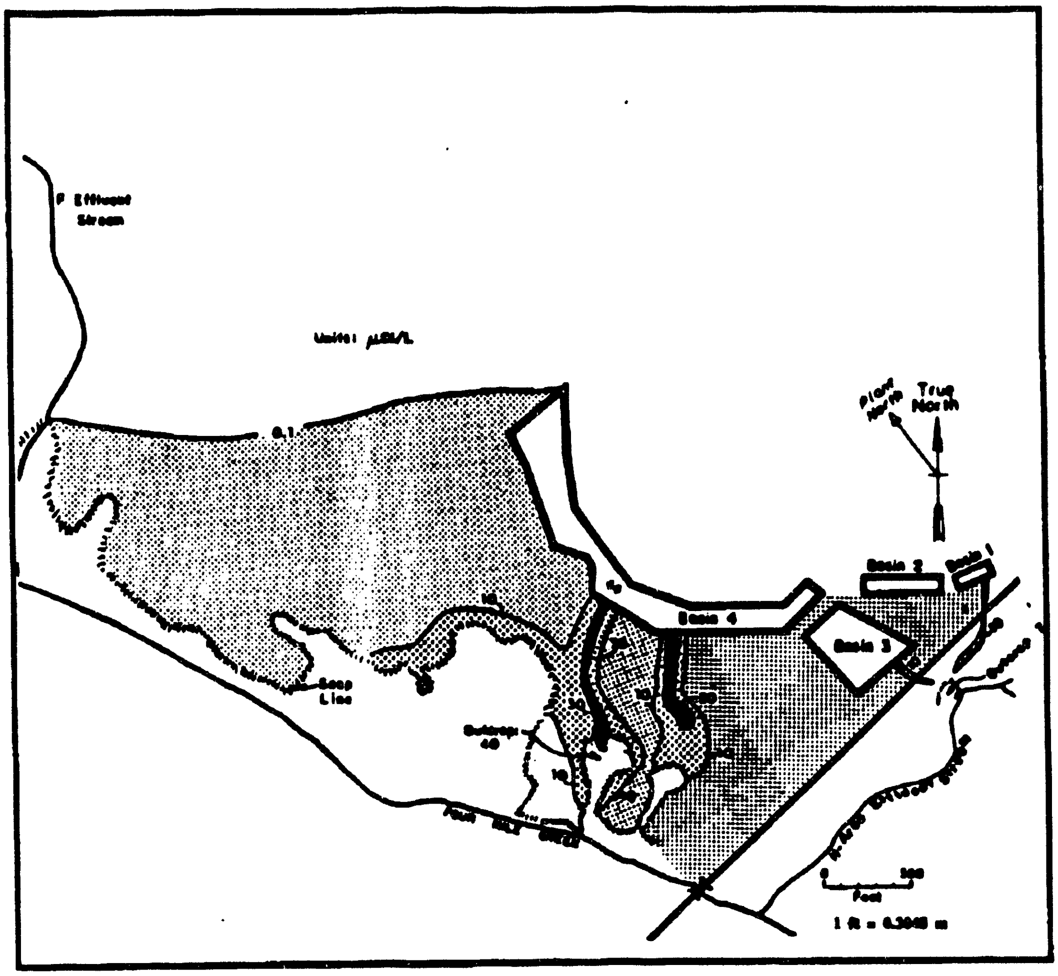


Figure 3.56 Tritium Plumes from H-Area Seepage Basins

Table 3-6. Tritium Activity in H-Area Seepage Basin Wells, Annual Average (pCi/mL)

	Year									
Well	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
H2	19,000	18,000	50,000	31,000	23,000	22,900	-	-	-	-
H4	4,400	1,400	46,000	30,000	18,000	14,900	61,900	-	-	-
H6	41,000	33,000	28,000	47,000	48,000	27,500	38,900	40,505	-	-
H7	120	94	120	450	1,100	176	1,112	3,103	-	-
H8	3,900	5,000	5,100	4,900	6,800	5,470	4,483	5,756	-	-
H9	3,000	3,400	4,900	5,700	6,300	5,070	3,865	4,180	-	-
H10	4,100	3.400	3,000	3,000	2,600	2,170	1,873	1,190	-	-
H11	330	120	96	180	190	510	3,475	4,156	-	-
H12	1,000	4,900	9,100	2,300	1,300	475	319	-	-	-
H13	560	170	510	1,000	2,900	835	3,590	3,582	1,572	-
H14	1,000	640	760	3,500	5,100	2,270	4,975	5,826	3,875	1,317
H15	55	67	65	64	58	56	75	-	8	25
H16	59	74	63	140	110	66	58	51	876	25
H17	75	75	62	60	66	76	72	44	21	21
H18	62	62	120	60	-	-	-	-	-	-
H18A	-	-	-	-	33	54	64	30	22	20
H19	5,300	790	360	1,500	-	1050	1,170	-	-	40
BG 10	-	-	-	38,000	21,000					

Solid Waste Disposal Facility

The Solid Waste Disposal Facility is a radioactive waste burial ground located near the center of the SRS. The Solid Waste Disposal Facility (SWDF) is used to store all radioactive solid waste processed at the site, as well as periodic shipments from other DOE facilities. Tritium is one of the primary radionuclides contained in the SWDF. Between 1952 and 1985, an estimated 2400 m^3 of tritium-contaminated solid radioactive waste was stored.

The primary forms of tritium-containing waste in the SWDF are the waste crucibles from the tritium extraction process, other process vessels, and the job control waste containing tritium. The waste crucibles are steel cylinders containing lithium/aluminum alloy and residual tritium.

Over the years, operations shifted from open trenches to "engineered low-level trenches", improving the isolation of waste from the environment. Beginning in 1987, the open ends of the crucibles were sealed with an epoxy plug to minimize the release of tritium. For this reason, the highest concentrations and fluxes of tritium from the waste are in the groundwater beneath the original burial facility (643-E, see Figures 3.57 and 3.58).

Unlike most other radionuclides, tritium is rapidly leached and moves freely with flowing groundwater. Tritium plumes exist in the groundwater beneath the SWDF and extend to the south toward Fourmile Branch. Tritium concentrations averaged over all grid monitoring wells in 643-E for the years 1974-1984 are listed in Table 3-7, along with estimates of the total amount of tritium in the groundwater. Tritium concentrations obtained from the grid monitoring wells in 643-7E and 643-28E have increased steadily since 1981.

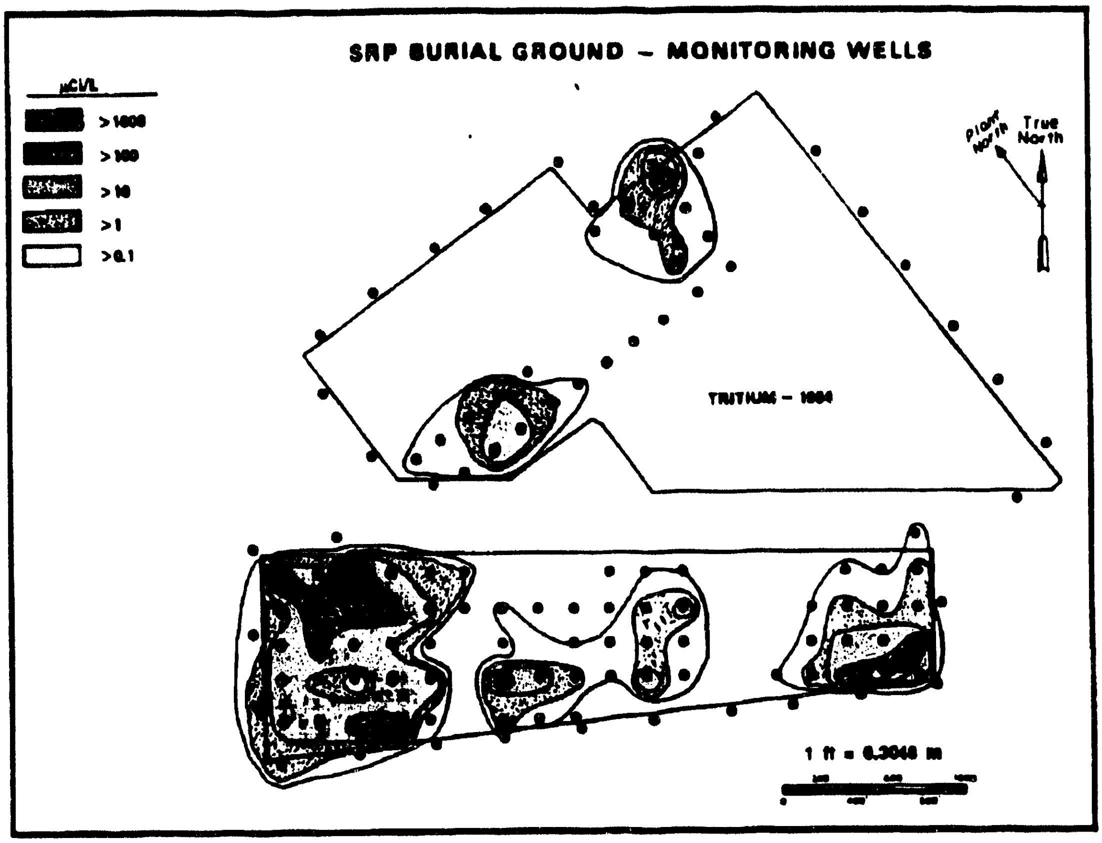


Figure 3.57 Tritium Zones in Groundwater at the Burial Ground

Table 3-7 Estimates of Tritium in Groundwater Beneath 643-E.

Year	Average Concentration (pCi/L)	Tritium in 643-E Plume (Ci)
1974	31.6	13,300
1975	59.8	25,200
1976	58.0	24,400
1977	59.9	24,800
1978	90.4	38,100
1979	65.8	27,700
1980	91.6	38,600
1981	88.8	37,400
1982	57.7	24,300
1983	34.7	14,600
1984	87.5	36,800

Estimates of the total amount of tritium in the groundwater beneath portions of 643-7E and 643-28E are shown in Table 3-8. For 1984, the estimate was 5600 Ci of tritium. In addition, substantial amounts of tritium are suspected in groundwater beneath portions of the SWDF not monitored by grid wells (see Figure 3.58). Most of these areas are not yet amenable to well installation because of active operations. As an indication of the amounts of tritium in the eastern side of 643-7E and 643-28E burial grounds, a special study in 1983 of a 2028-m^2 site in that area showed approximately 2000 Ci of tritium in the groundwater.

Table 3-8 Annual Average Concentrations of Tritium in 643-7E and 643-38E Grid Wells

Year	Annual Average Concentration (pCi/L)	Total Tritium in Plume (Ci)
1981	600	200
1982	2,800	900
1983	8,800	2,800
1984	18,000	5,600

The SWDF is located in an interstream area between two tributaries of the Savannah River: Upper Three Runs Creek to the north and Fourmile Branch to the south. The sediments below the burial ground are saturated with groundwater, beginning at a depth of approximately 12 m. Part of this groundwater flows to Fourmile Branch and part to Upper Three Runs Creek. Measurements in cluster wells show that the pressure in sediments in the McBean Formation is lower than the pressure above and below. Thus, water flows to the Gordon Aquifer Formation from both above and below, limiting the depth of circulation of water from the burial ground. Of particular hydrogeologic significance are the confining beds, which retard the vertical movement of the groundwater beneath the burial ground.

The difference in elevation between Upper Three Runs Creek and Fourmile Branch influences the flow of groundwater. The bed of Upper Three Runs Creek has eroded approximately 16.8 m deeper than that of Fourmile Branch near the burial ground area, and the difference in stream bed elevation has displaced the water table divide about 300 m toward Upper Three Runs Creek. The water table gradient from the southern edge of the 643-E Burial Ground to Fourmile Branch is 0.01 m/m; the gradient from the northern boundary of the 643-7E Burial Ground to Upper Three Runs Creek is 0.02 m/m. The gradient in the Gordon Aquifer from the Burial Ground to Upper Three Runs Creek is approximately 0.003 m/m.

Although sediments in the SWDF area are highly heterogeneous, flow over a distance apparently tends to reduce the effect of this variability. Sixteen groundwater velocity tritium tracer tests have been made throughout the area over a period of several years. Simultaneously, water table gradients were observed. A least square linear regression analysis of the data shows a strong correlation between water table gradient and groundwater velocity. The average velocity varies at the rate of 14.5 m/yr/1% gradient, with a correlation coefficient of 0.988.

Water flowing through porous media, such as the sediments of the SWDF, exhibits a distribution of velocities in the small flow channels due to the heterogeneity of the media and to a friction gradient extending from the channel walls out to the center where friction is least. As a result, a tracer released into the system will assume a normal distribution in the longitudinal direction as flow proceeds. The leading edge of the distribution will precede the centroid by some multiple of the centroid depending on pore and grain characteristics.

Results of a flow experiment in the southwest corner of the SWDF are shown in Figure 3.59. Three tritium sources, (two irradiated crucibles at each of three burial locations) were buried in 1957 and observed at intervals until 1970. The centroid was 76 m downgradient, but the leading edge had not arrived at detection wells 80 m beyond the centroid. The leading edge was moving not more than twice the average rate. The conservative estimate to apply to the leading edge is, therefore, twice the average rate.

Applying these rates to observed water table gradients on flow paths originating in the east, middle, and southwest parts of original burial area (643-E) produces results shown in Figure 3.60. The figure shows the estimated time required for tritium released at the head of the flow path to move to the outcrop. The average velocities for three flow paths are 12 m/yr, 18 m/yr, and 24 m/yr. These velocities are consistent with the detailed horizontal (and vertical velocities) that resulted from calibrated groundwater models.

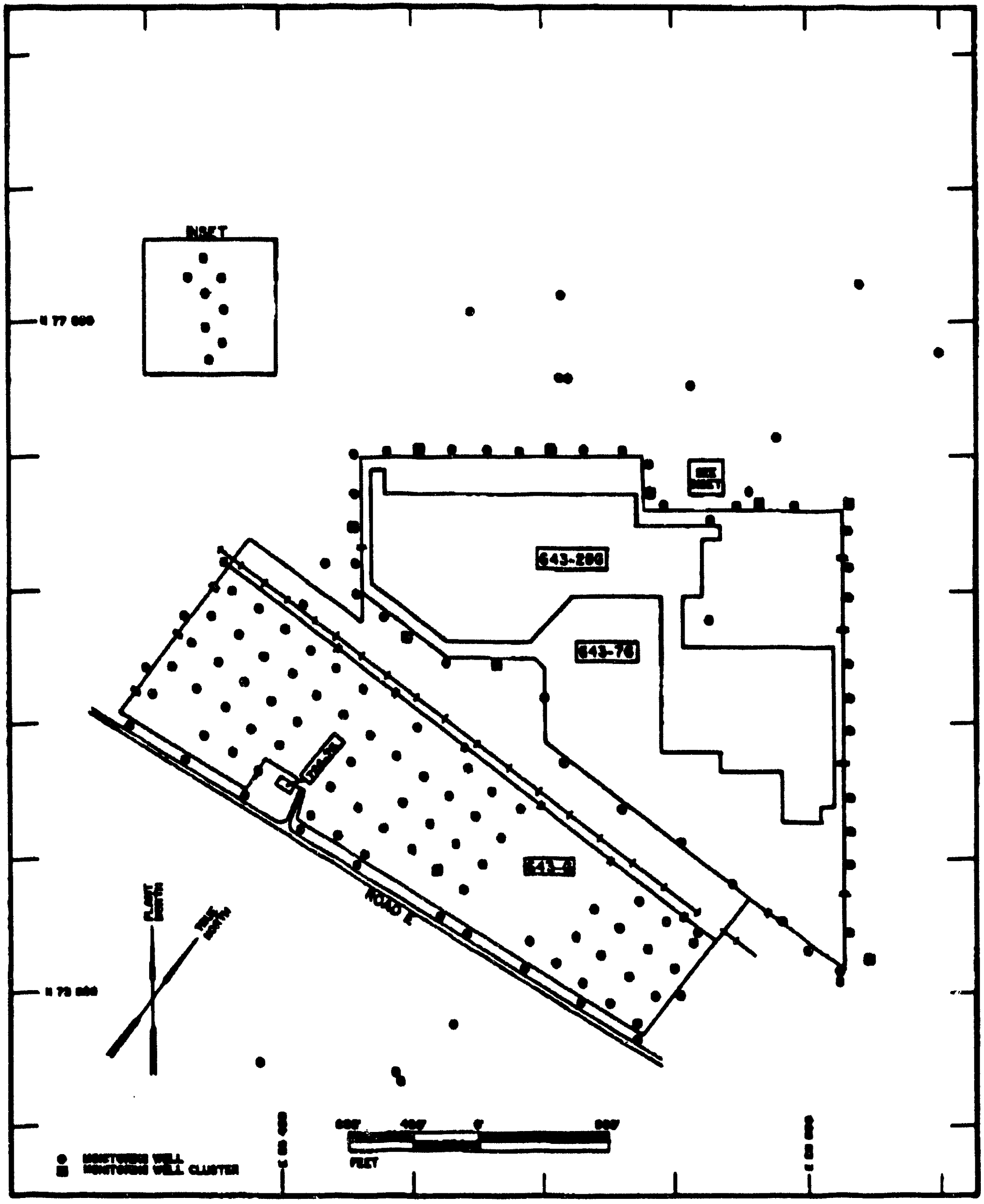


Figure 3.58 Schematic of Grid Wells in the Low-Level Waste Burial Ground

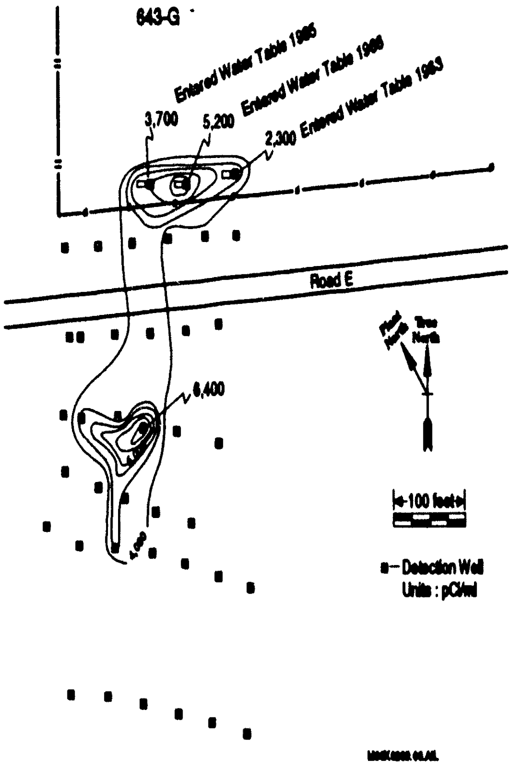


Figure 3.59 Tritium from Spent Melt Test in Groundwater in October 1970

It was estimated that 4.5 million Ci of tritium had been interred in the Burial Ground since the beginning of SRS operations to the present (1991). After decay, it is estimated that 1.5 million Ci remains which is leachable and could get to the groundwater. As described previously, tritium fluxes from the original burial area (643-E) are the most significant releases from the SWDF. This is due to a combination of burial practices, amount of tritiated waste received by this facility, and proximity to a receiving stream. Water from the original burial area flows toward the south and west, exiting from the southwest corner of the facility and outcropping in a natural tributary of Fourmile Branch (Albenesius and Fenimore 1779). The burial of crucibles in the southwest corner of 643-E in 1957 and subsequent burials throughout the facility provide a relatively long-term, stable source of tritium to the groundwater. As shown in Table 3-9, monitored tritium releases from the SWDF to the tributary of Fourmile Branch have been relatively constant, with no obvious trend, over the entire period of measurement from 1982 to 1991. During this period releases have ranged from 3,600 to 10,500 Ci/yr with a mean of 5,500 Ci/yr (Looney et al. 1993).

The combination of a relatively large source distributed over a large area and the past history of releases, suggest that tritium releases from the SWDF into Four Mile Branch will remain at elevated levels for a period in the order of 20-100 years, based on the groundwater velocities calculated above and the length of the flow paths (Stone and Christensen 1983). The exact release rates would be expected to remain close to historic levels at first, decreasing slowly through radioactive decay and depletion of the tritium in 643-E.

Reactor Area Seepage Basins

The reactor area seepage basins were constructed and operated, beginning in 1957, to receive low-level radioactive wastewater from disassembly basin purges in R, K, P, C, and L Areas. The basins were constructed on relatively high ground outside the area perimeter fences. The basins in K and R Areas were last used in 1960 and 1964, respectively. The basin in C area was last used in 1986, while the basins in L Area were out of service between 1968 and 1985. From 1965 to the present, the containment basin in K Area was used for the disassembly basin purges.

K-Area Seepage Basins

The location of the K-Area Seepage Basin is shown in Figure 3.61. The K-Area Seepage Basin was used intermittently from 1959 until 1965 at which time it was removed from service. During the period of operation, approximately 5200 Ci of tritium were released to the basin. Although no measurements were made, most of the tritium is believed to have left the basin via the atmospheric or groundwater pathways. The basin is located on a very gentle slope leading to Indian Grave Branch, a tributary to Pen Branch, 710 m to the west of the basin. Monitoring wells were established around the seepage basin in 1984. The levels of tritium activity observed in these wells are relatively low, ranging from 40 to 730 pCi/mL (Table 3-10).

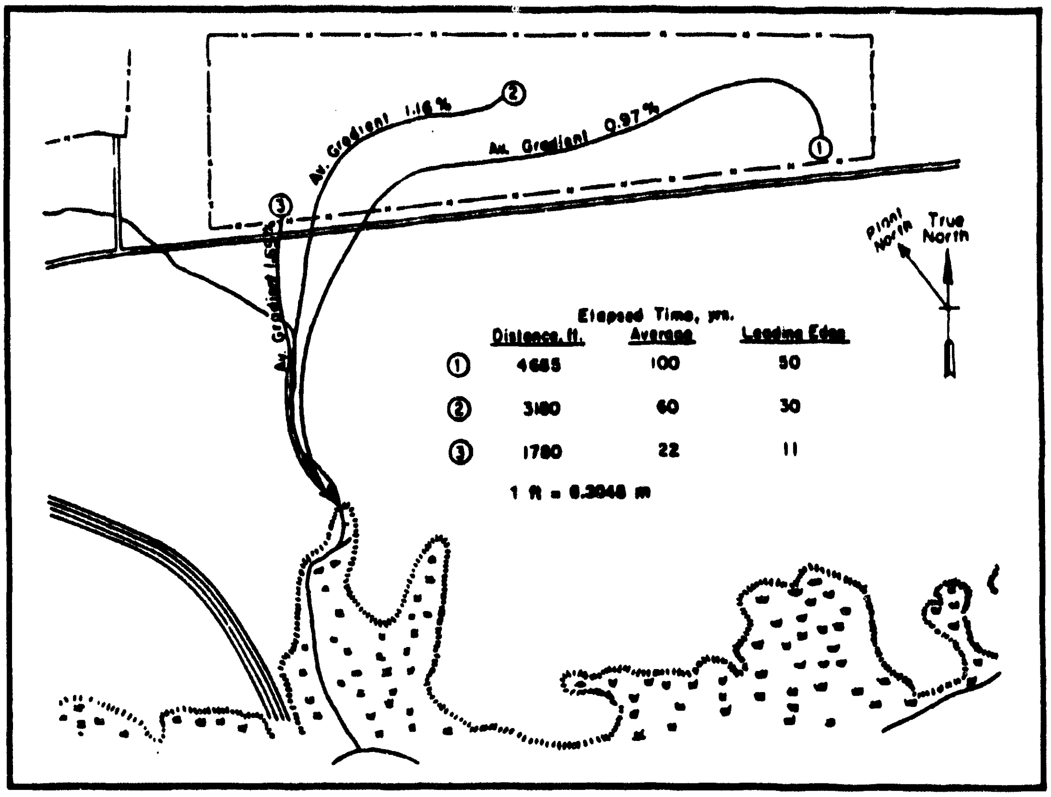


Figure 3.60 Time for Water and Tritium to Travel 643-E Burial Ground Flow Paths

Table 3-9 Releases of Tritium from the Solid Waste Disposal Facility to a Tributary of Fourmile Branch.

Year	Liquid Releases (Curies)
1979	4000
1980	
1981	
1982	4000
1983	4018
1984	10516
1985	7295
1986	5210
1987	6150
1988	3670
1989	3600
1990	4280
1991	6420

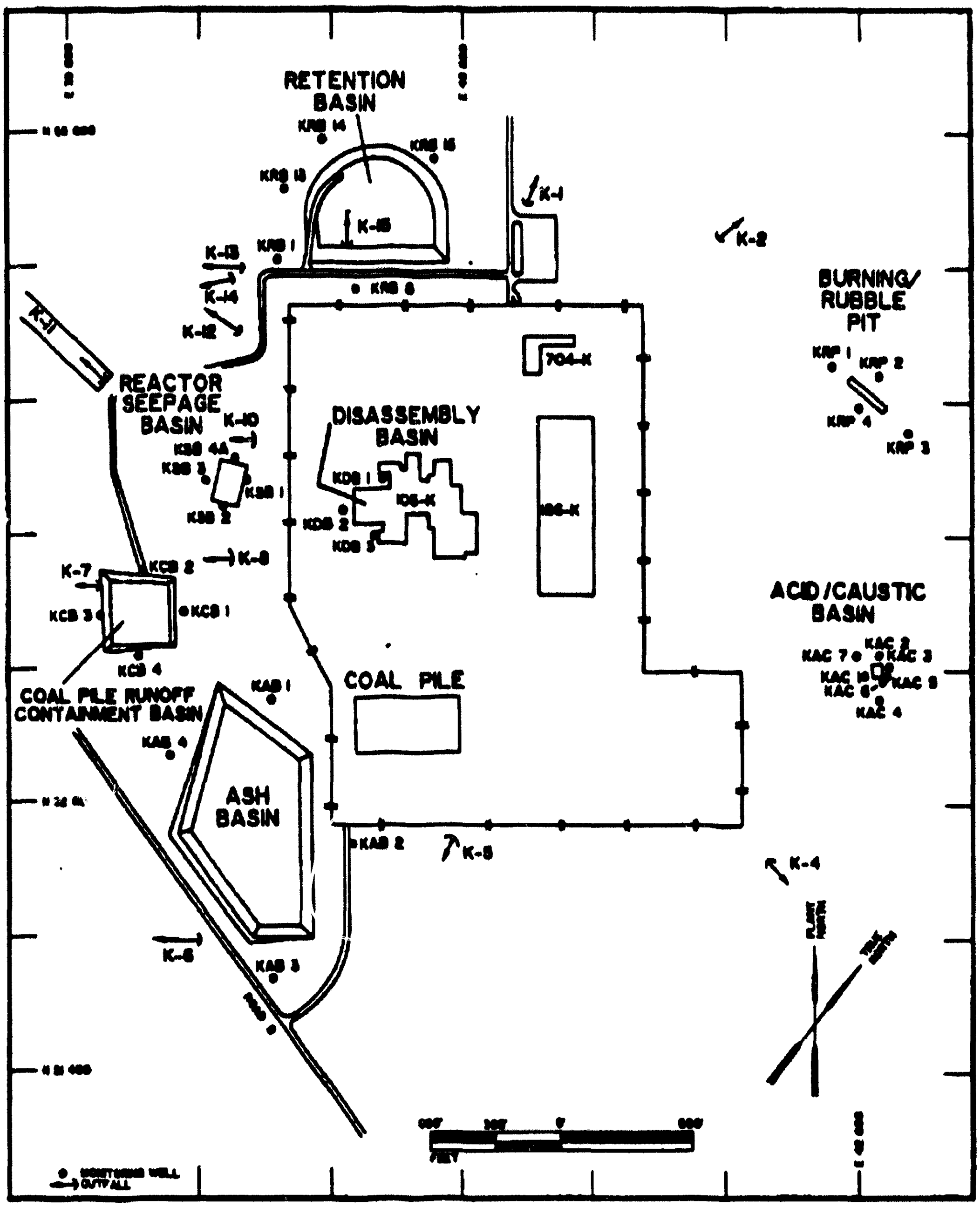


Figure 3.61 K-Area Showing Locations of the Reactor Seepage and Containment Basins and the Monitoring Wells Around Each Basin

Table 3-10 Tritium Concentrations in K-Area Seepage Basin Monitoring Wells (pCi/mL)

Well Number	1985	1986	1987	1988	1989	1990	1991
1	160	280	730	232	868	3131	1366
2	56	55	42	39	46	42	56
3	-	-	-	-	137	553	116
4	-	-	-	-	247	115	25,571

It is assumed that the tritium which seeped from the basin to the groundwater moved to Indian Grave Branch, where it discharged to the stream. This is calculated to have resulted in a peak concentration of 0.00014 pCi/mL of tritium in the Savannah River.

K-Area Containment Basin

The K-Area containment basin has been used since 1965 for the disposal of purge water from the K-Area disassembly basin. The basin, a 190,000 m^3 capacity facility, is about 12 m above the water table. From 1963 through 1982, a total of 585,000 Ci of tritium were released to the basin. Two monitoring wells were installed in 1963 when the basin was constructed, and three additional monitoring wells were drilled and placed in service in 1966. The locations of the monitoring wells are shown in Figure 3.61. Monitoring results for the years 1982-1991 are given in Table 3-11.

Because of the soil characteristics of the containment basin, water moved into the ground at a high rate. Once the tritium left the containment basin it migrated through the unsaturated zone to the water table approximately 12 m below the ground surface. Once it reached the water table, it moved in a westward direction to Indian Grave Branch where about 10,000 Ci/yr outcrops to the stream. Recent modeling studies have indicated that the source leaks through the aquitard and enters the Gordon Aquifer then continues to migrate westward toward the Savannah River. This flow path covers a great distance and therefore little tritium will reach the river by this pathway.

Table 3-11 Tritium Concentrations in K-Area Containment Basin Monitoring Wells (pCi/mL)

Well	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	930	180	81	64	160	211	194	92	42	-
8	31,000	25,000	330,000	73,000	230,000	223,000	58,075	6,023	3,844	-
13	70,000	49,000	69,000	25,000	31,000	10,900	13,513	34,855	21,881	-
14	68,000	25,000	29,000	14,000	19,000	14,600	34,425	39,994	13,679	-
15	63,000	27,000	32,000	86,000	110,000	71,800	95,175	64,602	50,045	-
16D	-	-	-	-	-	-	-	-	-	20,600
17D	-	-	-	-	-	-	-	-	-	5,680
18D		-	-	-	-	-	-	-	-	-1,030
19D	-	-	-	-	-	-	-	-	-	78,900

L-Area Oil and Chemical Basin

The L-Area oil and chemical basin is located near the L-Area seepage basin (Figure 3.62). It has a volume of approximately 2300 m^3. This basin was put into operation in 1961 and received wastewater from all areas of the site, but primarily from the reactor areas. It became inactive in 1979. The amount of tritium released to the basin was estimated in 1985 to be 35,000 Ci (Du Pont 1986).

Monitoring wells were installed around the perimeter of the L-Area oil and chemical basin, and these wells have been sampled quarterly since 1982. Table 3-12 gives the results of the monitoring for tritium in these wells. Figure 3.64 shows a cross section of the basin and the flow path of water from the basin to the shallow water table. Flow from the basin was to Steel Creek while the basin was active. The present flow is to L Lake. The groundwater discharges to Steel Creek or L Lake.

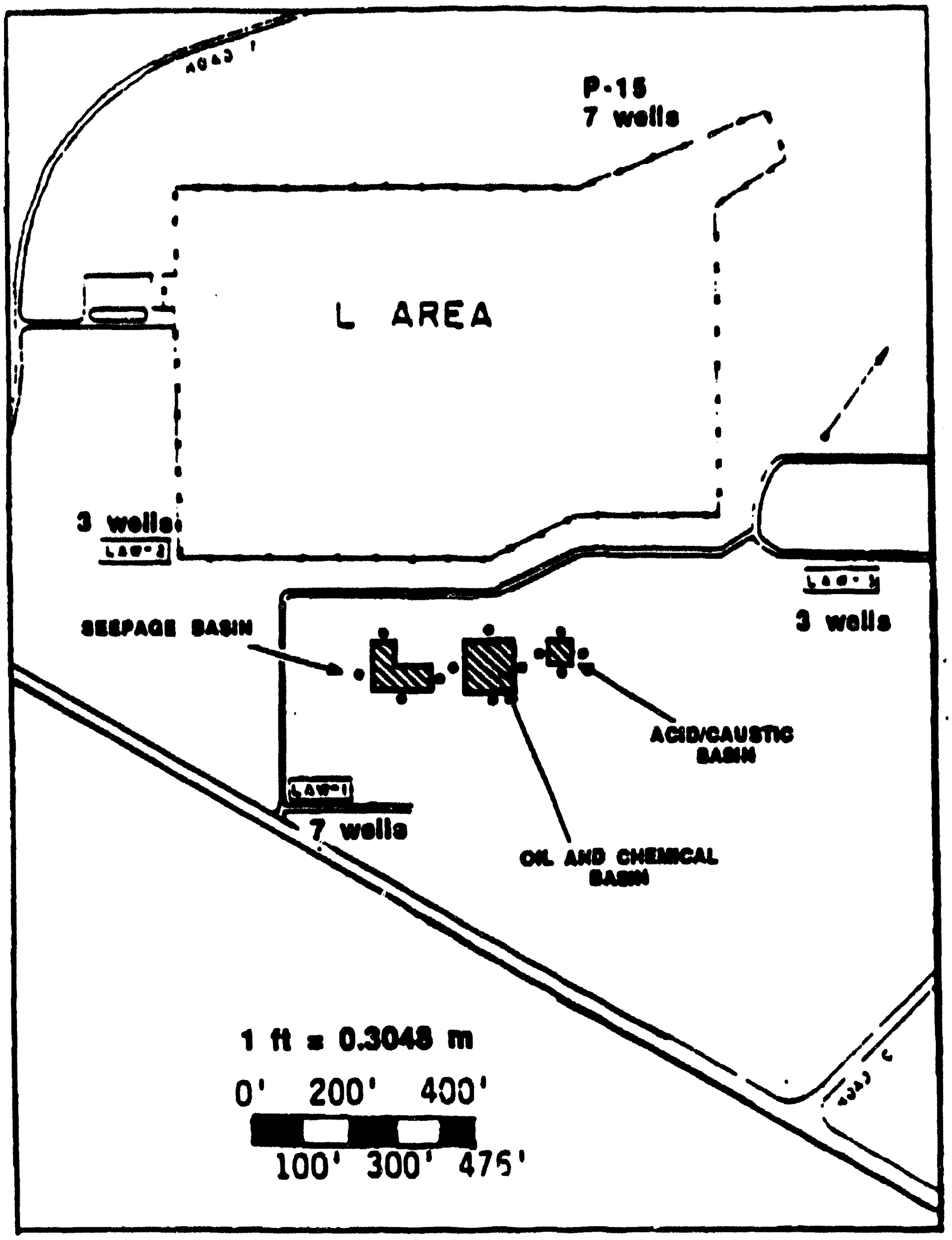
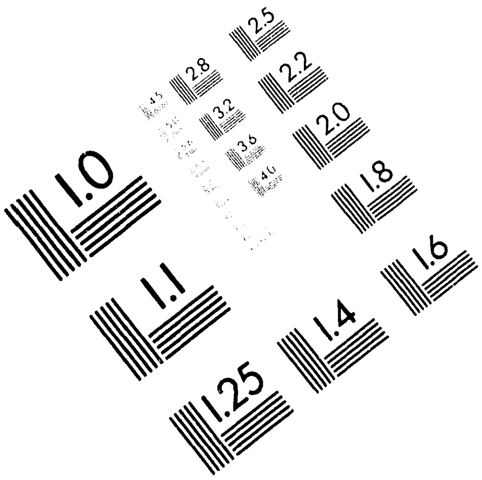


Figure 3.62 L-Area Showing the Locations of the Reactor Seepage and Oil and Chemical Basins with the Monitoring Wells at Each Basin



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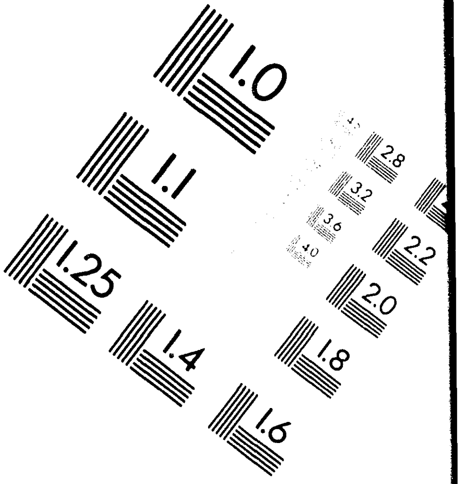

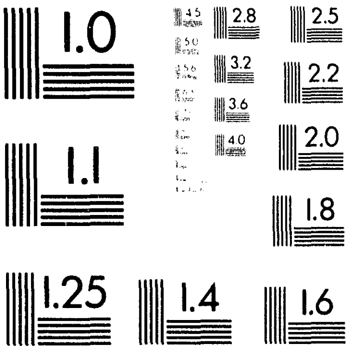

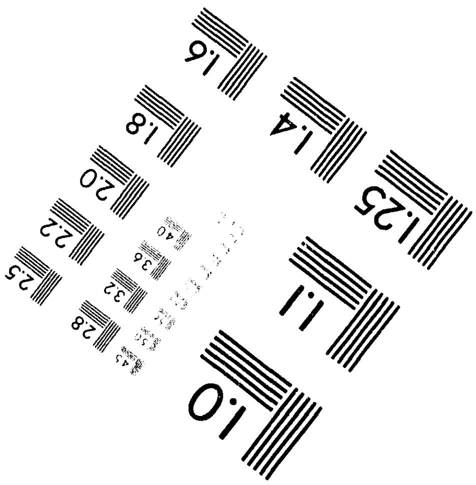

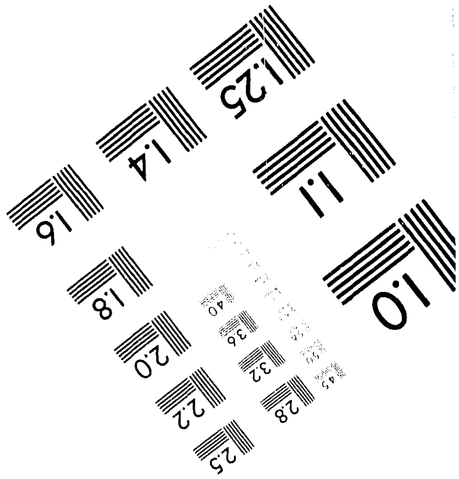

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Table 3-12 L-Area Monitoring Well Average Tritium Concentrations for 1988-1991 (pCi/mL)

Well	Year			
Number	1988	1989	1990	1991
LCO-1	769	342	420	469
LCO-2	4	7	7	7
LCO-3	5	5	6	10
LCO-4	77	97	47	49
LSB-1	1617	3526	4220	4181
LSB-2	4	5	5	5
LSB-3	16	22	22	33
LSB-4	2325	3389	3321	2050

L-Area Seepage Basin

The reactor in L Area operated from 1955 until 1968, when it was placed on standby. During this period, purge water was released to the L Area seepage basin in 1958-1959, 1961-1965, and 1967-1969. The reactor was restarted in 1985, and since that time fuel storage basin purges have again been sent to the seepage basin. The location of the L-Area seepage basin is shown in Figure 3.62.

The water table at the seepage basin is rather shallow, about 6.2 m below the ground surface. The basin was about 760 m from Steel Creek prior to construction of L Lake, and currently it is about 458 meters from L Lake. From 1955 through 1988, about 8000 Ci of tritium were released to the L-Area seepage basin (Du Pont 1986).

Following the release to the L-Area seepage basin, water moved generally vertically downward through the unsaturated zone to the water table. Once the saturated zone was reached, the water traveled principally in a horizontal flow path to Steel Creek (later L Lake) due to the existing gradient (about 0.02 m/m). Therefore, all the tritium leaving the L-Area basin discharged to Steel Creek or L Lake. The basin has been monitored by four wells of the LSB series. Table 3-12 gives the results of monitoring for tritium in those wells.

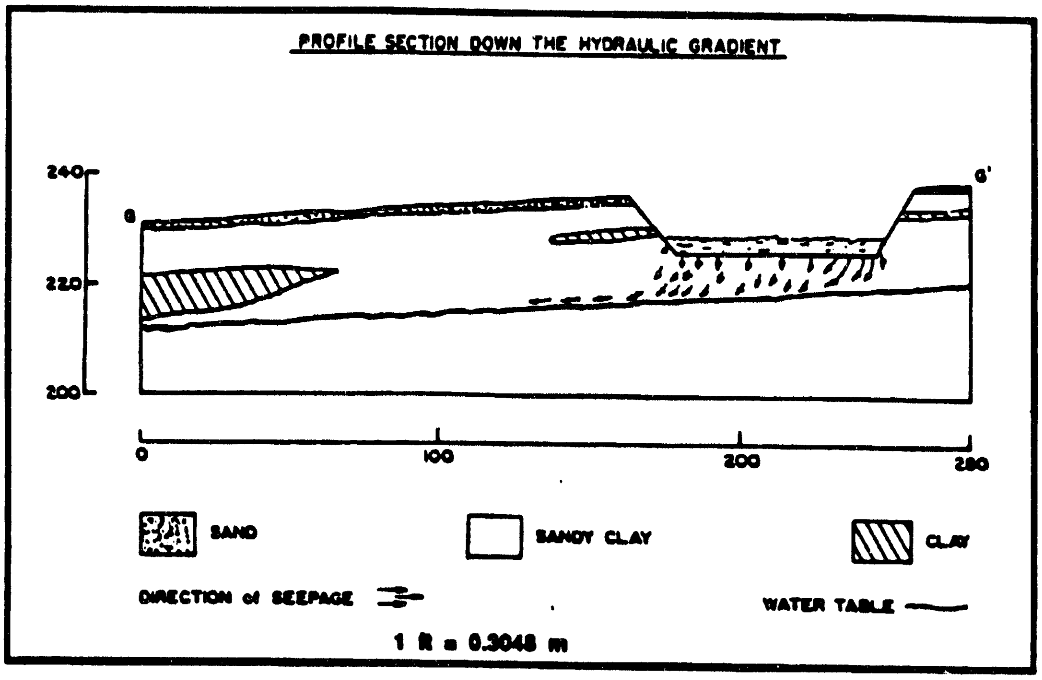

Figure 3.63 Cross Section of the L-Area Oil and Chemical Basin Based on Preconstruction Data

C-Area Seepage Basins

The C-Area seepage basins are located near the center of the site. These seepage basins received discharge purge waters from 1959 to 1970, and from 1978 to 1985. (C Reactor last operated in 1985.) The basins are connected in series, with water entering Basin 1 then moving through to Basins 2 and 3. Through 1985, approximately 56,000 Ci of tritium were discharged to the seepage basins (Du Pont 1986).

Monitoring wells were placed around the C-Area seepage basins in the 1960s and monitored regularly for tritium. The annual average concentration of tritium in the wells for 1982-1991 is given in Table 3-13. The locations of these monitoring wells are shown in Figure 3.64.

Table 3-13 Tritium Concentrations in C-Area Seepage Basin Wells (pCi/mL).

Well Number	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1A	44	43	52	29	30	61	42	-	-	761
2A	38	35	350	70	64	70	80	103	180	13
3A	1,600	1,900	58,000	110,000	82,000	67,000	35,850	37,023	42,229	15,435
4A	88	63	74,000	84,000	70,000	55,300	38,500	17,471	33,399	37,300
5A	360	180	13,000	11,000	8,000	6,440	4,973	6,086	3,824	1,470
6A	13,000	160,000	46,000	4,100	6,100	2,230	1,852	400	876	250

The infiltrating water from the seepage basins moves vertically through the unsaturated zone to the water table. Upon reaching the water table it moves in a path with both vertical and horizontal components generally southwestward toward Fourmile Branch.

P-Area Seepage Basins

P Area, which is located in the south central portion of SRS, discharges its purge water to three seepage basins southwest of the reactor (Figure 3.65). Lower Three Runs Creek to the east, Steel Creek to the southwest, and Meyers Branch to the south and east create a groundwater island in P Area. Through 1991 a total of 70,000 Ci of tritium had been released to the P-Area seepage basins. Groundwater monitoring began around the basins early, and seven wells of the PSB series are now used to monitor for tritium. The locations of these monitoring wells are shown in Figure 3.65. Results of the monitoring program are presented in Table 3-14.

Table 3-14 Tritium Concentrations in P-Area Seepage Basin Wells (pCi/mL)

Well Number	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1A	200,000	32,000	99,000	320,000	180,000	219,000	222,250	207,920	194,636	173,735
2A	220,000	130,000	120,000	170,000	160,000	140,000	146,750	122,984	102,821	72,975
3A	170,000	120,000	140,000	130,000	49,000	128,000	97,000	50,036	42,726	57,129
4A	34	22	91	61	3,400	141,000	5,600	24,291	24,849	2,544
5A	37	1,300	1,200	49	40	209	36	29	31	38
6A	190,000	210,000	170,000	170,000	190,000	142,000	92,425	70,165	89,579	84,514
7A	140,000	76,000	68,000	150,000	53,000	46,900	16,325	11,973	10,456	10,129

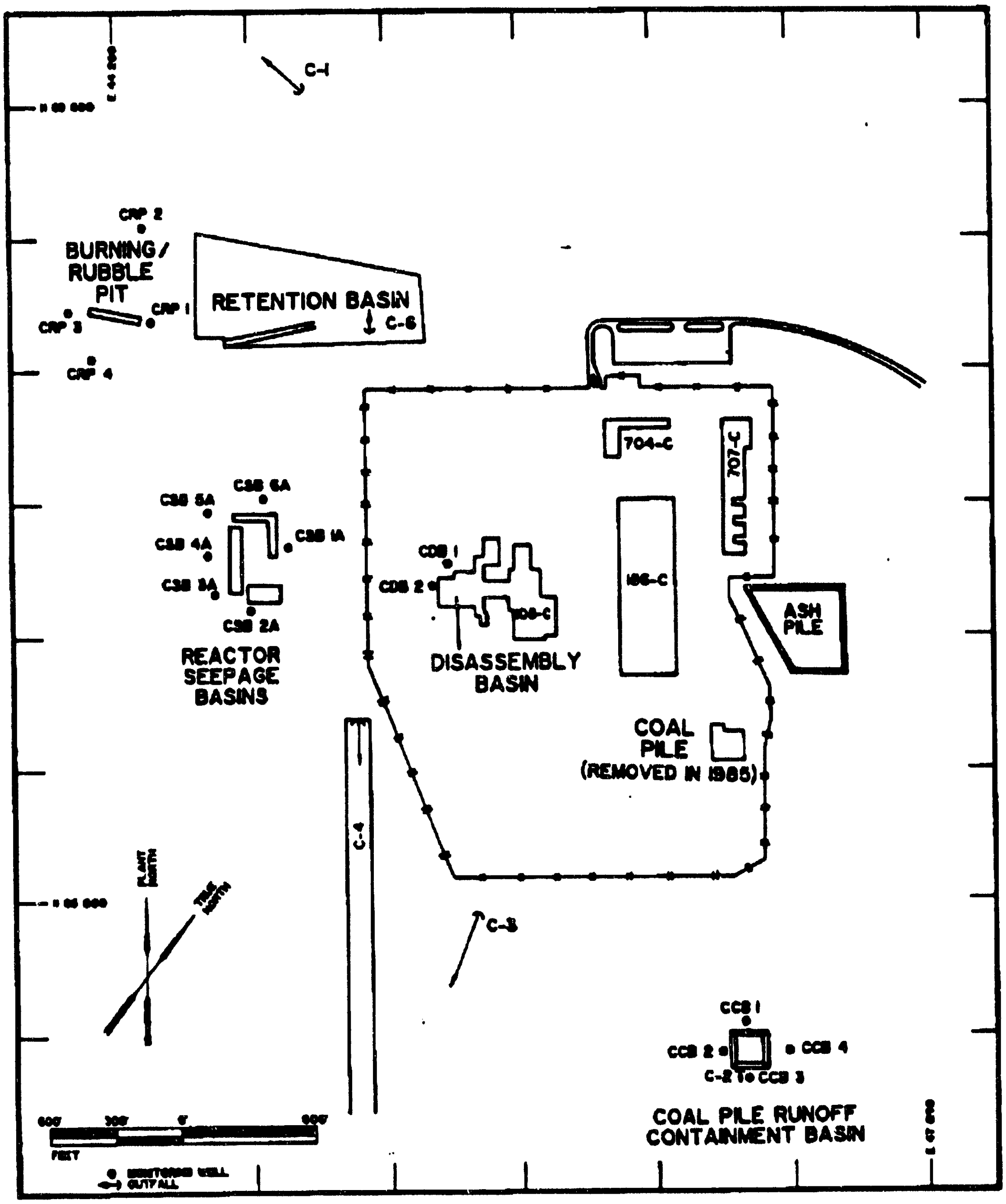

Figure 3.64 C-Area Showing the Location of the Reactor Seepage Basins and the Associated Monitoring Wells

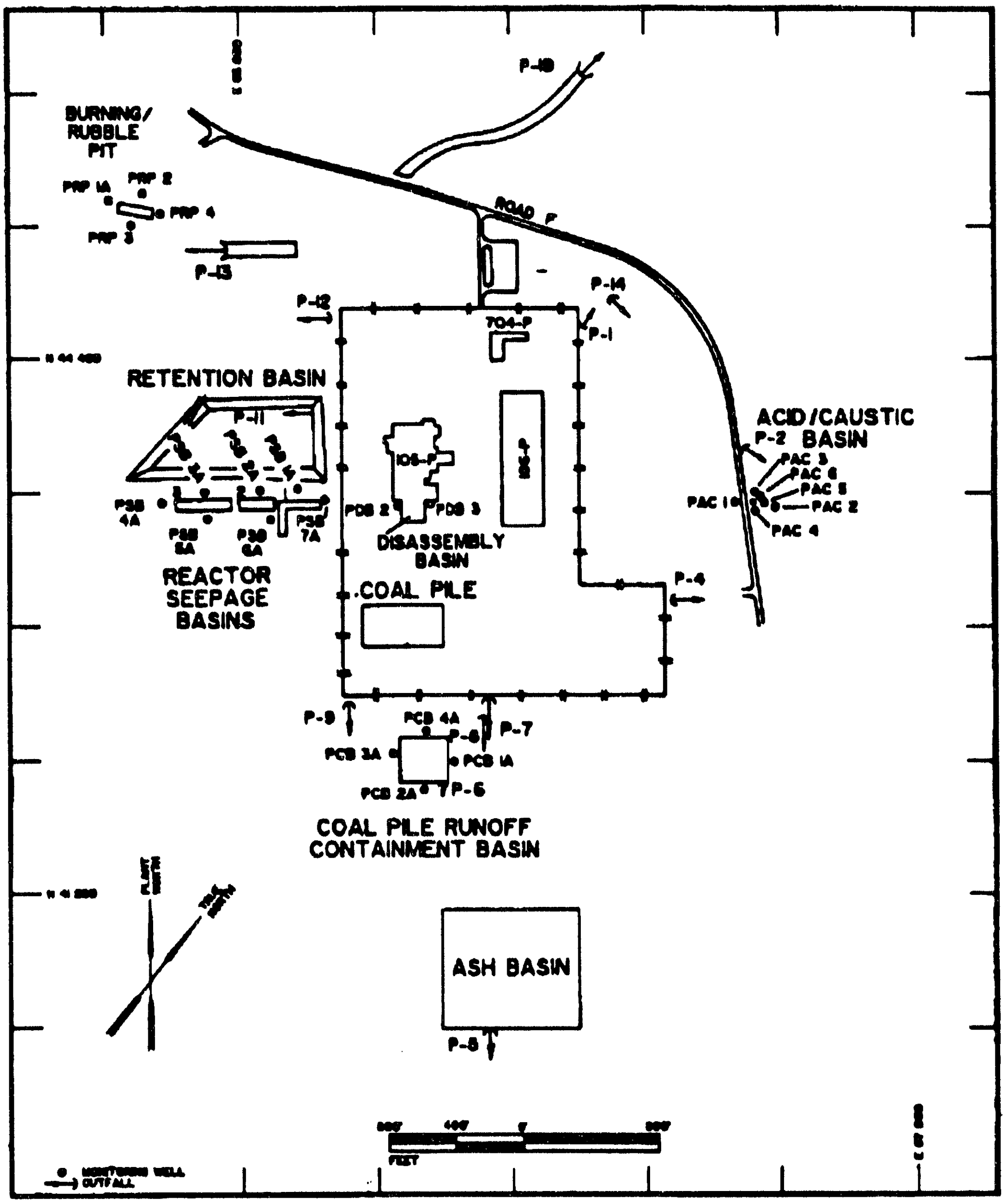

Figure 3.65 P Area Showing the Locations of the Reactor Seepage Basins and Monitoring Wells

The hydraulic gradient in the water table varies across P Area and increases near the surface streams. From the seepage basins, water generally moves vertically downward in the unsaturated zone (a depth of about 9 m). Once in the saturated zone, flow occurs in both a horizontal and vertical direction toward the west and Steel Creek. Recent modeling indicates that approximately 10% of the volume of tritium leaving the seepage basins discharges to Steel Creek from the water table. The remaining 90% moves across the aquitard into Gordon Aquifer and moves in a southwesterly direction toward the Savannah River.

Ford Building Seepage Basin

Small amounts of tritium (470 Ci) were released to the Ford Building seepage basin. By 1991, this tritium had decayed to an inventory of 104 Ci. There is no indication that any of this tritium has migrated to a surface outcrop or that a significant amount will reach an outcrop before decaying.

A/M Area Groundwater

Tritium has entered the groundwater in the A/M Area of the Savannah River Site from several sources:

- natural cosmogenic tritium from precipitation
- "bomb tritium" from above ground testing of nuclear weapons
- tritium released into the atmosphere from SRS facilities

Tritiated water has also been released directly into ground water from sources such as seepage basins and outfalls of various facilities in A/M Area (Strom and Kaback, 1992). Approximately 243 Ci of tritium were released to the SRTC seepage basin. By 1991, this tritium had decayed to an inventory of 55 Ci.

Over much of the A/M Area, the clay units in the Ellenton Formation serve as barriers to downward migration of groundwater. Beneath A-Area, however, groundwater derived from precipitation during the past 40 years has penetrated through the Ellenton Formation into the Crouch Branch Aquifer in Cretaceous sediments. The tritium activity in these waters range from about 300 pCi/L to about 3,500 pCi/L. Tritium activity in excess of these values, up to a maximum of about 35,000 pCi/L have been found associated with the Savannah River Technology Center outfalls and the SRTC seepage basins. Elevated values are found in both the water table aquifer and in a semiconfined aquifer in Tertiary aged sediments of the McBean Formation (Figures 3.50 and 3.51). The direction of migration of the tritium plume is eastward, away from the plant boundary, and toward an intermittent tributary of Tim's Branch. Small amounts of tritium, assumed to come from this source, have been detected in Tim's Branch in 1991. The plume is currently being remediated for organic contaminants and the tritium will likely be captured during this remediation effort.

Off-Site Groundwater Investigations

In October 1991 the Georgia Department of Natural Resources (GDNR) issued a press release notifying the public that tritium had been measured in elevated levels (1,200 - 1,500 pCi/L) in water samples collected from drinking water wells in Georgia across from the Savannah River Site (SRS) in Aiken County, South Carolina (Figure 3.66). There was concern over the source of the tritium in the groundwater and the possibility of migration under the Savannah River from contaminated groundwater within the SRS boundary. None of the elevated results were above the Primary Drinking Water Standard for tritium of 20,000 pCi/L. The GDNR initiated two surveys to determine the source and extent of elevated tritium:

- baseflow survey of surface water quality
- well evaluation program.

Results from the two surveys indicate that the tritium measured in groundwater wells in Georgia is not the result of a groundwater flow from South Carolina under the Savannah River and into Georgia. Atmospheric transport and consequent rainout and infiltration has resulted in an increase of tritium in the water-table aquifer in the vicinity. Water samples collected from drinking water wells believed to have been installed in the aquifer beneath the water-table aquifer were actually from the shallower water-table aquifer. Water samples collected from the wells contain the amount of tritium expected for the water-table aquifer in the wells sample area. The measured tritium levels in the and baseflow samples do not exceed Primary Drinking Water Standards. Tritium levels in the water-table in Georgia will decline as the atmospheric releases from SRS decline, tritium undergoes natural decay, and infiltration of water with less tritium flushes through the subsurface.

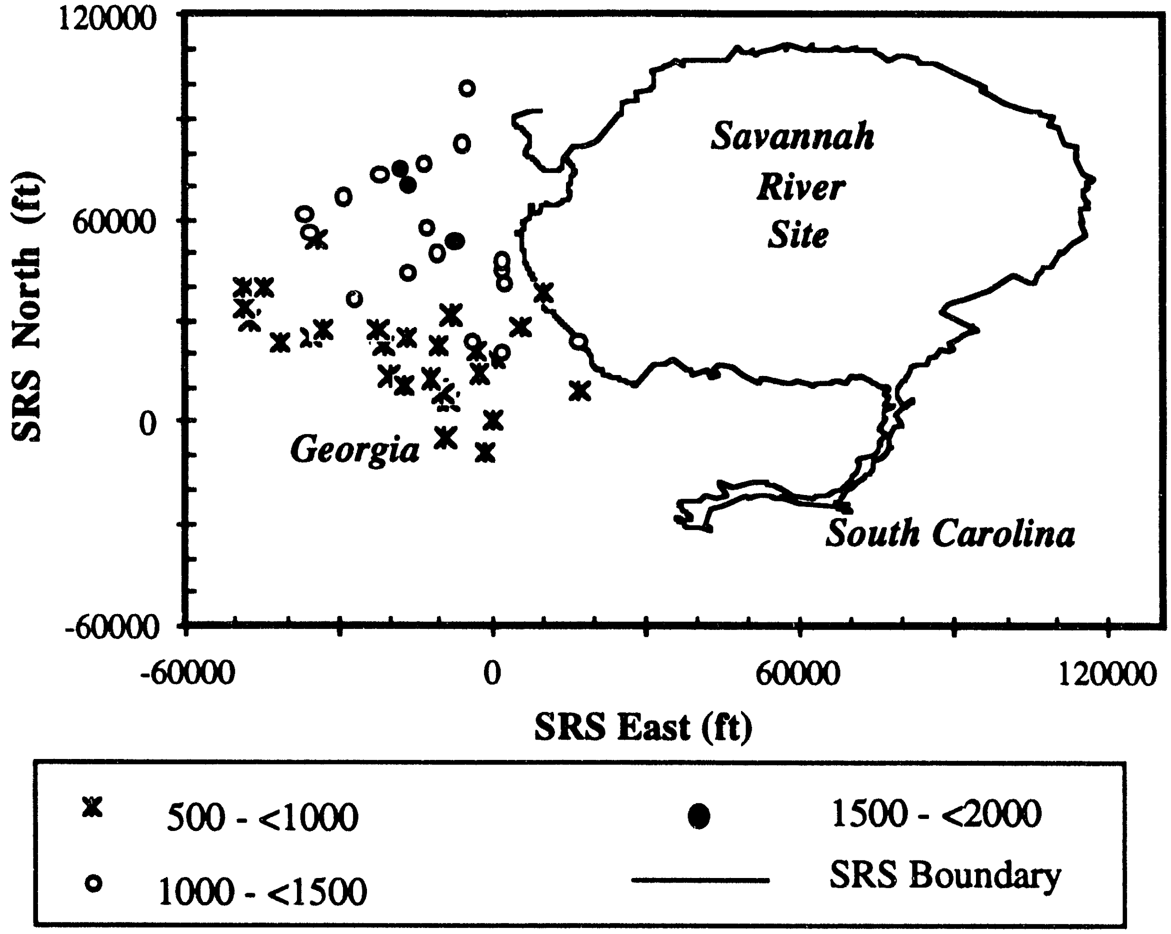

Figure 3.66 Tritium in Georgia Wells near SRS (pCi/L)

Tritium Concentrations from Inadvertent Releases to the Atmosphere

Introduction

Dispersion of inadvertent, short-term releases into the atmosphere is affected by the same physical and biological processes that determine the concentration from the chronic releases from normal activities. However, because of the short duration and the relatively large amount of tritium released during these periods, the concentrations can be higher and less uniformly distributed than the concentrations due to routine releases.

All unplanned releases enter the environment from a stack (usually the 60-m tritium facility stack). The released material mixes into an increasingly larger volume of the atmosphere as the release moves downwind from the stack. The horizontal and vertical spread of the release depends on the size and intensity of the turbulent eddies and the wind speed. The greater the turbulent spreading and the lower the wind speed, the further the release will spread at any distance from the release point.

At some distance downwind, the edge of the release will spread to the surface of the ground. At this point the tritium will interact with the vegetation, fauna, and soil in the path of the release.

At distances less than 80 km, many of the releases appear to have a Gaussian concentration cross section, with a single peak at the center of the path, which slopes to zero concentration on both sides. However, unevenness of the terrain and meandering of the wind often cause non-Gaussian patterns of spread. Further from the release point, the volume of air containing tritium will grow to a size that interacts with the large-scale weather systems. At this point, the release may split or double back on itself, causing a very complex pattern of dispersion. By this time, however, the tritium concentration will decrease substantially.

The first indication that a release is taking place may come from some incident in the separation facility or the reactor facility, or it may be detected by the tritium monitors located in the stacks. Once the release is confirmed, survey teams begin taking field samples of air, air moisture, vegetation moisture, soil moisture, surface water, and milk from locations downwind of the release. The location of the sampling points is determined by the path forecast by the SRTC WIND system (see Appendix 1 for description) and the access to sample points on roads crossing the path of the plume.

Air sampling capability has increased since 1985 with the development of the sampling apparatus and the capabilities of the TRAC vehicle (see Appendix 1 for description). However, there was no field instrument available at the time of the releases reported in this section that could measure air tritium at the concentration found in the environment. Samples were collected, processed, and later counted. This meant that the air concentration measurements could not be used to determine the centerline (highest concentration) of the release. The same was true of vegetation, soil, and surface water samples. However, vegetation, soil, and water samples are easier to collect than air samples and a greater number of samples can be collected and brought back to the laboratory for later analysis. This procedure usually provides the best confirmation of the paths forecast by the WIND system.

The environmental concentration during and immediately after inadvertent releases are higher than those measured under average releases and result in the highest concentrations found in the environment from SRS operations.

Because of the complex factors determining the spread and uptake of tritium from a short-term release, it is necessary to treat each release as a special case. The following section will, describe the characteristics of the 12 inadvertent atmospheric releases that occurred from site startup in 1952 through 1991.

A summary of the tritium concentration in the environmental samples collected after nine of the largest and best-documented releases will be presented and discussed with the purpose of looking for patterns that allow a general conclusion to be drawn about how tritium interacts with the environment following comparatively large releases of short duration.

Summary of Inadvertent Atmospheric Tritium Releases

May 2, 1974. A valve failure resulted in a 479,000-Ci release from a 60-m stack located in the Separation Area. The release occurred over a 4-min period beginning at 0755 hours eastern standard time (EST). The tritium form was estimated to be primarily tritiated hydrogen gas with less than 1% tritiated water. At the time of the release, light winds carried the tritium in a northeasterly direction (azimuth 210-225 deg) at 6.4 to 9.7 km/hr. Cloud cover at Bush Field in Augusta, GA, was 90%-100%. The atmospheric stability was judged to be neutral. The trajectory of the release carried the tritium north of Columbia, SC, beyond which point it was difficult to predict because of complex weather patterns.

Extensive measurements were made of the tritiated water content of vegetation, soils, and surface water. A single air sample collected about 5 hours after the release had a 30-minute average concentration of 390,000 pCi/mL, of which less than 1% was in the form of tritiated water. The highest vegetation, surface water, and soil water concentrations were 4630, 10,000, and 138 pCi/mL, respectively. Milk collected from a beef cow was found to have an elevated tritium concentration of 375 pCi/mL.

December 31, 1975. At 2000 hours EST, 182,000 Ci of tritium gas was released from a stack in the tritium separations area. Ninety percent of the tritium was released in the first 1.5 minutes. Air samples indicated that 0.6% of the release was in the form of tritiated water with the rest in the hydrogen form.

The cloud cover was about 30% and the windspeed 35 km/hr at the time of the release. The atmospheric stability was neutral. The wind carried the release in an easterly direction (azimuth 270-289 deg). The trajectory of the release carried the tritium north of Charleston, SC, where it passed over the ocean between 0500 and 0600 hours on January 1.

Maximum air moisture, surface water, and soil tritium concentrations were 687, 27, and 242 pCi/mL, respectively. Air, water, and milk samples collected after the release were within the values routinely measured at other times.

March 27, 1981. At approximately 0845 hours EST, 33,000 Ci of tritium were released to the atmosphere from a separation area processing facility. The duration of the release was about 2.5 hours. Analyses of stack samples taken during the incident indicated that 99.7% of the tritium was released as tritiated water vapor.

The sky was sunny, with scattered cumulus clouds forming in the afternoon. The temperature was between 75°and 80°F. The surface wind at the time of the release was blowing at 18 km/hr toward the east. Later in the day this increased to 21 to 26 km/hr. The trajectory carried the release northeastward where it crossed the coastline at approximately the North Carolina-South Carolina boundary.

Maximum tritiated water concentrations were 270, 9, and 39 pCi/mL for vegetation, surface water, and soil water samples, respectively, collected outside the boundary of SRS. A vegetation sample inside the SRS boundary was found to have a tritiated water concentration of 4860 pCi/mL. Milk and foodstuff samples were within the values measured at other times.

July 16, 1983. At 2213 hours EST, 56,000 Ci of tritium were released from the tritium separations area. The release took place over a period of approximately 3 minutes. Analysis of samples of the released gases indicated that about 1% of the release was tritiated water vapor and the remaining 99% was in the hydrogen form.

The sky was 75% to 100% covered with clouds at the time of the release, with rain and thundershowers early in the evening. The cloud cover dissipated by 0200 hours of the following day. Surface winds were 18 km/hr around the time of the release, blowing toward the northeast. The trajectory carried the release offshore north of Charleston, SC.

Vegetation, surface water, and rainwater tritium concentrations were 150, 23, and 18 pCi/mL, respectively. Milk and air moisture samples were within the concentration range routinely measured in samples in the vicinity of SRS.

March 23, 1984. At 0440 EST, a leak in a process line led to a release of 7500 Ci from a stack in a separation facility. The majority of the release occurred in the first 2 hours and 20 minutes. Approximately 70% of the release was in the tritiated water vapor form; the remaining 30% was in the hydrogen form.

During the morning of the release, the winds were blowing toward the east-southeast (azimuth of 280 deg) at 21 km/hr. Skies were clear with a 10% cloud cover. There was a low-level inversion at the time of the release, indicating stable atmospheric conditions. The inversion dissipated by 0930 hours, and unstable atmospheric condition prevailed from that time forward. The release trajectory moved to the south-southeast for the first 2 hours then swung to the southeast for the next 8 hours before turning to the northeast and moving over the ocean near Charleston, SC.

Maximum vegetation and surface water tritiated water concentrations were 1380 and 120 pCi/mL, respectively. Two sampling teams measured tritium forms in atmospheric samples. The highest concentration was found to be 6170 pCi/m^3, with about 90% of the sample in the water vapor form. The maximum tritium concentration in milk was 69 pCi/mL.

September 2-7, 1984. Beginning at 1900 hours EST, a release of 57,900 Ci of tritium occurred from a stack in the Separations Area. Approximately 43,800 Ci were released in the first 5 hours of the period, with the remainder slowly entering the environment over the next five days. The release consisted of 99% tritiated water vapor.

At the beginning of the release, the wind was blowing in the direction of Aiken, SC (azimuth 170 deg). The wind speed remained steady at 16 km/hr during the first five hours after the release. The wind later shifted toward the east carrying the tritium near Lexington, SC. Temperature profiles from the instruments on the WJBF TV tower indicated an inversion existed, and the stable atmospheric conditions kept the plume in a narrow band as it moved away from the source.

Sampling teams measured atmospheric tritium along the path of the release. Because the release path was narrow, it was difficult to obtain samples in the center of the release. The highest tritium concentration measured was 15871 pCi/m^3 at Blythewood, SC, about 124 km from the release source. Vegetation samples from this location indicated that this may have been very close to the center of the path. Vegetation and milk samples were collected by SRS and South Carolina Department of Health and Environmental Control (SCDHEC) sampling teams. The highest concentration of tritiated water in vegetation was 9800 pCi/mL, measured at a location 40 km from the release point. The highest concentration near the SRS boundary was 2500 pCi/mL. The highest concentration found in milk was 47 pCi/mL near Windsor, SC.

January 31, 1985. A total of 9285 Ci of tritium was released from the stack of the tritium separations area. The release took place from 1400 to 1700 hours EST. The majority of the tritium, 7400 Ci, was released in the first 15 min. Of the total release, 54% was in the tritiated water form and the remaining 46% was in the hydrogen form.

At the time of the release, the wind was blowing toward the north-northeast at 21 km/hr. The cloud cover at Bush Field, Augusta, GA, was 100%.

The atmospheric stability ranged from mildly unstable to neutral during the release period. The release trajectory passed Windsor, SC, and could be tracked, with substantially decreased concentration, to the southwest of Columbia, SC.

Measurements were taken of vegetation, surface water, and milk following the release. The highest concentrations were, respectively, 7600, 140, and 4.3 pCi/mL. Milk tritium concentrations were within the concentrations normally measured by the SRS Environmental Survey. The air tritiated water vapor content at Windsor was measured at 576 pCi/m^3.

March 27, 1985. The release, from the separation area stack, began at 1353 hours EST and averaged about 90 Ci/min until 1830 hours when the released ceased. Stack sampling indicated that of the 19,422 Ci in the release, 99.9% was tritiated water vapor. Meteorological observations at Bush Field, Augusta, GA, showed that the cloud cover was 70% and the wind speed from 16 to 23 km/hr. The atmospheric stability varied from slightly unstable to neutral during the period when the release was passing though South Carolina. The trajectory of the release initially carried the tritium in a northeasterly direction, passing southeast of Columbia, SC. The release crossed into North Carolina before moving over the ocean.

The highest vegetation and surface water concentrations measured within the SRS boundary were 61,800 and 384 pCi/mL, respectively. These values had decreased to 971 and 1.4 pCi/mL by the time the tritium reached the SRS boundary. Milk samples collected after the release showed levels that were within the range normally measured by SRS surveys. Air sampling was done by the TRAC mobile laboratory and sampling teams with mobile tritium forms samplers. The highest concentration of tritium measured in the air was 21,689 pCi/m^3. The tritium form of this sample was greater than 99% tritiated water vapor.

July 31, 1987. The release occurred from the separations area stack between 0817 and 0855 hours EST. The estimated total amount released, based on the tritium forms monitor, was 172,000 Ci. The oxide fraction, based on the stack air monitor, was 2.7%. The remaining 97.8% was in the hydrogen form.

The weather on July 31 was characterized by very weak wind (8 km/hr) blowing toward the northeast and very unstable atmospheric temperature stratification. The height of the atmospheric mixing zone was 200 m at 0830 hours and 2200m by midafternoon. Afternoon showers and the associated wind further dispersed the tritium as it moved beyond Blackville, SC. Traces of the tritium were found from Swansea to Orangeburg, SC.

SRS Environmental Monitoring teams collected vegetation, water, and milk samples on and off the site, while SCDHEC collected vegetation samples offsite. The highest concentrations were 5760 and 47 pCi/mL for vegetation and surface water, respectively. The concentration in milk was within the range normally found by SRS Environmental Surveys. Extensive measurements were made of the air concentration with tritium forms samplers. The highest concentration was about 12.4 million pCi/m^3. Samples collected near the release point showed a fairly uniform concentration of tritiated water vapor, averaging around 3%. Farther from the SRS boundary, the fraction of tritiated water vapor ranged from 0.3% to 84% (in a sample with a total tritium concentration of 3300 pCi/m^3). The separation of the forms of tritium is thought to be the result of differences in uptake at the surface or from washout of tritium in the vicinity of the rain storms.

March 1, 1988. Approximately 20,000 Ci of tritium were released to the atmosphere from the separations area stack. The tritium forms were 14% tritiated water vapor and 86% tritiated hydrogen. The TRAC mobile laboratory responded to the release, and seven air samples were collected at locations approximately 160 km southwest of SRS in the vicinity of McRae, GA. Additional air samples were collected along the intersection of US Highway 221 and Interstate Highway 20, west of the TRAC laboratory sampling locations. The tritium concentration in air ranged from 3.6 to 85.7 pCi/m^3 of tritiated hydrogen and 4.3 to 79.6 pCi/m^3 of tritiated water.

Samples of surface water and vegetation were taken downwind of the release point within the SRS boundary. The highest concentrations were 43 pCi/mL in vegetation water and 8 pCi/mL in surface water.

June 7, 1988. Approximately 3650 Ci of tritium were released to the atmosphere from a separations area tritium facility. The release was 96% tritiated hydrogen gas and 4% tritiated water vapor.

Environmental sampling was conducted downwind of the release point within the SRS boundary. Eight vegetation samples were collected. The highest concentration in the vegetation moisture was 23 pCi/mL.

October 6, 1988. Approximately 7000 Ci of tritium were released to the atmosphere from a separations area tritium facility. Approximately 11% of the tritium was in the form of tritiated water vapor. The remaining 90% was in the form of tritiated hydrogen gas.

Environmental samples were collected within the SRS boundary downwind from the release point. The highest concentrations measured were 68 pCi/mL in vegetation and 19 pCi/mL in standing water.

December 7, 1988. Approximately 3500 Ci of tritium were released to the atmosphere from a separations area facility. The release was 99.5% tritiated water vapor, with the remaining 0.5% tritiated hydrogen gas.

Environmental sampling was conducted downwind of the release point near the northeast boundary of SRS. The maximum vegetation moisture concentration was 77 pCi/mL. One surface water sample containing 17 pCi/mL of tritium was collected.

January 3, 1989. Approximately 500 Ci of tritium were released to the atmosphere from the

H-Area tritium facility. The fraction of HTO was not measured. Eight vegetation and five surface water samples were collected downwind of the release. Three of the vegetation samples were collected within the plant boundary. The remaining five vegetation samples and all of the water samples were collected at the plant perimeter. The tritium concentration in the vegetation samples varied from 21 to 180 pCi/mL of vegetation water. The surface water (standing water) samples varied from 15 to 72 pCi/mL. These measurements are higher than the normal background in the sampling area and confirm the existence of the release.

March 30, 1989. Approximately 1,100 Ci of tritium were released to the atmosphere from an H-Area tritium facility. The chemical forms of the tritium were measured as 97% HTO and 3% HT. Five vegetation samples and one standing water sample were taken at the SRS perimeter downwind from the source. The vegetation samples ranged from 22 to 198 pCi/mL of vegetation water. The water sample had a tritium concentration of 3.8 pCi/mL. The vegetation samples, but not the water sample, were above the background normally found in the sampling area.

October 19, 1989. Approximately 800 Ci of tritium were released to the atmosphere from an H-Area tritium facility. The release was 100% HTO. Five vegetation and four surface water samples were measured at the location where the plume was predicted to cross the SRS boundary. The tritium concentration of the vegetation ranged from 3.6 to 15.8 pCi/mL of vegetation water. The water samples ranged from 0.3 to 6.7 pCi/mL. The highest vegetation samples were slightly greater than the normal background for the area in which they were collected (background 1-10 pCi/mL). The water samples were within the normal range of rainwater collected near the sampling location.

February 7, 1990. Approximately 100 Ci of HTO was released from K-Area Reactor following a spill of 20 gallons of moderator water during a maintenance operation. Twenty-six vegetation and six surface water samples were collected at the SRS boundary, downwind from the source. The tritium concentration of the water separated from the vegetation ranged from 1 to 11 pCi/mL. The water samples ranged from 1.4 to 2.4 pCi/mL. The vegetation samples were only slightly higher than the normal background in the sampling area. However, the maximum concentrations coincided with the predicted path of the plume.

Table 3-15 summarizes the conditions immediately after each of the atmospheric tritium releases described above. The releases have taken place under a wide range of meteorological conditions, during different seasons of the year and beginning at different times of the day. Table 3-16 summarizes the tritium concentration in vegetation, surface water, and milk samples collected after the nine releases where extensive environmental measurements were made. There is a great deal of variation in the concentration of tritium in environmental samples relative to the amount of tritium released.

In a previous section, it was shown that the annual average tritium concentration in vegetation due to SRS releases is related to the air concentration of tritiated water vapor. Annual vegetation tritium concentrations tend to average the effects of specific meteorological conditions from any one release, making it easier to see the patterns due to other factors. However, it is possible to take into account meteorologic effects by using atmospheric models. For an atmospheric release of short duration, the concentration of tritiated water in the leaves of vegetation should be related to the exposure of the leaf to the tritiated water vapor in the air. Exposure, the average concentration in the air multiplied by the time of contact with that air, can be calculated using the model described by Slade (1968). Figure 3.67 shows the results of calculations of the maximum centerline exposure compared to the maximum concentration measured in the vegetation at approximately 40 km from the release source. The meteorological conditions shown in Table 3-15 were used in the calculations. The concentration in the vegetation immediately after the passage of the release is a function of the exposure to tritiated water vapor.

The decrease in tritium concentration in the environment was followed after some of the larger inadvertent releases. The pattern of decrease in the tritiated water content of vegetation was found to differ between releases where the tritium was largely in the hydrogen form and releases where the tritium was largely in the water vapor form. Table 3-17 shows a comparison of two releases, one of which was largely water vapor and the other that was largely hydrogen gas.

Table 3-15 Tritium Release Characteristics

Date	Time	Release Curies	%HTO	HTO Curies	Wind Speed, m/s	Atmospheric Stability Class
5/2/74	755	479000	1.0	4790	3	Neutral
12/31/75	2000	182000	0.6	1092	10	Neutral
3/27/81	845	32934	100.0	32934	7	Unstable
7/16/83	2013	56000	1.0	560	6	Neutral
3/23/84	440	7500	70.0	5250	5	Stable
9/7/84	1900	43800	100.0	43800	5	Stable
1/31/85	1400	9300	50.0	4650	5	Neutral
3/27/85	1353	19422	99.9	19403	7	Neutral
7/31/87	855	172000	2.7	4644	2	Unstable
3/1/88	616	20000	15	3000	4	Stable
6/7/88		3650	4	146	4	Neutral
10/6/88	730	7086	10	700	7	Neutral
12/7/88	2248	3082	99.5	3500	5	Neutral
1/3/89	NA	500	NA	NA	NA	NA
3/30/89	1015	1,100	97	1067	15	Stable
10/19/89	NA	800	100	800	NA	NA
2/7/90	2330	100	100	100	11	Neutral

NA - Information not available in written reports.

Table 3-16 Maximum Environmental Concentrations Following Tritium Releases, pCi/ml

	Vegetation					
Date	**On Site**	**Perimeter**	**~40 km**	**~80 km**	**Surface Water**	**Milk**
5/2/74	25	4630	310	41	138	375
12/31/75	687	92	8		3	9
3/27/81	4860	270			9	11
7/16/83	150	110	80	27	23	4
3/23/84	89	500	1380	190	120	69
9/2/84	500	2500	9900	240	ND	47
1/31/85	7600	450	380	180	140	2
3/27/85	61800	970	590	143	384	6
7/31/87	5760	4690	34	8	47	4

Table 3-17 Comparison of Characteristics of HTO and HT Releases

	Maximum HTO Concentration					Vegetation
Date	**Form**	**Release Curies**	**Vegetation pCi/ml**	**Soil pCi/ml**	**Release Maximum**	**Half-life In Days**
5/2/74	HT	479000	4600	7240	0.02	5
3/27/81	HTO	32934	4900	40	0.15	<<1

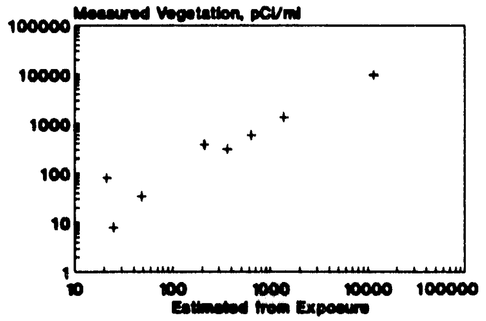

Figure 3.67 The Maximum Tritiated Water Content of Vegetation Leaves Collected at Approximately 40 km from the Source of the Release Compared to Estimates Calculated from Exposure to Tritiated Water Vapor for Each Release

When the release was in the water vapor form, the highest concentration of tritium found after the release was in the vegetation leaves. The concentration in the soil was comparatively small. The tritiated water content of the leaves decreased very rapidly after exposure. The concentration had decreased to half the highest value within a few hours of exposure. (Sweet et al., 1983).

When the release was in the hydrogen form, the highest concentration of tritium was found in the soil water. The tritiated water content of the vegetation leaves decreased more slowly than in the exposure to tritiated water. The decrease to half the maximum value took nearly 5 days (Figure 3.68). The tritiated water found in the leaves is largely from oxidation of tritiated hydrogen to tritiated water by microorganisms in the soil. When compared to a tritiated water vapor exposure, the longer exposure of vegetation to tritiated water after an exposure of the system to tritiated hydrogen is more than compensated for by the lower maximum concentration of tritium in any component of the environment relative to the total amount of tritium released. (Morter 1974a).

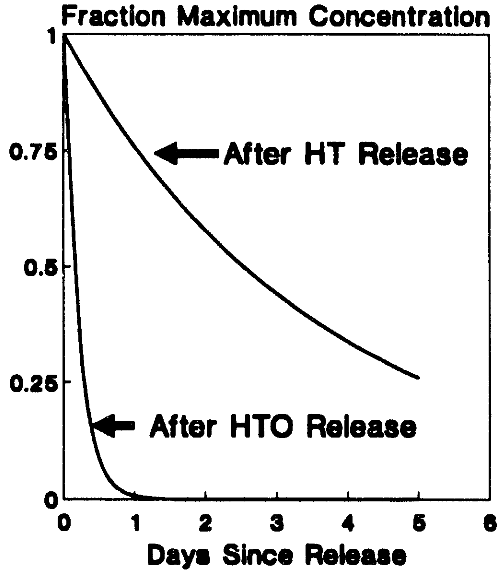

Figure 3.68 The Characteristic Release Curves for Tritiated Water in Vegetation Following Exposure to Atmospheric Tritiated Water Vapor and Tritiated Hydrogen

Summary of Inadvertent Liquid Tritium Releases to SRS Streams

March 19, 1972

A process upset in 1972, in the Rework Unit, caused a release of about 4200 Ci of tritium to the process sewer which drains into the 400-Area effluent. This release resulted in the highest recorded weekly tritium concentration in the 400-Area effluent (9274 pCi/mL).

A special study was made to measure the tritium concentrations in the Savannah River below SRS following this release (Buckner and Hayes, 1975). At Highway 301, 53 km down river from the 400 Area, the peak tritium concentration had decreased to 280 pCi/mL (primarily due to mixing with the large flow of the Savannah River). By the time the peak had arrived in the vicinity of the water treatment intakes (another 140 km down river), the peak had decreased to 120 pCi/mL (Figure 3.69). The decrease down river of Highway 301 was a result of increased river flow, dispersive dilution, and local water

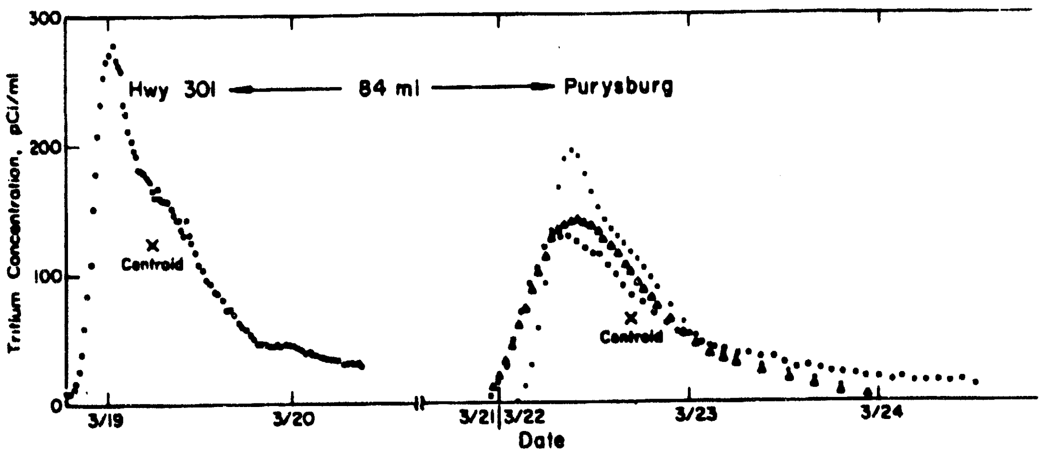

Figure 3.69. Tritium Concentration in the Savannah River following the Release March 19, 1992

additions in the vicinity of the sampler, which was located near the edge of the river.

December 22-25, 1991

Some releases of tritium to the environment are part of normal operation of the SRS facilities. Other releases are the result of mechanical or human process error. The second type of release was classified as an inadvertent release in WSRC-RP-90-424-1. In the period from 1988-1990, inadvertent releases have been small compared with some previous years.

However, a relatively large inadvertent liquid release occurred in 1991. The history, environmental monitoring results, and dose assessment following this release has been thoroughly documented (Hamby et al. 1992). Only a summary of the results will be given here.

Between December 22 and 25, 1991, approximately 150 gallons of tritiated moderator water (10 Ci/L) leaked from one of the K-Reactor heat exchangers into Pen Branch. The tritium from Pen Branch emptied into the Savannah River reaching the Highway 301 Bridge on December 26 and the Beaufort-Jasper water treatment plant intake on the morning of December 28. The maximum concentration of tritium was detected about 30 hours after the initial detection in both locations. The maximum concentration at the Highway 301 Bridge was 66.9 pCi/mL. Integration of the water concentration and Savannah River flow over the release period, led to an estimate of 5700e curies of tritium released.

A maximum dose of 0.035 mrem was calculated for a hypothetical individual who drank 2 liters of river water at Highway 301 each day for the duration of the period of elevated tritium concentration. This dose is 100 times smaller than the Environmental Protection Agency (EPA) drinking water standard of 4 mrem/yr. Average individual dose to users of the Beaufort-Jasper and Port Wentworth domestic water supplies was 0.0048 and 0.015 mrem, respectively.

Transport of Tritium from the SRS to the Environment

In Chapter 1 of this report, it was shown that tritium is released from SRS facilities into the local environment in one of three forms, tritiated hydrogen, tritiated water vapor, or liquid tritiated water. Tritiated hydrogen and tritiated water vapor are released to the atmosphere. Liquid tritiated water is released to surface water bodies or to seepage basins. A part of the water released to seepage basins will enter the ground and become part of the groundwater. After release, the tritium will become part of the hydrologic cycle on the plant site, leading to some redistribution of the form and location of the tritium before it moves beyond the SRS boundary.

Figure 3.70 illustrates the relationship between the facility releases and the redistribution that takes place at SRS before the tritium leaves SRS. The total atmospheric releases between 1952 and 1991 consisted of 23.8 million Ci (98% of the atmospheric releases) that were directly released to the atmosphere from facility stacks and 410,000 Ci (2%) that resulted from evaporation of tritiated water in liquid releases to seepage basins or lakes.

Some of the tritium released to the atmosphere is involved in the hydrologic cycle of the environment inside the SRS boundary. An estimate of the removal and cycling of tritium by the SRS environment before transport beyond the SRS boundary can be made on the basis of the measured concentrations of tritiated air moisture, tritiated air hydrogen, and tritiated rain water. The deposition of rainwater tritium inside the site boundary is calculated by summing the product of the concentration and the rainfall rate along the gradient of rainfall concentration demonstrated in this chapter (Figure 3.71). The same procedure can be followed for deposition of tritiated water vapor and tritiated hydrogen where the deposition velocity for each form of tritium is used in place of the rainfall rate. Separate deposition velocities have been used for the vegetation and soil for each form of tritium in the calculations. The values were taken from published estimates of deposition velocity for each of the cases, as presented in Table 3-18. (Garland and Cox, 1982, Murphy et al., 1979)

Table 3-18 Deposition Velocities (cm/s)

Form/Sink	Vegetation	Soil
HT	0.0	0.05
HTO	0.4	0.04

The distribution of tritium after it has entered the soil can be estimated on the basis of the local hydrologic cycle, under the assumption that tritiated water will act as other water. A review of the available publications, and the meteorological and hydrological data provided the annual components for SRS conditions shown in Tablee 3-19.

Table 3-19 Components of the Hydrologic Cycle at SRS

Component	Annual Amount (in.)	Percent
Precipitation	48	100
Runoff	3	6
Evaporation	30	63
Seepage to Groundwater	15	31
Deep Layers	1	2

Approximately 650,000 Ci (2.6%) of the total tritium released entered the hydrologic cycle inside the SRS boundary. However, most of this tritium (571,000 Ci or 2.3%) re-entered the atmosphere through evapotranspiration from the vegetation. Only 78,000 Ci (0.3%) entered the groundwater where significant decay of the tritium could take place before the tritiated water moved beyond the plant boundary.

The situation is somewhat different for seepage basin releases where liquid tritiated water is purposely put into the groundwater to allow time for radioactive decay of the tritium to nonradioactive helium. Of the approximately 4.1e million Ci of tritium released to seepage

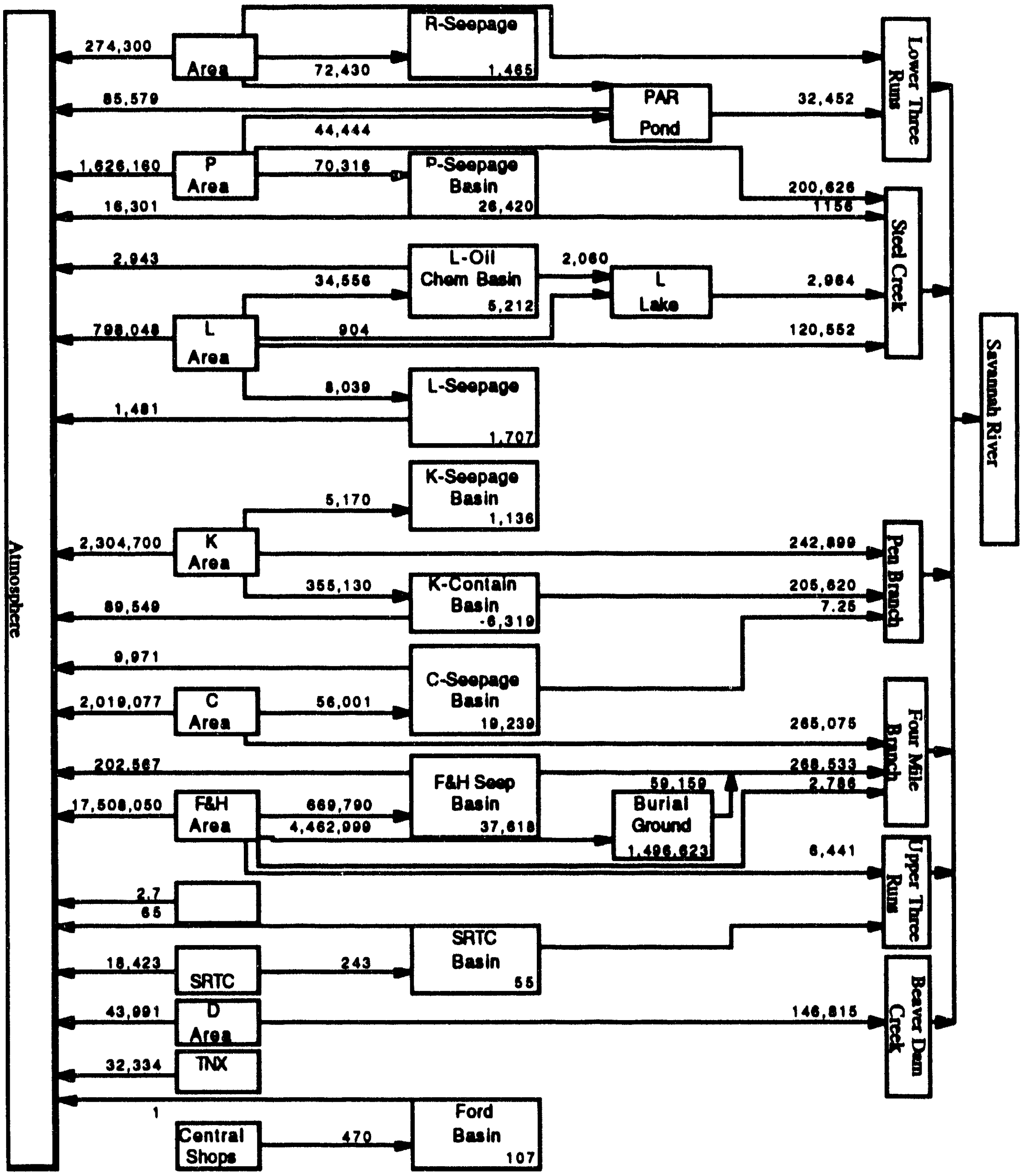

Figure 3.70 The Transport of Tritium at the Savannah River Site During the Period 1952 to 1991 (numbers are in Curies)

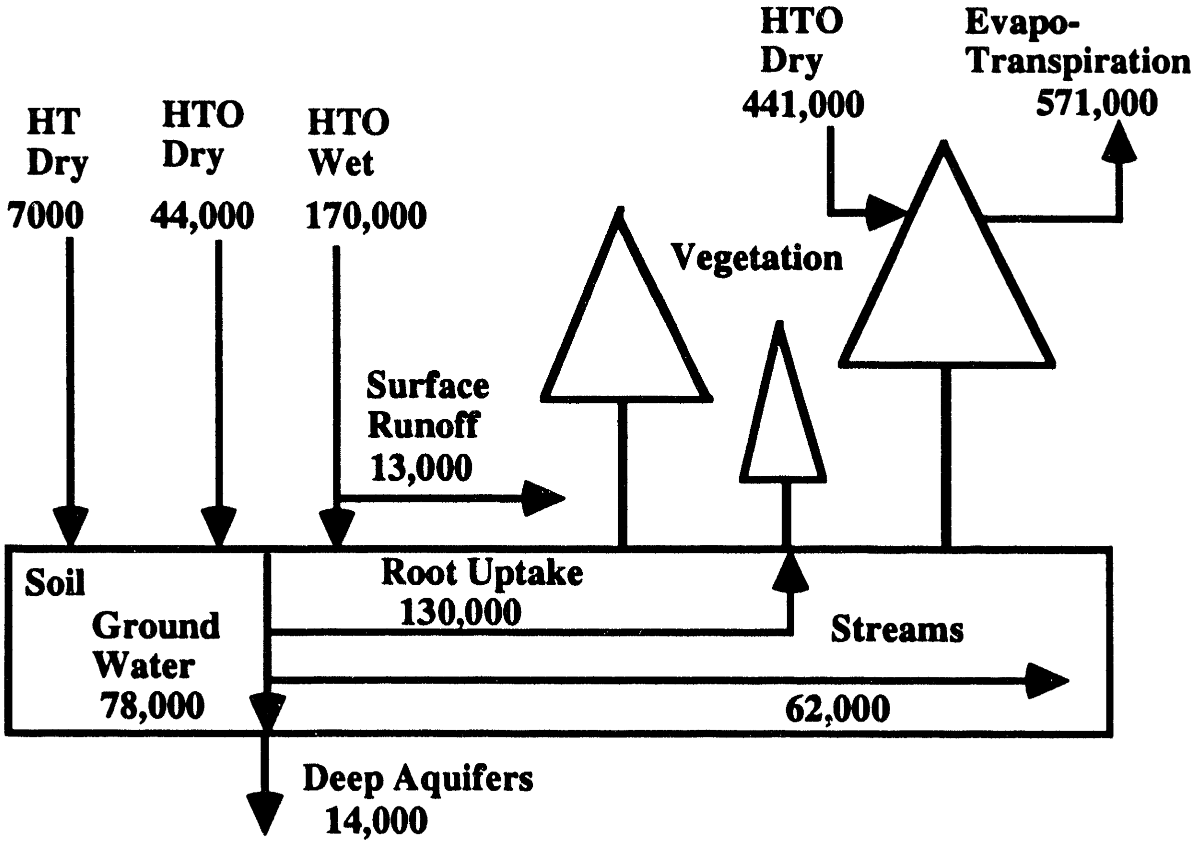

Figure 3.71 The Cycling of Tritium (in Curies) Released to the Atmosphere at SRS from 1952-1991

basins between 1952 and 1991, 302,000 Ci (25%) have decayed before leaving SRS, and 0.086 million Ci (13%) remain in the ground where much of it will decay before it is transported offsite. The rest of the seepage basin releases have already left the site. Approximately 475,000 Ci (36%) have entered surface streams or lakes and left SRS through the Savannah River, and 323,000 Ci (27%) have entered the atmosphere by evaporation.

Between 1954 and 1991, liquid tritiated water has been released into six surface stream drainages: Lower Three Runs Creek, Steel Creek, Pen Branch, Fourmile Branch, Upper Three Runs Creek, and Beaver Dam Creek. Since construction of Par Pond in 1956, releases to Lower Three Runs have passed through Par Pond. Since 1985, releases to Steel Creek have passed through L Lake. Of the approximately 1.6 million Ci of tritium (70%) released directly to surface waters and 475,000 Ci (30%) entering surface waters from seepage basins, 1.5 million Ci (94%) moved offsite into the Savannah River. The remaining 82,000 Ci evaporated into the atmosphere from the cooling lakes.

The other major repository of tritium onsite is the SWDF. Of the 4.2 million Ci of tritium buried, only 1.5 million Ci remained at the end of 1991. Almost all of the decrease in the inventory is due to radioactive decay. A small amount of tritium is known to have left the SWDF by way of Fourmile Branch.

The main paths for tritium leaving SRS are by transport in the atmosphere and in site streams to the Savannah River. Since site startup in 1952 through 1991, 25 million Ci of tritium (94%) have left the plant site through the atmosphere and 1.6 million Ci (6%) have left through the Savannah River.

Tritium Cycling Within 100 Kilometers of SRS

Tritium cycling in the environment near SRS can be estimated by the same procedure that was used to determine the magnitude of cycling inside the SRS boundary. The deposition within a radius of 100 km indicates that much of the tritium interacts with the local environment in the vicinity of SRS (Table 3-20).

Table 3-20 Deposition of Tritium Within 100 Km of SRS

Mechanism	Total Deposition 1954-1991*	Percent of Release
Water Vapor		
Vegetation	4,819,000	20
Soil	483,000	2
Hydrogen Soil	105,000	<1
Rain	1,753,000	7
Total	7,810,000	29

*Curies

The results of the calculation indicate that almost one-third of the tritium released has become part of the hydrologic cycle before leaving the 100-km zone around SRS. The redistribution in the environment can be estimated by using Tablee 3-19.

These calculations show (see Table 3-21) that even though 29% of the tritium released interacts with the environment in the vicinity of SRS, two-thirds of the interaction is deposition followed by almost immediate re-evaporation from the vegetation. Another 20% of the deposited tritium is eventually re-evaporated from the soil, either from the soil surface or through uptake by the vegetation. Therefore, only 10% of the deposited tritium, or 2.7% of the total releases, has become part of the groundwater, and less than 0.2% has percolated to the deeper layers of the soil. From this analysis, it can be concluded that most of the tritium released from SRS does not remain in the local environment but becomes part of the global inventory of tritium.

Table 3-21 Redistribution of Tritium in the Hydrologic Cycle in the Vicinity of SRS

Mechanism	Amount 1954-91*	Percent Deposition	Percent Release
Evaporation			
Soil	1,459,000	20	5.7
Vegetation	4,808,000	67	19.2
Run-off	147,000	2	0.6
Groundwater	682,000	10	2.7
Deep Layers	52,000	1	0.2

*Curies

The Fate of SRS Tritium in the Global Environment

The fate of SRS tritium, once it has been released to the environment, has been assessed by using the global compartment model described in NCRP Report No. 62 (NCRP 1979a). This model was developed to determine the dose to the worldwide population from all tritium sources. As described in Chapter 1, the main source of tritium is the bomb tritium released to the upper atmosphere during nuclear testing in the 1950s and early 1960s. Tritium concentrations in air moisture and streams have been used to validate this model with reasonable success.

The model is based on seven compartments, which are the main global reservoirs for water. The compartments are the atmospheric moisture, soil moisture, groundwater, surface fresh waters (rivers and lakes), inland saline surface waters, the well-mixed surface ocean, and the deep ocean. Tritium is assumed to move with the water. The transport of water between compartments is based on the generalized global water budget.

The fate of SRS tritium was estimated by using the SRS atmospheric and stream releases as input for the model. The tritium released to the burial ground and the tritium that still resides under the seepage basins was not included since it has not left the SRS. The results are illustrated in Figuree 3.72. The results indicate that most of the tritium is rapidly moved to the surface ocean. After only 10 years, 70% of the tritium remaining after radioactive decay is in the surface ocean. The movement into the deep ocean is somewhat slower, but at the end of 1988, 91% of the total tritium remaining in the environment from SRS releases is in either the surface (47%) or deep ocean (44%).

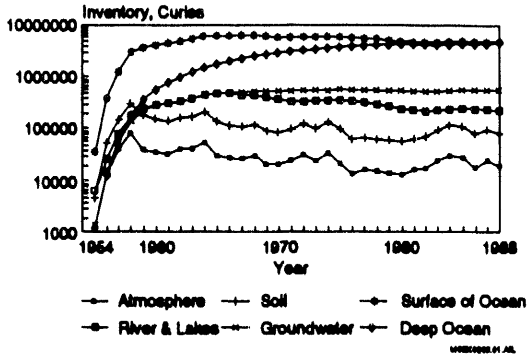

Figure 3.72 The Global Distribution of SRS Tritium Releases According to the NCRP Seven-Compartment Model

The tritium in the ocean is greatly diluted by the large mass of water. The calculated surface ocean concentration due to SRS releases is only 0.0002 pCi/ml. The concentration in the deep ocean is calculated to be even less, 0.000003e pCi/ml.

The tritium in the atmosphere and soil have decreased slowly since a peak in 1957. This is a reflection of the trend of decreasing SRS releases following the peaks in the early 1950s. The decrease in the surface and groundwater tritium inventory is slower, with peaks in 1965 and 1973, respectively. This is a reflection of the slower turnover of groundwater.

Because of the rapid distribution and dilution of tritium in the global water reservoir, the consequences of tritium released from SRS nuclear facilities are quite small.

Chapter 4. Assessment of Dose/Risk from SRS Tritium Releases

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Relationship of Dose to Risk and Health Effects

Ionizing Radiation

Ionizing radiation is radiation that strips electrons from matter through which it passes. The interaction of ionizing radiation with biological systems can produce, through a series of chemical and physical reactions, permanent changes in the genetic material of the cell. These changes (mutations) may cause abnormal functioning within the cell or may lead to cell death.

The nature of radiation-induced cellular changes is dependent upon the magnitude of the dose and the rate at which it is received. For the low doses and dose rates encountered in the environment from SRS releases, the most significant effect is cancer induction.

This is believed to be a stochastic effect; i.e., an increase in dose increases the probability of the effect, but the severity of the effect is independent of the dose.

A characteristic of a stochastic risk is the absence of a threshold. In other words, it is conceivable that any dose of radiation, no matter how small, might give rise to a cancer. On the other hand, there is no way to be certain that a given dose, no matter how large, has caused or ultimately will cause a cancer in an individual.

Cancer Risk Estimates

The most comprehensive estimates of cancer induction by exposure to ionizing radiation come from studies of the atomic bomb survivors at Hiroshima and Nagasaki. Less definitive studies include those of medical patients exposed to therapeutic and diagnostic radiation. Studies of laboratory animals have increased the understanding of dose effect relationships. The International Commission on Radiological Protection (ICRP) has evaluated all of these studies and concluded that the best estimate of lifetime risk of fatal cancer for members of the general population is approximately 500 cases per 1,000,000 person-rem. This is equivalent to one case per 2,000 person-rem (ICRP, 1991).

Tritium Exposure and Dose To Man

Tritium in the environment becomes an exposure risk to man when it is inhaled, absorbed through the skin, or ingested in food or drinking water. Tritium does not contribute to the external radiation dose because the energy of the beta particle is too weak to penetrate the sensitive tissues of the body such as the lens of the eye and the basal layer of the epidermis (ICRP 1978).

The magnitude of the risk from tritium is dependent upon whether it is present in a form that is biologically active (water or water vapor) or inert (elemental gas). Significant amounts of both forms of tritium are released to the environment from the SRS. Additionally, a minor amount (less than 1%) is released in an organic form, tritiated methane.

Distribution and Retention of Tritium in the Body

Tritiated Water

Inhalation and absorption - Essentially all of the tritium inhaled in the form of water vapor will be absorbed by and retained in body fluids, and will do so within seconds (NCRP 1979a, ICRP 1978). Tritium may also be absorbed through the skin during periods of exposure to tritiated water. For an average person ("Reference Man"), the amount absorbed is approximately equal to 50% of that inhaled (ICRP 1974). Tritium absorbed through the skin will be transported to, and distributed among, body fluids via the same mechanisms as tritium introduced by inhalation.

Ingestion - Ingested tritiated water is assumed to be completely and instantaneously absorbed from the gastrointestinal tract and mixed rapidly with body water so that, at all times following ingestion, the concentration in sweat, sputum, urine, blood, perspiration, and expired water vapor is the same (ICRP 1978).

Biological fate - Tritium that is uniformly distributed in body fluids will be eliminated at the same rate as ordinary water. The rate of elimination may vary considerably due to such factors as fluid intake, metabolism, and ambient temperature. The time required to eliminate 50% of the tritiated water present in the body ranges from 4 to 18 days. There is some evidence for longer tritium retention times in other body compartments, but this is believed to represent less than 10% of the whole body dose from tritiated water (ICRP,1978). For internal dose purposes, the ICRP assumes that tritiated water is uniformly distributed in all soft tissues at any time following intake and eliminated exponentially with a half-time of 10 days.

Elemental Tritium

When tritium is present in the atmosphere in an elemental form, it represents a very minor exposure hazard. The risks associated with inhalation and skin absorption are essentially eliminated in the case of elemental tritium because its low solubility prevents its absorption by body fluids. Only about 0.004% of the tritium entering the body is converted to tritiated water and retained in body fluids (NCRP 1979a).

The only direct hazard from exposure to elemental tritium is the dose received by the lungs when the tritiated gas is inhaled, but this is an insignificant source of exposure from SRS operations. During a typical year, the average concentration of elemental tritium at the site perimeter (about 90 pCi/m^3) would deliver a lung dose equivalent of less than 0.0001 mrem if inhaled continuously for a year.

Organic Forms

Inhalation - Many forms of tritiated organic compounds (e.g., thymidine) are of such low volatility that the probability of their being inhaled is quite small. In circumstances where they might be inhaled, it is assumed that they are instantaneously and completely translocated to the blood without a change in chemical form. Once in the bloodstream, there is some potential for partial catabolism to tritiated water.

Ingestion - When tritiated organic compounds are ingested in food or water, a large fraction may be broken down in the gastrointestinal tract, producing tritiated water. In rodents, for example, more than 90% of the tritiated thymidine is broken down in the gastrointestinal tract, and only about 2% is actually incorporated into DNA. Tritium may be incorporated into lipids, proteins, and carbohydrates at much higher percentages (van den Hoek 1979). However, it is the potential incorporation of radioactive materials into DNA that presents a less probable but more serious threat to biological systems (NCRP 1979a).

Tritium Incorporation In DNA

The incorporation of tritium into DNA may result in undesirable genetic or somatic changes. The radioactive decay of a tritium atom located on a DNA molecule can result in a break or rearrangement of a DNA segment. However, for low doses and low dose rates, the biological effect of such an event is small in relation to the effect of ionization on the other components of the cell (NCRP 1979a, NCRP 1979b).

Tritium Transport And Dose Models

Tritium can be measured in food, air, and water. Because it is impractical to collect sufficient monitoring data to determine individual doses in a large population group, radiation doses to offsite populations are calculated with mathematical models. These models use known transport mechanisms for atmospheric and liquid releases and known major pathways of exposure to man. Environmental measurements of tritium oxide (which is released during normal operations) are used to verify atmospheric dispersion in the transport models.

Calculational Models

The models used for calculating the SRS average annual offsite doses are the transport and dose models developed for the nuclear industry (NRC 1977a and 1977b) to assess the effects of operations of licensed nuclear facilities. The models are implemented at SRS in the following computer programs:

Atmospheric Releases

- MAXIGASP: - calculates maximum and average doses to offsite individuals.
- POPGASP: - calculates offsite population doses.

Liquid Releases

- LADTAP: - calculates maximum and average doses to offsite individuals and collective doses to offsite populations.

MAXIGASP and POPGASP are SRTC-modified versions of the Nuclear Regulatory Commission programs XOQDOQ and GASPAR. The modifications were made to accommodate the input of physical and biological data that are specific to the

SRS. The basic calculations in the XOQDOQ and GASPAR programs have not been modified.

LADTAP XL (Hamby, 1991a) utilizes the same basic dispersion and dosimetric models as the NRC version, LADTAP II (Simpson and McGill, 1980), and can be run on a personal computer in a user-friendly environment.

Modeling Atmospheric Dispersion of Radioactive Releases

The routine atmospheric transport of radioactive materials from the SRS is evaluated on the basis of meteorological conditions measured continuously at nine onsite and one offsite meteorological towers. The towers relay wind speed, direction, and atmospheric stability information at 5-sec intervals to the Savannah River Technology Center via the WIND (Weather INformation and Display) system. A data base of this information containing the 60-min average values for the period 1982-1986 is accessed by the dispersion codes to determine site specific atmospheric dispersion characteristics.

The dispersion of an atmospheric release from SRS is modeled using the nuclear industry computer program, XOQDOQ (Sagendorf, and Goll, 1976). XOQDOQ computes concentrations in the plume as a function of downwind distance and compass sector. At the user's option, the plume can be depleted due to dry deposition and/or radioactive decay. Also at the user's option, plume concentrations can be reduced by taking into account the upward displacement of the plume resulting from thermal buoyancy and/ or momentum effects. This option is not used at SRS; i.e., no credit is taken for plume rise.

The plume concentration information generated by XOQDOQ is then used by a dose modeling program, GASPAR, to estimate doses to offsite individuals and populations. GASPAR (Eckerman 1980) estimates doses from a number of pathways, which are illustrated in a general sense in Figure 4.1.

The doses produced by GASPAR are reported on a pathway-specific basis as follows:

- Plume - external dose from radioactive materials suspended in the atmosphere
- Ground - external dose from radioactive materials deposited on the ground
- Inhalation - internal dose from inhalation of radioactive materials present in the plume
- Vegetation - internal dose from consumption of contaminated crops
- Milk - internal dose from consumption of milk produced in a contaminated area
- Meat - internal dose from consumption of meat products produced in a contaminated area

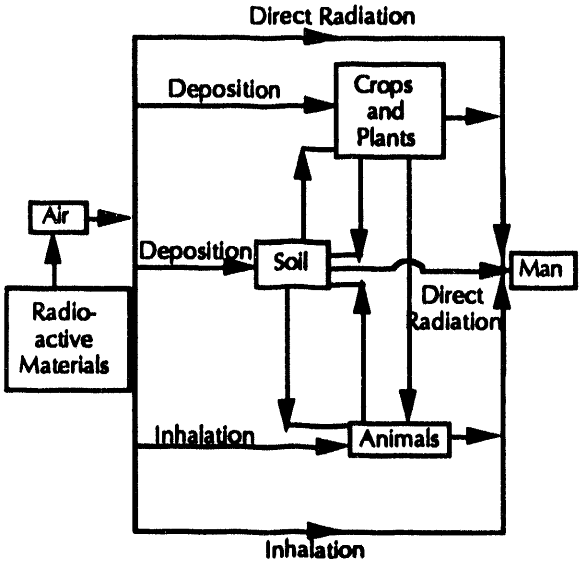

Figure 4.1 Simplified Pathways Between Radioactive Materials Released to the Atmosphere and Man

The method of modeling the concentration of radioactivity as it moves through these pathways is fairly consistent from radionuclide to radionuclide. There is, however, a significant modification made for tritium. For dose purposes, it is assumed that the tritium concentration in vegetation does not exceed 50% of the tritium concentration in atmospheric water vapor. This reflects the fact that not all of the water content of a plant is derived from water vapor impacted by SRS operations. Distant sources of water such as rain have very little tritium content and therefore dilute the tritium concentration of the plant.

MAXIGASP - The calculations required by XOQDOQ and GASPAR to estimate maximum and average individual doses are performed at the SRS using the computer program MAXIGASP. MAXIGASP calculates annual average air and ground deposition concentrations per unit release at a number of points along the site boundary in each of the 16 compass sectors.

The main outputs from the program are the doses at the location of the maximum effective dose equivalent to individuals along the SRS perimeter. The maximally exposed individual is assumed to reside continuously at the location of highest exposure. This individual is also assumed to have living and eating habits which maximize his dose. These assumptions provide a ceiling on doses from atmospheric releases because no such individual is believed to exist.

The average dose at the site perimeter is calculated for a number of locations along the perimeter, and these data are then averaged. Calculations for average individual doses are made with living and eating parameters that are more realistic than those for a maximum individual.

The parameters used to calculate doses with MAXIGASP are shown in Table 4-1.

POPGASP - The calculations required by XOQDOQ and GASPAR to estimate population doses from atmospheric releases are performed at the SRS using a computer program called POPGASP. POPGASP calculates annual average air and ground deposition concentrations per unit release for each of 160 segments (16 wind direction sectors at 10 distances per sector) within a 80-km radius of the release location.

In addition to sector-specific meteorological information, POPGASP uses sector-specific data on population density and milk, meat, and vegetable production and consumption. These data are quite extensive and are available for review in the SRS Environmental Reports published annually. With srespect to the human parameters used in POPGASP, the key values are presented in Table 4-1.

Table 4-1 Site-Specific Parameters for Atmospheric Releases

Demographic Data

Population Group	Population Size
80-mile radius	555,100

Exposure Pathway	Maximum Individual (MAXIGASP) Adult
Inhalation (m³/yr)	8,000
Ingestion	
Cow's milk (L/yr)	230
Meat (kg/yr)	81
Leafy vegetables (kg/yr)	43
Fruits, grains, and other leafy vegetables (kg/yr)	276
External exposure	
Transmission factor for shielding from buildings	0.7

Exposure Pathway	Average Population (POPGASP) Adult
Inhalation (m³/yr)	8,000
Ingestion	
Cow's milk (L/yr)	120
Meat (kg/yr)	43
Leafy vegetables (kg/yr)	21
Fruits, grains, and other vegetables (kg/yr)	163
External exposure	
Transmission factor for shielding from buildings	0.5

Modeling Doses from Liquid Releases

The consequences of liquid releases from the SRS are modeled using LADTAP XL (Liquid Annual Doses To All Persons). The potential pathways of exposure from liquid releases to the environment are shown in Figure 4.2. The pathway-specific doses calculated by LADTAP XL are grouped into the following four categories:

- **Potable drinking water** - internal dose from consuming drinking water of Savannah River origin
- **Sports fish and commercial fish** - internal dose from consuming fish of Savannah River origin
- **Saltwater invertebrates** - internal dose from consuming shellfish from estuaries of the Savannah River
- **Recreation** - external dose from recreation (boating, swimming, and shoreline) activities in and along the Savannah River

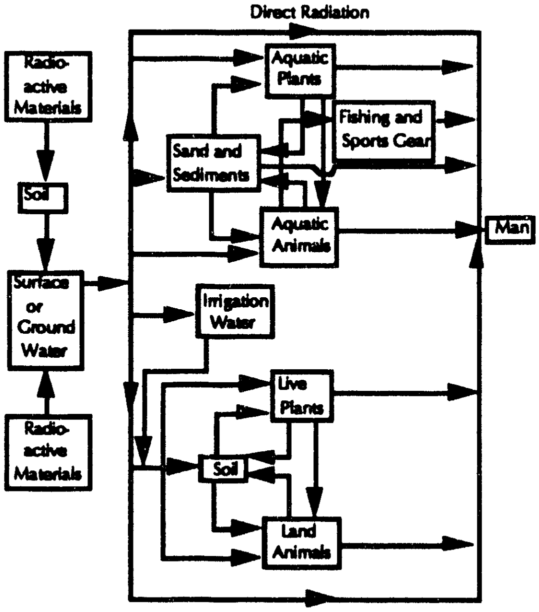

Figure 4.2 Simplified Pathways Between Radioactive Materials Released to Groundwater or Surface Waters and Man

LADTAP XL estimates individual and doses at specific downstream locations. The only removal mechanism included in the transport model as it is used at the SRS is radioactive decay. There is no credit for adsorption on stream sediments.

The major assumption inherent in the application of LADTAP XL to SRS' releases is that liquid discharges undergo complete mixing in the Savannah River before reaching potentially exposed populations. This assumption is supported by repeated measurements indicating that complete mixing occurs in the river between the SRS and the Highway 301 sampling station (Cummins et al., 1990a).

LADTAP XL generates maximum individual and population doses for all the exposure pathways identified above. LADTAP XL calculations are performed with SRS-specific information to the extent that it is available. Summary tables of principal input values used in LADTAP XL are shown in Tables 4-2 and 4-3.

Radioisotope concentrations in the Savannah River are diluted by the inflow of streams downriver from the SRS. Additional dilution occurs at the Beaufort-Jasper water treatment plant due to the inflow of surface water and at the Port Wentworth water treatment plant due to the close proximity of Abercorn Creek to the intake. Since tritium is readily measured in the processed water of each system, a derived river flow rate can be calculated which allows better estimates of radionuclide concentrations at these treatment plants (Hayes and Marter 1991).

DOE Internal Dose Factors

To calculate the committed dose equivalent to specific organs and the committed effective dose equivalent to an individual, the dose codes described above access dose factor libraries. The libraries contain radionuclide specific and exposure pathway-specific factors which express the 50-year committed dose that would result from the intake of a unit quantity of radioactivity, normally 1 becquerel (1 Bq) or 1 picocurie (1 pCi).

DOE internal dose factors are used at the SRS. They are based on methods and data from ICRP 1978 and DOE 1988. (The dose factors used by DOE are in the form of mrem/pCi of intake.)

For tritium oxide, the DOE dose factors are:

- 9.5×10^{-8} mrem/pCi inhaled (includes skin absorption) and,
- 6.3×10^{-8} mrem/pCi ingested.

Table 4-2 Site-specific Parameters for Liquid Releases

	Maximum Individual Dose Assessments (LADTAP XL)
Site Parameters	
Savannah River flow rate, (ft^3/sec)	6,000 or measured average
Transit time from SRS to Savannah River, (hr)	24
Transit time from river to water treatment plants, (hr)	72
Transit time from water treatment plant to consumer, (hr)	24
Shore-width factor	0.02
	Maximum Individual
Human Parameters	**Adult**
Water Consumption (L/yr)	370 (730)[a]
Fish Consumption (kg/yr)	19
Shellfish Consumption (kg/yr)	8
Shoreline Recreation (hr/yr)	23
Swimming (hr/yr)	8.9
Boating (hr/yr)	21

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[a] The value in parentheses is the EPA parameter mandated for use when calculating maximum individual doses to Beaufort-Jasper and Port Wentworth water users.

Table 4-3 Additional Site-Specific Parameters for Liquid Releases

	Average Individual/Population Dose Assessments (LADTAP XL)
Site Parameters	
Savannah River flow rate, (ft^3/sec)	10,000 or measured average
Transit time from SRS to Savannah River, (hr)	24
Transit time from SRS to water treatment plants, (hr)	72
Retention time in water treatment system, (hr)	24
Shore-width factor	0.2
River dilution in estuary	3
Aquatic food harvest, edible portions (kg/yr)	
Sport fish	35,000
Commercial fish	2,700
Saltwater invertebrates	390,000
Demographic Data	
Population Group	**Size**
50-mile radius	555,100
Beaufort-Jasper water users	50,000
Port Wentworth water users	15,000
	Average Individual
Human Parameters	**Adult**
Water Consumption (L/yr)	370
Fish Consumption (kg/yr)	9
Shellfish Consumption (kg/yr)	2
	Usage (person-hr)
Shoreline Recreation (hr/yr)	960,000
Swimming (hr/yr)	160,000
Boating (hr/yr)	1,100,000

Verification of Models Using Monitoring Data

Atmospheric Releases

The tritium concentrations predicted by MAXIGASP and POPGASP are routinely compared with measured values of tritium in air to evaluate the performance of the codes. Table 4-4 shows a comparison of calculated and measured tritium oxide concentrations in air at the site perimeter. Other comparisons of predicted and measured concentrations have been performed (Marter 1984) and have exhibited similar results. Thus, the available data suggest that calculated concentrations of tritium in air are generally conservative estimates of actual offsite values.

Table 4-4 Comparison of Average Calculated and Measured Concentrations of Tritium at the Site Boundary

	Tritium Oxide Concentration (pCi/m^3)		
Year	**Calculated**	**Measured**	**Ratio: Calc/Measured**
1985	190	120	1.6
1986	88	79	1.1
1987	81	81	1.0
1988	87	54	1.6
1989	65	37	1.8
1990	53	32	1.7
1991	42	21	2.0
		Average	1.5

Liquid Releases

The Savannah River flow rate is one of the major parameters in the dose calculation. The flow rate at Highway 301 is taken from USGS records and the flow rate at the water treatment plants is calculated from actual tritium measurements (Hayes and Marter, 1991). Water pumped from the Savannah River for the Beaufort-Jasper treatment plant is diluted with surface water inflow and water for the Port Wentworth treatment plant is diluted with water from Abercorn Creek. Calculation of dose for the water treatment plants is based on a "derived" river flow rate rather than actual flow rate, and takes into account dilution of the river water.

Impact of SRS Tritium Releases on the Offsite Population

The computer codes MAXIGASP, POPGASP, and LADTAP have been used to calculate effective dose equivalents (EDEs) theoretically received by segments of the offsite population from tritium exposure over the course of SRS operations. The results are presented in Tables 4-5 and 4-6 for doses attributable to atmospheric and liquid releases, respectively. Atmospheric tritium release levels have consistently exceeded liquid tritium release levels, and this trend is reflected in the doses to the offsite populations reported in the tables.

Doses from Atmospheric Releases

As shown in Table 4-5, the largest annual dose equivalent theoretically received by an individual occurred in 1958, the year atmospheric releases peaked. Doses to the "maximum" and "average" individuals at the site perimeter in 1958 were 1.87 and 0.89 mrem, respectively. However, the SRS "maximum" individual is a hypothetical person who lives at the SRS boundary and consumes large amounts of milk, meat, and vegetables, all of which are produced near that location. No such individual is known to exist.

The maximum dose equivalent over the 38-year period of plant operation was 19 mrem. Over a 38-year period, however, an individual living in the central Savannah River area would receive a dose of approximately 11,970 mrem from exposure to natural sources of radioactivity and an additional 2,400 mrem from medical practices and various consumer products (WSRC 1991). Therefore, the cumulative contribution to dose from SRS atmospheric tritium releases to an average offsite individual at the site boundary was less than 0.13%.

Table 4-5 Atmospheric Tritium Releases and Offsite Doses (1955-1991)

	Atmospheric Tritium Releases			Offsite Annual and Cumulative Dose		
Year	Total Original Release (Ci)a	HTO Component (Ci)b	Total Decay Corrected (Ci)c	Max Ind EDE (mrem)	Avg Ind EDE (mrem)	80-km POP EDE (per-rem)e
1954	$2.16x10^{2}$		$2.64x10^{1}$	$1.72x10^{-4}$	$8.16x10^{-5}$	$1.06x10^{2}$
1955	$3.61x10^{4}$		$4.66x10^{3}$	$2.87x10^{-2}$	$1.36x10^{-2}$	$1.77x10^{0}$
1956	$4.69x10^{5}$		$6.40x10^{4}$	$3.72x10^{-1}$	$1.77x10^{-1}$	$2.30x10^{1}$
1957	$1.20x10^{6}$		$1.73x10^{5}$	$9.53x10^{-1}$	$4.54x10^{-1}$	$5.88x10^{1}$
1958	$2.36x10^{6}$		$3.60x10^{5}$	$1.87x10^{0}$	$8.92x10^{-1}$	$1.16x10^{2}$
1959	$1.05x10^{6}$		$1.70x10^{5}$	$8.34x10^{-1}$	$3.97x10^{-1}$	$5.15x10^{1}$
1960	$9.51x10^{5}$		$1.62x10^{5}$	$7.55x10^{-1}$	$3.59x10^{-1}$	$4.66x10^{1}$
1961	$8.86x10^{5}$		$1.60x10^{5}$	$7.03x10^{-1}$	$3.35x10^{-1}$	$4.34x10^{1}$
1962	$1.11x10^{6}$		$2.12x10^{5}$	$8.81x10^{-1}$	$4.20x10^{-1}$	$5.44x10^{1}$
1963	$1.13x10^{6}$		$2.28x10^{5}$	$8.97x10^{-1}$	$4.27x10^{-1}$	$5.54x10^{1}$
1964	$1.52x10^{6}$		$3.25x10^{5}$	$1.21x10^{0}$	$5.75x10^{-1}$	$7.45x10^{1}$
1965	$7.44x10^{5}$		$1.68x10^{5}$	$5.91x10^{-1}$	$2.81x10^{-1}$	$3.65x10^{1}$
1966	$6.75x10^{5}$		$1.61x10^{5}$	$5.36x10^{-1}$	$2.55x10^{-1}$	$3.31x10^{1}$
1967	$6.89x10^{5}$		$1.74x10^{5}$	$5.47x10^{-1}$	$2.60x10^{-1}$	$3.38x10^{1}$
1968	$7.62x10^{5}$		$2.04x10^{5}$	$6.05x10^{-1}$	$2.88x10^{-1}$	$3.73x10^{1}$
1969	$4.96x10^{5}$		$1.40x10^{5}$	$3.94x10^{-1}$	$1.87x10^{-1}$	$2.43x10^{1}$
1970	$5.13x10^{5}$		$1.54x10^{5}$	$4.07x10^{-1}$	$1.94x10^{-1}$	$2.51x10^{1}$
1971	$6.21x10^{5}$		$1.97x10^{5}$	$4.93x10^{-1}$	$2.35x10^{-1}$	$3.04x10^{1}$
1972	$8.22x10^{5}$		$2.75x10^{5}$	$6.53x10^{-1}$	$3.11x10^{-1}$	$4.03x10^{1}$
1973	$6.01x10^{5}$		$2.13x10^{5}$	$4.77x10^{-1}$	$2.27x10^{-1}$	$2.94x10^{1}$
1974	$9.37x10^{5}$		$3.51x10^{5}$	$7.44x10^{-1}$	$3.54x10^{-1}$	$4.59x10^{1}$
1975	$5.18x10^{5}$		$2.05x10^{5}$	$4.11x10^{-1}$	$1.96x10^{-1}$	$2.54x10^{1}$
1976	$3.04x10^{5}$		$1.27x10^{5}$	$2.41x10^{-1}$	$1.15x10^{-1}$	$1.49x10^{1}$
1977	$3.81x10^{5}$		$1.69x10^{5}$	$3.03x10^{-1}$	$1.44x10^{-1}$	$1.87x10^{1}$
1978	$3.60x10^{5}$		$1.69x10^{5}$	$2.86x10^{-1}$	$1.36x10^{-1}$	$1.76x10^{1}$
1979	$3.33x10^{5}$		$1.65x10^{5}$	$2.64x10^{-1}$	$1.26x10^{-1}$	$1.63x10^{1}$
1980	$3.17x10^{5}$		$1.66x10^{5}$	$2.52x10^{-1}$	$1.20x10^{-1}$	$1.55x10^{1}$
1981	$3.95x10^{5}$		$2.19x10^{5}$	$3.14x10^{-1}$	$1.49x10^{-1}$	$1.94x10^{1}$
1982	$4.34x10^{5}$		$2.55x10^{5}$	$3.45x10^{-1}$	$1.64x10^{-1}$	$2.13x10^{1}$
1983	$6.18x10^{5}$		$3.84x10^{5}$	$4.91x10^{-1}$	$2.34x10^{-1}$	$3.03x10^{1}$
1984	$7.86x10^{5}$		$5.16x10^{5}$	$6.24x10^{-1}$	$2.97x10^{-1}$	$3.85x10^{1}$
1985	$6.67x10^{5}$	$4.87x10^{5}$	$4.63x10^{5}$	$3.87x10^{-1}$	$1.84x10^{-1}$	$2.39x10^{1}$
1986	$4.25x10^{5}$	$2.85x10^{5}$	$3.12x10^{5}$	$2.26x10^{-1}$	$1.08x10^{-1}$	$1.40x10^{1}$
1987	$5.90x10^{5}$	$2.70x10^{5}$	$4.58x10^{5}$	$2.14x10^{-1}$	$1.02x10^{-1}$	$1.32x10^{1}$
1988	$4.62x10^{5}$	$2.88x10^{5}$	$3.80x10^{5}$	$2.29x10^{-1}$	$1.09x10^{-1}$	$1.41x10^{1}$
1989	$3.09x10^{5}$	$2.18x10^{5}$	$2.69x10^{5}$	$1.73x10^{-1}$	$8.24x10^{-2}$	$1.07x10^{1}$
1990	$2.53x10^{5}$	$1.75x10^{5}$	$2.33x10^{5}$	$1.39x10^{-1}$	$6.62x10^{-2}$	$8.58x10^{0}$
1991	$2.00x10^{5}$	$1.37x10^{5}$	$1.94x10^{5}$	$1.09x10^{-1}$	$5.18x10^{-2}$	$6.71x10^{0}$
TOTALS	$2.49x10^{7}$	$1.86x10^{6}$	$8.58x10^{6}$	$1.90x10^{1}$	$9.03x10^{0}$	$1.17x10^{3}$

Notes

a All doses based on undecayed activity.

b The ratio of elemental tritium to tritium oxide is known for the period 1985-1991 based onmeasurements of elemental and total tritium. Because elemental tritium is an insignificant contributor to dose, the dose calculations for that period were based exclusively on tritium oxidevalues. For previous years tritium doses have been overestimated, as they were based on the very conservative assumption that all releases were 100% oxide.

c Annual releases have been decay-corrected to 01-01-92 to show remaining tritium inventory.

d Dose values are effective dose equivalents.

e Population dose equivalents are environmental dose commitments (EDCs) to the population within an 80-km radius of SRS.

Table 4-6 Liquid Tritium Releases (1955-1991)

				Tritium Releases to Streams			
Year	River Flow Rate (cfs)[a]	B-J Derived Flow Rate (cfs)	PW Derived Flow Rate (cfs)	Direct Releases to Streams (Ci)	Seepage to Streams (Ci)	Original Total Release (Ci)	Decay Corrected Total (Ci)[b]
1955	5974		7528	$5.87x10^{3}$	$0x10^{0}$	$5.87x10^{3}$	$7.57x10^{2}$
1956	6309		7949	$9.39x10^{3}$	$0x10^{0}$	$9.39x10^{3}$	$1.28x10^{3}$
1957	8312		10473	$1.50x10^{4}$	$0x10^{0}$	$1.50x10^{4}$	$2.17x10^{3}$
1958	11038		13908	$2.40x10^{4}$	$4.00x10^{2}$	$2.44x10^{4}$	$3.73x10^{3}$
1959	9748		12283	$4.12x10^{4}$	$8.00x10^{2}$	$4.20x10^{4}$	$6.78x10^{3}$
1960	13112		16521	$4.69x10^{4}$	$1.60x10^{3}$	$4.85x10^{4}$	$8.28x10^{3}$
1961	10909		13745	$5.38x10^{4}$	$2.00x10^{3}$	$5.58x10^{4}$	$1.01x10^{4}$
1962	10580		13331	$4.67x10^{4}$	$1.70x10^{3}$	$4.84x10^{4}$	$9.25x10^{3}$
1963	11138		14034	$7.47x10^{4}$	$2.70x10^{3}$	$7.74x10^{4}$	$1.56x10^{4}$
1964	20497		25826	$8.07x10^{4}$	$4.70x10^{3}$	$8.54x10^{4}$	$1.83x10^{4}$
1965	12785	28254	16109	$9.84x10^{4}$	$5.60x10^{3}$	$1.04x10^{5}$	$2.35x10^{4}$
1966	11175	18376	14080	$7.73x10^{4}$	$4.60x10^{3}$	$8.19x10^{4}$	$1.96x10^{4}$
1967	10573	22066	13322	$6.40x10^{4}$	$5.60x10^{3}$	$6.96x10^{4}$	$1.76x10^{4}$
1968	9624	16615	12126	$5.58x10^{4}$	$5.79x10^{3}$	$6.16x10^{4}$	$1.65x10^{4}$
1969	10945	22034	13790	$4.54x10^{4}$	$1.88x10^{4}$	$6.42x10^{4}$	$1.82x10^{4}$
1970	8208	27280	10342	$2.39x10^{4}$	$1.29x10^{4}$	$3.68x10^{4}$	$1.10x10^{4}$
1971	10686	43977	13464	$2.02x10^{4}$	$1.78x10^{4}$	$3.80x10^{4}$	$1.20x10^{4}$
1972	11235	27385	14156	$2.88x10^{4}$	$1.72x10^{4}$	$4.60x10^{4}$	$1.54x10^{4}$
1973	14431	23162	16544	$4.30x10^{4}$	$2.78x10^{4}$	$7.08x10^{4}$	$2.51x10^{4}$
1974	11101	22598	13182	$3.29x10^{4}$	$2.71x10^{4}$	$6.00x10^{4}$	$2.25x10^{4}$
1975	15408	30978	18987	$2.81x10^{4}$	$2.75x10^{4}$	$5.56x10^{4}$	$2.20x10^{4}$
1976	13914	35172	16660	$3.17x10^{4}$	$2.79x10^{4}$	$5.96x10^{4}$	$2.50x10^{4}$
1977	11646	19841	15306	$2.72x10^{4}$	$1.66x10^{4}$	$4.38x10^{4}$	$1.94x10^{4}$
1978	10522	24332	11450	$1.72x10^{4}$	$2.04x10^{4}$	$3.76x10^{4}$	$1.76x10^{4}$
1979	13252	34937	17469	$1.01x10^{4}$	$1.93x10^{4}$	$2.94x10^{4}$	$1.46x10^{4}$
1980	13201	30464	17219	$1.03x10^{4}$	$1.44x10^{4}$	$2.47x10^{4}$	$1.30x10^{4}$
1981	6599	11698	8579	$9.60x10^{3}$	$1.42x10^{4}$	$2.38x10^{4}$	$1.32x10^{4}$
1982	7169	19594	10135	$1.10x10^{4}$	$2.15x10^{4}$	$3.25x10^{4}$	$1.91x10^{4}$
1983	12348	12760	14723	$1.42x10^{4}$	$1.98x10^{4}$	$3.40x10^{4}$	$2.11x10^{4}$
1984	12759	26368	17196	$1.05x10^{4}$	$2.23x10^{4}$	$3.28x10^{4}$	$2.15x10^{4}$
1985	7167	9290	8959	$6.10x10^{3}$	$1.89x10^{4}$	$2.50x10^{4}$	$1.74x10^{4}$
1986	6175	8305	7526	$7.30x10^{3}$	$2.05x10^{4}$	$2.78x10^{4}$	$2.04x10^{4}$
1987	8955	13219	12619	$4.50x10^{3}$	$1.83x10^{4}$	$2.28x10^{4}$	$1.77x10^{4}$
1988	5364	7463	7152	$5.40x10^{3}$	$1.39x10^{4}$	$1.93x10^{4}$	$1.59x10^{4}$
1989	7966	8462	8650	$3.60x10^{3}$	$1.37x10^{4}$	$1.73x10^{4}$	$1.50x10^{4}$
1990	11858	15775	12958	$2.60x10^{3}$	$1.36x10^{4}$	$1.62x10^{4}$	$1.49x10^{4}$
1991	11598	19420	15981	$1.13x10^{4}$	$1.61x10^{4}$	$2.74x10^{4}$	$2.66x10^{4}$
TOTAL				$1.10x10^{6}$	$4.76x10^{5}$	$1.58x10^{6}$	$5.72x10^{5}$

Notes:

[a] Flow rates based on USGS measurements and Hayes, 1991.

[b] Decay corrected to 1/1/92. Doses based on original release.

Because the contribution of SRS tritium releases to any one individual's total radiation is so small, it is necessary to pool the radiation exposures from a given population if an assessment of potential health risks is desired. The population dose within an 80-km radius is the figure-of-merit frequently used to make such an assessment.

The collective doses to the 80 km population reported in Table 4-5 are based on 1980 census data (555,150 people) and current meteorological and dose factor data. If it is assumed that this population has lived in the SRS vicinity throughout the period of site operation, the total collective dose received by that population through 1991 was 1,170 person-rem. This dose is about 10% less than reported previously (Murphy, 1991), and is due to the use of more representative consumption values (Hamby, 1991 b).

Doses from Liquid Releases

Liquid releases of tritium and Savannah River flow rates are shown in Table 4-6. Dose equivalents received by downstream consumers of Savannah River water and fish are shown in Table 4-7. The dose calculations are based on the total number of curies released to onsite streams during 38-years of SRS operations. The release levels reflect contributions from all known effluents and seepage basin outcrops. Dose equivalents resulting from drinking treated river water have been calculated for maximum individuals and for the populations served by two water treatment plants, both of which are located approximately 160 km downstream. The total collective dose received by that population through 1991 was 123 person-rem. This dose is about 40% less than reported previously (Murphy, 1991) and is due to the inclusion of dilution of river water before reaching the water treatment plants (see page 4-9).

As shown in Table 4-7, the maximum dose equivalent reported was 0.33 mrem in 1965 for a user of the Port Wentworth water treatment plant. This maximum value, however, is based on a 2-L/day water consumption rate and is primarily used for comparison with EPA drinking water standards. More realistic water intake rates are used to generate the "average" downstream individual dose equivalents. However, even at the 2-L/day intake rate, the cumulative dose from liquid tritium releases throughout the period of site operation would be on the order of 6 mrem. Since this individual's dose from natural and other manmade sources of radiation for that same period would have exceeded 14,000 mrem, it may be concluded that the contribution to downstream individuals' doses by SRS releases to streams is insignificant.

With respect to the effect of liquid tritium releases on the downstream Savannah River population, drinking water doses for users of the Beaufort-Jasper, SC, (51,000 customers) and Port Wentworth, GA, (15,000 effective consumers) water treatment plants have also been calculated. Different terminology is used to describe the two populations to reflect the difference in their compositions. The Beaufort-Jasper plant serves residential areas and, therefore, provides full-scale domestic water service. The Port Wentworth facility serves a commercial complex in which contact with treated Savannah River water is possible for industrial workers who consume tap water.

In addition to these two groups of Savannah River water users, dose calculations for consumers of commercial and sport fish harvested from the Savannah River have been included in Table 4-7. If the cumulative tritium doses received by all three of these populations were summed, the collective dose equivalent is 123 person-rem and is dominated by the drinking water pathway.

Summary

Although tritium is a primary contributor to offsite doses from SRS operations, it is an essentially insignificant component of an average individual's total annual dose equivalent. The maximum individual dose was 19 mrem, a tiny fraction of the 14,000 mrem recorded over 38 years from natural and non-SRS sources. When examined on a population basis, the total cumulative dose attributable to atmospheric and liquid tritium releases from the SRS during 38 years of operation was 1,300 person-rem distributed among 620,000 people.

Table 4-7 Liquid Tritium Releases and Offsite Doses (1955-1991)

	Max Ind Dose (mrem)			WTP Pop Dose (person-rem)			
Year	Below SRS	B-J WTP	PW WTP	B-J WTP	PW WTP	80 km	Total Pop Dose (per-rem)
1955	$2.65x10^{-2}$		$3.98x10^{-2}$		$3.04x10^{-1}$	$8.58x10^{-3}$	$3.13x10^{-1}$
1956	$4.02x10^{-2}$		$6.02x10^{-2}$		$4.61x10^{-1}$	$1.30x10^{-2}$	$4.74x10^{-1}$
1957	$4.87x10^{-2}$		$7.30x10^{-2}$		$5.59x10^{-1}$	$1.58x10^{-2}$	$5.74x10^{-1}$
1958	$5.97x10^{-2}$		$8.95x10^{-2}$		$6.84x10^{-1}$	$1.93x10^{-2}$	$7.04x10^{-1}$
1959	$1.16x10^{-1}$		$1.74x10^{-1}$		$1.33x10^{0}$	$3.76x10^{-2}$	$1.37x10^{0}$
1960	$9.99x10^{-2}$		$1.50x10^{-1}$		$1.14x10^{0}$	$3.23x10^{-2}$	$1.18x10^{0}$
1961	$1.38x10^{-1}$		$2.07x10^{-1}$		$1.58x10^{0}$	$4.47x10^{-2}$	$1.63x10^{0}$
1962	$1.24x10^{-1}$		$1.85x10^{-1}$		$1.42x10^{0}$	$3.99x10^{-2}$	$1.46x10^{0}$
1963	$1.88x10^{-1}$		$2.81x10^{-1}$		$2.15x10^{0}$	$6.07x10^{-2}$	$2.21x10^{0}$
1964	$1.12x10^{-1}$		$1.69x10^{-1}$		$1.29x10^{0}$	$3.64x10^{-2}$	$1.33x10^{0}$
1965	$2.20x10^{-1}$	$1.88x10^{-1}$	$3.29x10^{-1}$	$4.79x10^{0}$	$2.52x10^{0}$	$7.10x10^{-2}$	$7.37x10^{0}$
1966	$1.98x10^{-1}$	$2.27x10^{-1}$	$2.97x10^{-1}$	$5.79x10^{0}$	$2.27x10^{0}$	$6.40x10^{-2}$	$8.13x10^{0}$
1967	$1.78x10^{-1}$	$1.61x10^{-1}$	$2.66x10^{-1}$	$4.10x10^{0}$	$2.04x10^{0}$	$5.75x10^{-2}$	$6.20x10^{0}$
1968	$1.73x10^{-1}$	$1.89x10^{-1}$	$2.59x10^{-1}$	$4.82x10^{0}$	$1.98x10^{0}$	$5.59x10^{-2}$	$6.86x10^{0}$
1969	$1.58x10^{-1}$	$1.49x10^{-1}$	$2.37x10^{-1}$	$3.79x10^{0}$	$1.82x10^{0}$	$5.12x10^{-2}$	$5.65x10^{0}$
1970	$1.21x10^{-1}$	$6.88x10^{-2}$	$1.81x10^{-1}$	$1.75x10^{0}$	$1.39x10^{0}$	$3.91x10^{-2}$	$3.18x10^{0}$
1971	$9.60x10^{-2}$	$4.41x10^{-2}$	$1.44x10^{-1}$	$1.12x10^{0}$	$1.10x10^{0}$	$3.10x10^{-2}$	$2.26x10^{0}$
1972	$1.11x10^{-1}$	$8.57x10^{-2}$	$1.66x10^{-1}$	$2.18x10^{0}$	$1.27x10^{0}$	$3.57x10^{-2}$	$3.49x10^{0}$
1973	$1.32x10^{-1}$	$1.56x10^{-1}$	$2.18x10^{-1}$	$3.97x10^{0}$	$1.67x10^{0}$	$4.71x10^{-2}$	$5.69x10^{0}$
1974	$1.46x10^{-1}$	$1.35x10^{-1}$	$2.32x10^{-1}$	$3.45x10^{0}$	$1.78x10^{0}$	$5.01x10^{-2}$	$5.28x10^{0}$
1975	$9.74x10^{-2}$	$9.15x10^{-2}$	$1.49x10^{-1}$	$2.33x10^{0}$	$1.14x10^{0}$	$3.22x10^{-2}$	$3.51x10^{0}$
1976	$1.16x10^{-1}$	$8.64x10^{-2}$	$1.82x10^{-1}$	$2.20x10^{0}$	$1.40x10^{0}$	$3.94x10^{-2}$	$3.64x10^{0}$
1977	$1.02x10^{-1}$	$1.13x10^{-1}$	$1.46x10^{-1}$	$2.87x10^{0}$	$1.12x10^{0}$	$3.15x10^{-2}$	$4.02x10^{0}$
1978	$9.65x10^{-2}$	$7.88x10^{-2}$	$1.67x10^{-1}$	$2.01x10^{0}$	$1.28x10^{0}$	$3.61x10^{-2}$	$3.33x10^{0}$
1979	$5.99x10^{-2}$	$4.29x10^{-2}$	$8.58x10^{-2}$	$1.09x10^{0}$	$6.56x10^{-1}$	$1.85x10^{-2}$	$1.77x10^{0}$
1980	$5.05x10^{-2}$	$4.14x10^{-2}$	$7.32x10^{-2}$	$1.05x10^{0}$	$5.59x10^{-1}$	$1.58x10^{-2}$	$1.63x10^{0}$
1981	$9.74x10^{-2}$	$1.04x10^{-1}$	$1.41x10^{-1}$	$2.64x10^{0}$	$1.08x10^{0}$	$3.05x10^{-2}$	$3.76x10^{0}$
1982	$1.22x10^{-1}$	$8.46x10^{-2}$	$1.64x10^{-1}$	$2.16x10^{0}$	$1.25x10^{0}$	$3.53x10^{-2}$	$3.44x10^{0}$
1983	$7.43x10^{-2}$	$1.36x10^{-1}$	$1.18x10^{-1}$	$3.46x10^{0}$	$9.01x10^{-1}$	$2.54x10^{-2}$	$4.39x10^{0}$
1984	$6.94x10^{-2}$	$6.34x10^{-2}$	$9.73x10^{-2}$	$1.62x10^{0}$	$7.44x10^{-1}$	$2.10x10^{-2}$	$2.38x10^{0}$
1985	$9.42x10^{-2}$	$1.37x10^{-1}$	$1.42x10^{-1}$	$3.50x10^{0}$	$1.09x10^{0}$	$3.07x10^{-2}$	$4.62x10^{0}$
1986	$1.22x10^{-1}$	$1.71x10^{-1}$	$1.88x10^{-1}$	$4.35x10^{0}$	$1.44x10^{0}$	$4.06x10^{-2}$	$5.83x10^{0}$
1987	$6.87x10^{-2}$	$8.80x10^{-2}$	$9.21x10^{-2}$	$2.24x10^{0}$	$7.05x10^{-1}$	$1.99x10^{-2}$	$2.97x10^{0}$
1988	$9.71x10^{-2}$	$1.32x10^{-1}$	$1.38x10^{-1}$	$3.36x10^{0}$	$1.05x10^{0}$	$2.97x10^{-2}$	$4.44x10^{0}$
1989	$5.86x10^{-2}$	$1.04x10^{-1}$	$1.02x10^{-1}$	$2.66x10^{0}$	$7.80x10^{-1}$	$2.20x10^{-2}$	$3.46x10^{0}$
1990	$3.69x10^{-2}$	$5.24x10^{-2}$	$6.38x10^{-2}$	$1.34x10^{0}$	$4.88x10^{-1}$	$1.38x10^{-2}$	$1.84x10^{0}$
1991	$6.38x10^{-2}$	$7.20x10^{-2}$	$8.74x10^{-2}$	$1.83x10^{0}$	$6.69x10^{-1}$	$1.89x10^{-2}$	$2.52x10^{0}$
TOTAL	$3.91x10^{0}$	$3.00x10^{0}$	$5.90x10^{0}$	$7.64x10^{1}$	$4.51x10^{1}$	$1.27x10^{0}$	$1.23x10^{2}$

Appendix 1. Environmental Monitoring of Concentrations and Releases

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Environmental Monitoring of Concentrations and Releases

Introduction

Tritium releases have been monitored at SRS since the beginning of tritium production. Measurement systems have been expanded and upgraded as the technology of tritium measurement evolved. An example of this is the routine measurement of tritium chemical forms in the separations areas stacks. Initial experimental measurements were made in the late 1970s and the present operational system was installed in 1985.

The measurement of tritium in the environment away from the production areas was sporadic in the early days of production because of the difficulty in measuring tritium at the concentrations which normally occur in the SRS environment with the techniques available at that time. In addition, the emphasis was on measurement of other nuclides that were known to be more radiotoxic. Environmental monitoring of tritium concentrations increased as better measurement techniques became available and the priority for tritium measurements increased.

Tritium measurements of milk samples were made as early as 1959. The measurement of stream water samples began in 1960. While these measurement were sufficient to guard against larger than ordinary releases, they could not detect the concentrations normally found in environmental samples near SRS. Measurement techniques improved continuously until around 1970, when the full use of liquid scintillation counting allowed routine measurement of most samples in the range of tritium concentrations found in the SRS environment.

The measurement of atmospheric tritiated water vapor at a number of standard sampling locations became routine in 1963. Tritium in rainfall was routinely measured at a network of rain gages after 1970. Tritium in vegetation water was added in 1974.

Tritium in selected deer and hogs killed in controlled hunts have also been monitored. The following section briefly describes the tritium effluent and environmental monitoring program at SRS. More detailed accounts can be found in the Annual Environmental Reports (see the Bibliography).

Atmospheric Effluent Monitoring

Most atmospheric discharges of tritium are measured by on-line monitoring equipment installed at effluent release points (stacks, in most cases). The majority of the tritium released to the atmosphere has been associated with the activities of the tritium production facilities and the reactors.

Reactor Stacks

The Reactor Department maintains and operates tritium monitoring devices used for both atmospheric losses of moderator as well as the associated tritium releases. The primary tritium monitoring instrument used is the Berthold Tritium Monitor (BTM). The BTM is a gas flow-through proportional counter. The sample exhaust air is mixed with a counting gas before it passes through a 1.3-L proportional counter. The BTM discriminates between tritium and the radioactive noble gases also released from the reactors by using pulse rise time discrimination. The beta particles from tritium have a short range and thus create, through interaction with the counting gas, ion pairs within a limited volume in the counter tube. The noble gases, because of their higher emitted beta energies, create ion pairs within a larger volume in the tube. This allows discrimination of the electrical signals resulting From low- and high-energy beta particles. The signals from the analyzer are interfaced to a computer which converts the signal voltages to radiation units and prints the results.

Another monitor used is the Stack Tritium Monitor (STM), which measures the forms of tritium. The STM consists of two gas flow-through ionization chambers. An unaltered sample stream of exhaust air flows through one ion chamber, and a dried sample of exhaust air flows through the other chamber. Silica gel is used to remove tritiated water vapor from the sample exhaust air. The wet chamber measures the tritium oxide, elemental tritium, and radioactive noble gases. The dried sample measures elemental tritium and radioactive noble gases. The dual chambers are electronically connected so that their output is proportional to the difference between the radioactivity measured in each chamber, which provides a measure of the tritiated water vapor exhausted from the stack. Since the majority of releases from the reactor areas are in the form of tritiated water from the heavy water moderator losses, this procedure provides another way of discriminating tritium from the radioactive noble gases.

A third device which is available to measure moderator tritium releases is a dehumidifier on the stack exhaust sample line. Moisture from the stack sample line is "frozen" by the dehumidifier on a continuous basis except for a daily "thawing" for liquid sample collection. The liquid condensate is analyzed for tritium by a laboratory and the tritium loss calculated by employing appropriate air moisture content and stack flow data. This was the principal reactor stack tritium measuring device from startup until 1986, when the advanced type of monitor was installed. This type of monitor also provides a means of checking the results of the other techniques and is a valuable backup when there are problems with the other monitors.

Disassembly Areas

The fuel and target storage basins (disassembly basins) were designed without any air supply system. The facilities are under a slight positive pressure and an exhaust occurs through doors and other openings in the facilities. The loss of tritium by evaporation from the disassembly basins is determined by drawing a sample of air from over the basin through a silica gel column. The sample is analyzed and appropriate flow and humidity factors are applied to estimate the tritium discharge.

Moderator Rework Facility

Tritium releases from buildings at the reactor moderator rework facility are determined by continuous dehumidifier sampling, analysis of the condensate collected, and calculation of the releases by applying appropriate air moisture content and stackflow data.

Tritium Facilities

Three methods are used to determine tritium releases and/or the forms of tritium released. The primary monitoring system used for stack releases is the Kanne ionization chamber and associated amplifier and strip chart recorder. The system continuously samples, monitors, and records tritium concentration. The stack recorder data and the stack flows are used to calculate the tritium releases.Tritium forms monitors are installed on the stacks of buildings releasing both tritiated hydrogen and tritiated water vapor. These monitors continuously measure and periodically report tritium releases by total tritium, total elemental tritium, and total oxide tritium. Monitoring is accomplished by pulling a sample of gas from the stack. The sample is then separated into two exactly equal streams. One stream is sent directly through a Kanne chamber to measure the total tritium in the gas. The other stream is sent through a drying column assembly, which strips the tritium oxide. The stripped stream is then sent to another Kanne chamber to measure the amount of elemental tritium in the gas. The amount of tritium oxide is determined by subtraction.

There are four Kanne chambers in each system—the Total Low Range and Total High Range, which measure both forms of tritium, and the Elemental Low Range and Elemental High Range, which measure only the elemental form. The computer receives information from each of the four chambers in the same manner. Each Kanne chamber produces a current proportional to the amount of activity in the gas. The electrical output is interfaced to a computer, which converts the signal to radiation units and records the results.

Parametrics System I Humidity Analyzer monitors the gas stream before it enters and after it leaves the drying column, in order to determine how well the column removes tritium oxide from the gas. The total of each form of tritium is made available to operations personnel through the computer monitor and paper printouts.

The tritium stack monitor integrator is a third system which can be used to measure tritium releases. A sample of the stack gas is sent through an ion chamber, which produces a current proportional to the amount of activity in the gas. This current is then sent to an electrometer. The electrometer measures the current and relays this information to the system's computer. The computer also receives two pressure readings. One reading comes from a transducer that measures the pressure in the ion chamber, and the other comes from a transducer measuring atmospheric pressure. They are used by the computer to calculate the rate at which tritium is being released. The computer uses the current reading and the two pressure readings to perform an integration, using a mathematical model, then updates the totals.

Some facilities use another type of tritium forms sampler to determine the portion of tritium associated with water vapor or hydrogen. The forms samplers continuously collect tritiated water vapor and tritiated hydrogen which has been oxidized to water after drying on molecular sieve collectors. The collectors are removed weekly and analyzed in a laboratory to determine the ratio of elemental to oxide tritium releases. Analysis of activity of the water is by liquid scintillation (described below).

Tritium Monitoring in Aquatic Media

The Environmental Monitoring Section collects and analyzes aquatic media to assess the contribution of tritium to the total activity of the environment. There are no in-line tritium liquid effluent monitors at SRS at the present time. All liquid releases are determined by laboratory analysis of effluent samples. Four types of aquatic media are routinely sampled: (1) area effluent outfalls, (2) streams, (3) the Savannah River, and (4) rainwater. The following is a summary of the collection methodology and analysis performed for each type of aquatic media sampled for tritium.

Area Effluent Outfalls

Area effluent outfalls are routinely sampled and analyzed for tritium by Environmental Monitoring Survey Teams and analyzed by the Environmental Monitoring for tritium. The types of samplers utilized to collect effluent samples vary. In some locations, continuous samplers are employed that take a measured sample at a preselected time or flow interval. These samples are usually composited over a period ranging from 1 week to 1 month. In other locations, effluents are sampled by dipping a water sample. The analysis of area effluent samples for tritium requires that the sample be diluted and a 5-mL aliquot be extracted. The aliquot is combined with 17 mL of Ecolite scintillation cocktail and is counted on a Beckman liquid scintillation counter for 20 min.

Streams

Streams are routinely sampled at strategic locations on the SRS. Six stream systems traverse the site: (1) Upper Three Runs, (2) Beaver Dam Creek, (3) Fourmile Branch, (4) Pen Branch, (5) Steel Creek, and (6) Lower Three Runs (Figure A.1). Sample collection methodologies include the employment of Brailsford pumps, ISCO smplers, paddlewheel samplers, and dip samples. Sampling frequency varies according to location and level of concern, but ranges from weekly to quarterly samples. The analysis of stream samples for tritium requires that a 5-mL aliquot of the sample be extracted and mixed with 17 ml of Ecolite. The cocktail is then counted for 20 min on a Beckman liquid scintillation counter. Sample analysis results or tritium are compared to control samples from the Edisto River, a small river 32 km from the SRS with water quality characteristics similar to site streams.

Savannah River

The Savannah River receives the outflow of all the streams located on the SRS, making it the most critical sample location from the perspective of an environmental impact of site operations. The Savannah River is sampled in six locations by continuous paddlewheel or ISCO samplers. A dip sample is taken along with the paddle wheel sample at location R-2. The sample locations are as follows:

R-2 Above SRS

R-3A Above Plant Vogtle

R-3B Below Plant Vogtle

R-8 A&B Steel Creek Landing *

R-8C Little Hell Landing

R-10 A&B Highway 301*

* Two samplers at the same location

The sampling frequencies vary from weekly, biweekly, to monthly depending on the location. The R-2 sample is used as a comparison for the remaining samples. The analysis of the Savannah River samples for tritium requires that the samples undergo a distillation phase to remove ions or organic compounds which might quench the sample. From the purified sample, a 5-mL aliquot is extracted and mixed with 17 ml of Ecolite. The cocktail is then counted twice for 150 min each. The results of the Savannah River analysis are then compared to the Edisto River control samples.

Rainfall

Rainwater samples are collected for tritium analysis from 35 locations in a 160-km radius around the site. Five samples are collected onsite, 14 samples at the plant perimeter, 12 at locations within the 40-km radius of the plant and 4 samples at appoximately 160-km from the center of the Site.

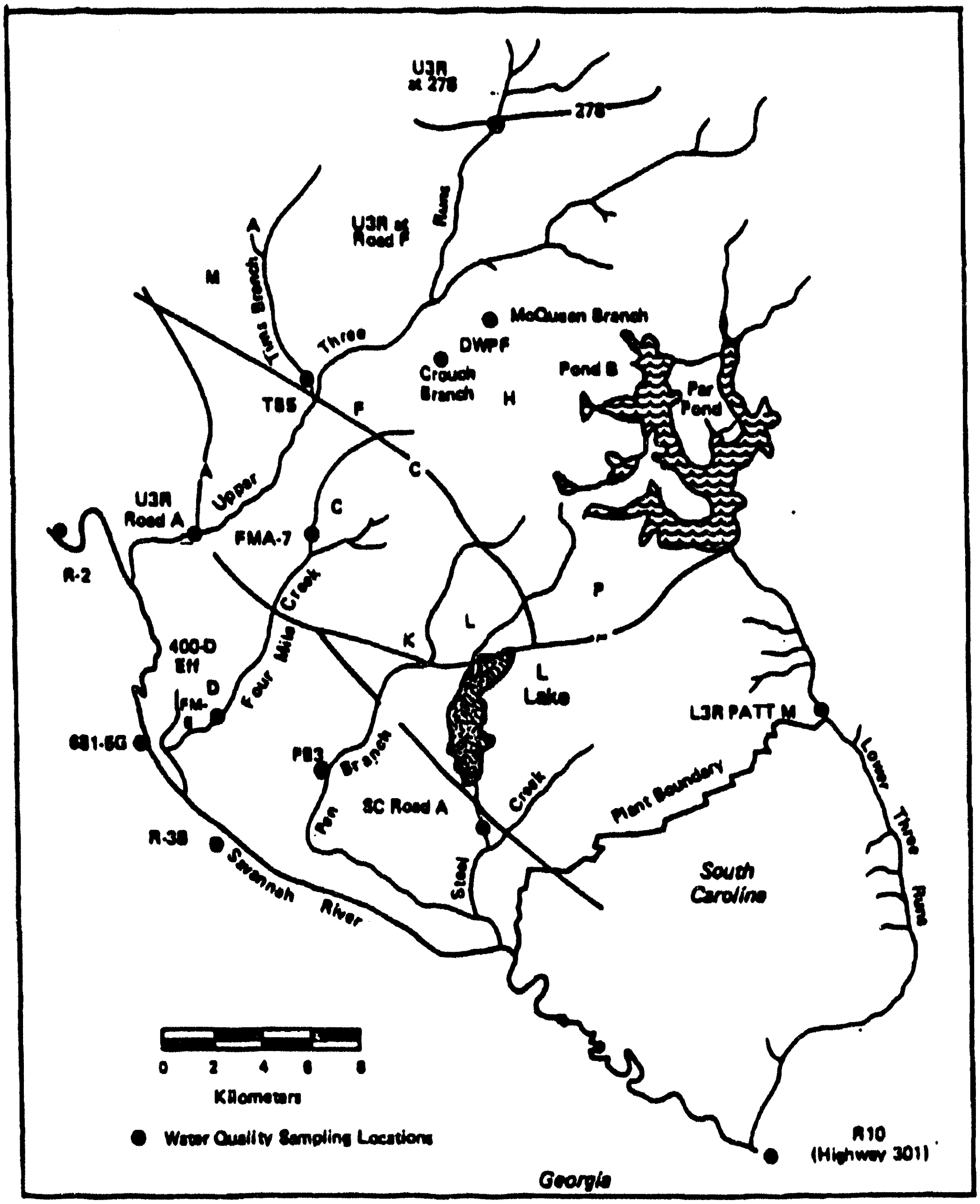


Figure A.1. Stream Location Monitored for Water Tritium Concentration

All locations are sampled biweekly, except the stations located at 160 km, which are sampled quarterly. The analysis of rainwater samples for tritium requires that the samples undergo a distillation phase to remove any ions or organic compounds which might quench the sample. From the purified sample, a 5-mL aliquot is extracted and mixed with 17 mL of Ecolite scintillant. The cocktail is then counted twice for 150 minutes each.

Atmospheric Environmental Monitoring

Concentrations of tritium water vapor in air are measured at eight monitoring stations on the SRS, 14 monitoring stations around the SRS perimeter, and 12 stations at distances of approximately 40 km from the center of the SRS (called 40-km-radius stations). The stations at the SRS perimeter and the 40-km-radius stations are arranged to permit continuous monitoring within each 30-degree sector (Figure A.2). This spacing enhances the probability of detecting a significant release of tritium from the SRS regardless of wind direction. Additional stations are monitored at a distance of approximately 160km.

The samplers operate continuously. Air is pumped through a silica gel column which collects the water vapor. The columns are changed weekly The water vapor is separated from the silica gel by distillation and the radioactivity of tritium in the vapor determined by liquid scintillation counting. Calculation of the air activity takes into account the volume of air sampled and water absorbed on the silica gel (mass difference). Sensitivity of the procedure is 0.3 pCi/mL of water collected with a counting time of 150 minutes. Recovery of water is very near 100%.

Monitoring Tritium in Biota

Vegetation

Vegetation samples are collected on the general plant site(28) and at the plant perimeter (14), 40-km radius (4), and 160-km radius (4) locations. Many of these locations are the same as those used for air monitoring. Approximately 25 grams of sample is freeze dried, and the liquid is counted for 150 minutes using liquid scintillation techniques. Bermuda grass is used for the samples when available. Other plant species are utilized as necessary.

Deer and Hogs

Annual hunts are conducted at SRS to control the site deer and hog populations and to reduce animal-vehicle accidents. Tritium samples have not been collected in recent years. When the program was active selected animals were analyzed for the tritiated water activity in flesh. Approximately 30 grams of flesh are freeze dried, and the liquid is counted as in the vegetation samples.

Monitoring Tritium in Food

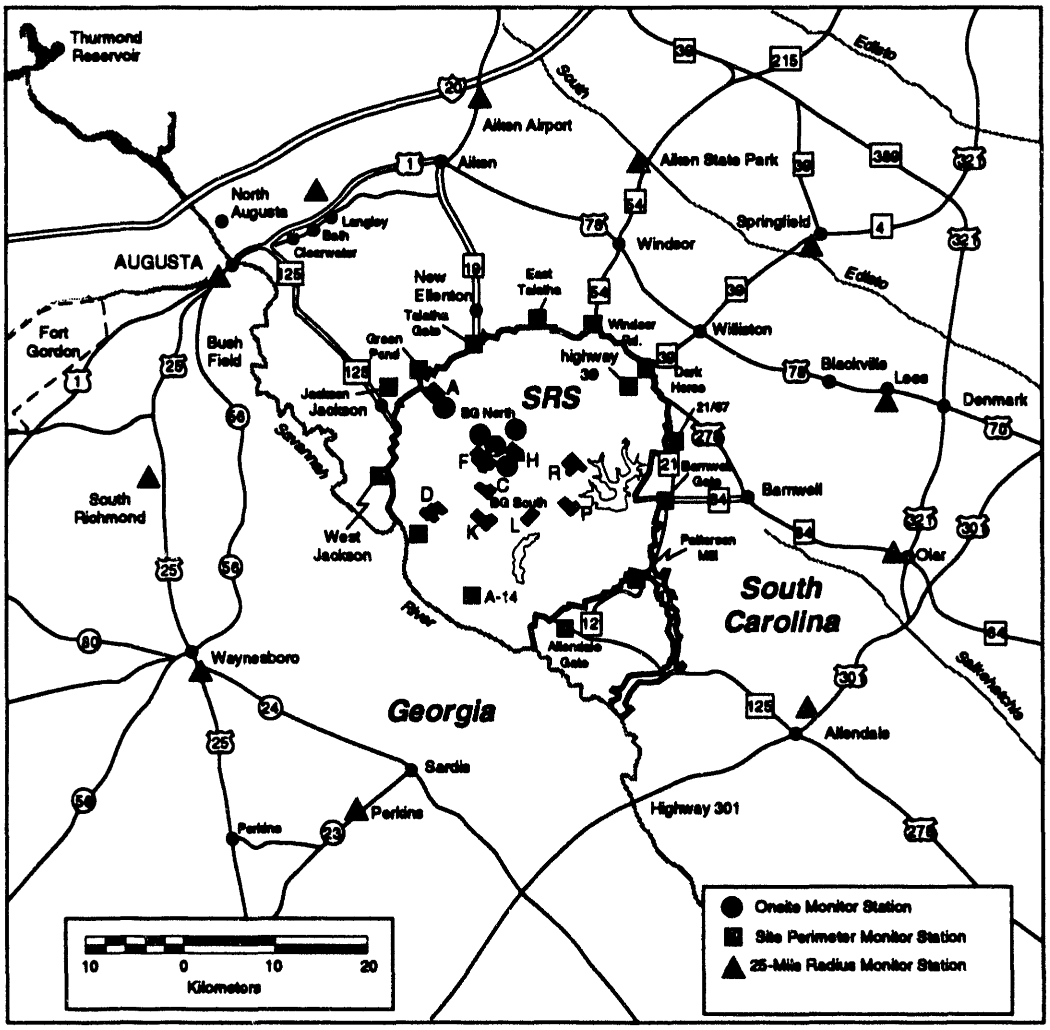
Tritium content of water in food produced in the vicinity of SRS has been measured since the early 1960s. However, before 1971 the instruments used to measure tritium could not detect the tritium in the food. Since 1971, milk and eight other types of food have been sampled and measured for tritiated water concentration.

Milk is collected from local dairies and from a distributor who collects milk from a number of local dairies. The number and location of the dairies varies as farmers enter and leave business. At present, samples are analyzed from six dairies and one distributor (Figure A.3). The milk is distilled and the water is collected in a cold trap. The water is mixed with a scintillant and counted on a liquid scintillation counter.

Food collections are made from local farms; often the collections are from growing crops in the field (Figure A.3). Four types of vegetable foods and an equal number of animal foods have been collected and analyzed. The animal foods include the flesh of beef, pork, and chicken and chicken eggs. The vegetable foods include collard greens, corn, fruits (usually plums or peaches), and grain (wheat or rye). The food portion of the animal is freeze dried and the water collected in a cold trap. The water is counted on a liquid scintillation counter.

Tritium Monitoring in Groundwater at SRS

The current groundwater monitoring program at SRS is a combination of several programs. The SRS Environmental Monitoring Section conducts both a radioactive monitoring program and a nonradioactive monitoring program. The radioactive monitoring program began in the early 1950s and has primarily monitored for gross alpha and nonvolatile beta activities and tritium concentrations at selected sites. The samples are collected by either pumping or



● Onsite Monitor Station

■ Site Perimeter Monitor Station

▲ 25-Mile Radius Monitor Station

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Figue A.2. Monitoring Station Locations for Measurements of Tritium in Air Moisture, Rain, and Vegetation

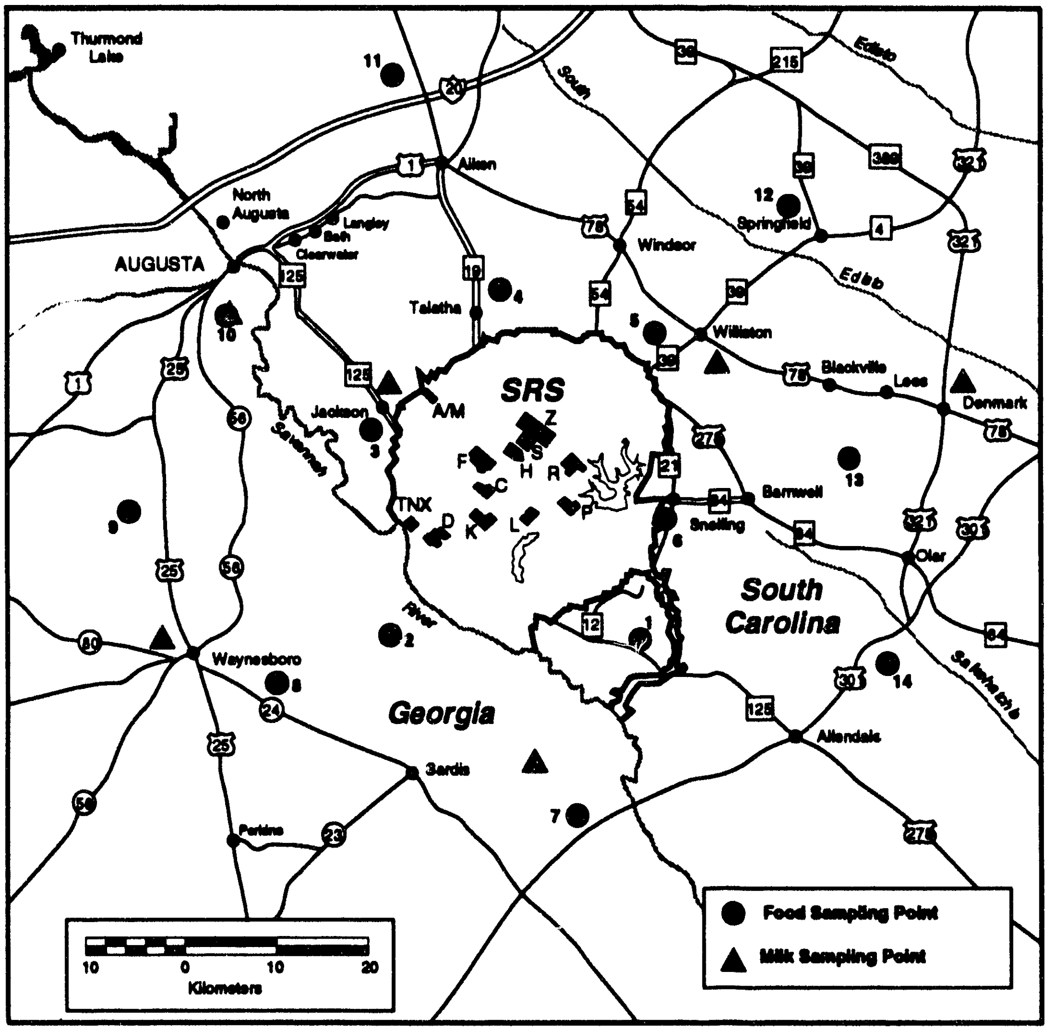

Figure A.3. Milk and Food Sampling Locations bailing wells, and the analyses are conducted by the Environmental Monitoring Section's laboratory and by contract laboratories. The scope of groundwater monitoring has expanded rapidly since the nonradioactive groundwater monitoring program was established in 1982.

Two other organizations monitor the groundwater: the SRS Raw Materials Engineering and Technology Department monitors for volatile organics in A and M Areas, and the Interim Waste Technology Division of the Savannah River Laboratory monitors selected wells within the burial grounds. All monitoring wells are analyzed for tritium at least every 2 years. Wells with elevated concentrations of tritium are analyzed either semiannually or quarterly. The Environmental Monitoring Section (EMS) currently monitors about 1200 wells located at all large waste sites at SRS and at many smaller waste sites or operating facilities. Analyses are generally performed by contract laboratories. Analytical results are released quarterly in groundwater monitoring reports and annually in the Annual Environmental Report. Results are stored in a large computer data base of groundwater monitoring data. This data base can be queried to satisfy specific needs.

Comparison of SRS Monitoring Data with SCDHEC and GDNR

For the past 30 years, the concentration of tritium in the Savannah River, in surface water, and in locally produced milk supplies have been regularly monitored by the EMS at the SRS. Additionally, the South Carolina Department of Health and Environmental Control (SCDHEC) and the Georgia Department of Natural Resources (GDNR) occasionallyconduct independent surveys of tritium levels in the vicinity of the site (Du Pont 1983a, 1983b, and 1984). A comparison of the levels reported by the various groups provides an indication of the accuracy of the environmental monitoring program at the SRS.

Average tritium concentrations upriver and downriver of the SRS over a 1-year period from July 1982 to June 1983 are given in Figure A.4. The GDNR and SRS yearly averages are in agreement to within 10%. This difference may be the result of comparing yearly averages of monthly "dip" samples taken by the GDNR and yearly averages of continuous weekly samples taken by the SRS.

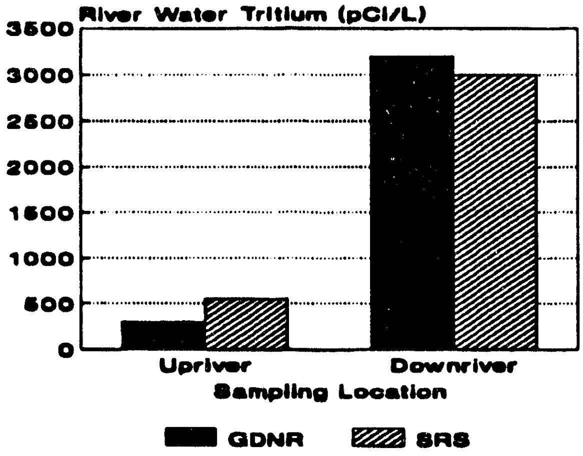

Figure A.4. Comparison of Average Tritium Levels in the Savannah River Measured by SRS and the Georgia Department of Natural Resources from 7/82-6/83

The average tritium concentrations shown in Figure A.5 were measured at Highway 301 at the Georgia/South Carolina border by all three groups during the same time period but not necessarily on the same day. Since the sampling point is the same, an unbiased comparison can be made with respect to collection location. The values reported in Figure A.5 are in very good agreement, indicating a high degree of precision among testing groups.

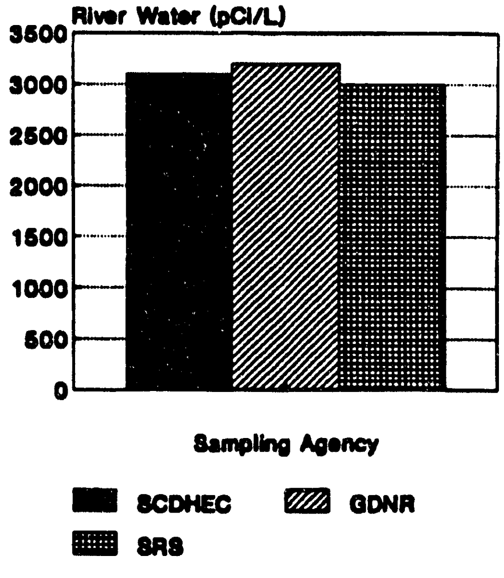

Figure A.5. Comparison of Tritium concentrations in the Savannah River at Highway 301, as Measured by SRS, the Georgia Department of Natural Resources, and the South Carolina Department of Health and Enivronmental Control

Concentrations of tritium in water collected at the Savannah Industrial and Domestic Water Treatment Facility at Port Wentworth, GA, are reported in Figure A.6. Annual averages of the values reported by the SRS and the GDNR for three 1-year periods are in good agreement. The range of values reported by the GDNR was from 1000 to 4300 pCi/L during the sampling period, while the concentration range reported by SRS was from 1200 to 3900 pCi/L.

Figures A.7 and A.8 show tritium concentrations in milk collected from three dairies in the vicinity of SRS. The figures are for the periods of June 1980 to June 1982 and July 1982 to June 1983, respectively. The concentrations of tritium in milk determined by the SRS Environmental Monitoring Group are plotted against similar values determined by the GDNR. In this type of plot, if perfect agreement between measurements were present, all points on the plot would fall on a line passing through the origin with a slope equal to one. These lines have been drawn in the figures. The comparison of measured tritium concentrations in milk for the time period covered by Figure A.7 shows that the GDNR values are systematically higher than the SRS values. However, a comparison of the concentrations obtained from July 1982 to June 1983 reveals that the SRS determinations are somewhat higher. This indicates that some systematic bias existed in both group's analysis techniques, but at different times.

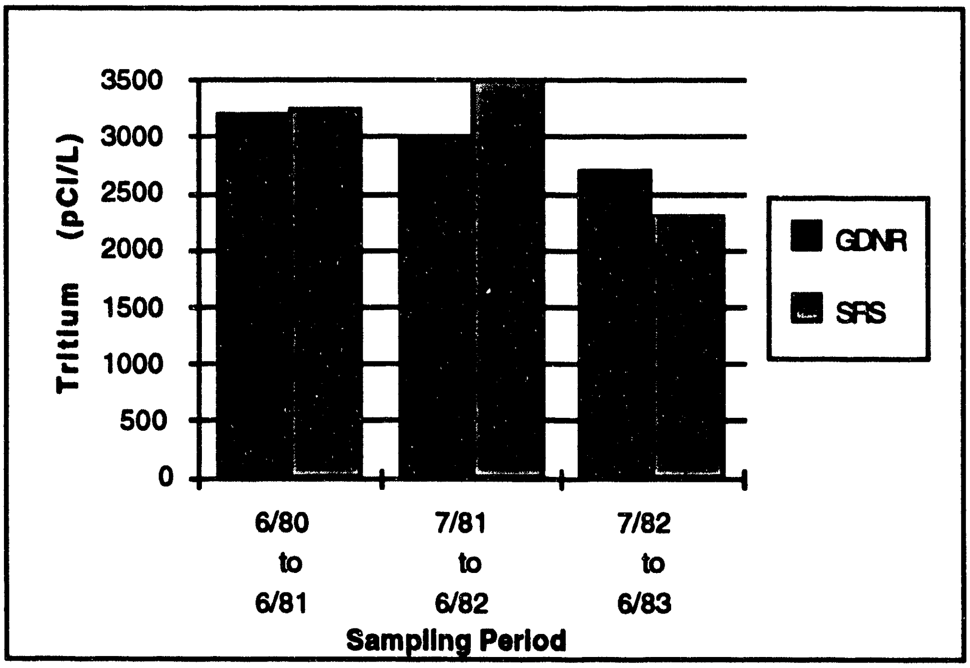

Figure A.6. Comparison of Average Tritium Levels in the Savannah River at Port Wentworth, GA, Measured by SRS and the Georgia Department of Natural Resources

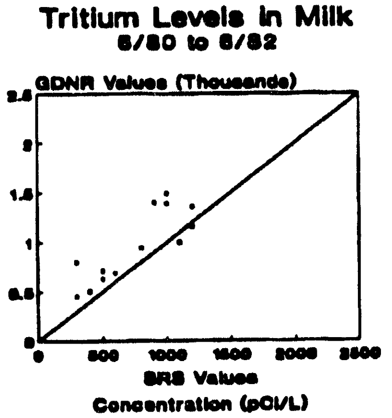

Figure A.7. Comparison of Tritium in Milk Measured by SRS and the Georgia Department of Natural Resources, 6/80-6/82

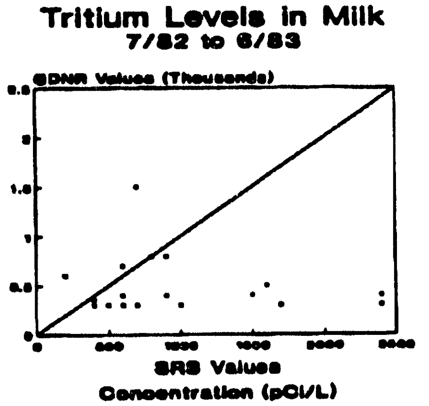

Figure A.8. Comparison of Tritium in Milk Measured by SRS and the Georgia Department of Natural Resources, 7/82-6/83

Tritium Emergency Response Program

WIND System

The SRS maintains a system of nine onsite and one offsite instrumented towers to collect real time meteorological data. Up to 125 data points are collected every 1.5 sec. In the event of a tritium release, these data would be available as input to the transport and dispersion codes on the WIND (Weather INformation and Display) system (WSRC 1989c, Addis 1988).

The WIND system uses real-time meteorological data, stack emission data, perimeter monitoring data, and either a one- or two-dimensional transport and dispersion model to predict and analyze the consequences of a release. WIND provides estimates of the plume's location and centerline concentrations, which may be used to optimize the positioning of mobile sampling equipment and to provide a preliminary assessment of the threat to public health. WIND output is available for examination in the Weather Center Analysis Laboratory (WCAL) and the Technical Support Center (Addis 1988).

TRAC Mobile Laboratory

Mobile monitoring capabilities for the SRS are provided by the Tracking Radioactive Atmospheric Contaminants (TRAC) laboratory. Tritium concentrations in air are measured by the TRAC lab using molecular sieve technology. Two types of sieves are used to support simultaneous collection of both forms of tritium (Sigg 1984). Should a major tritium release occur, WCAL personnel would dispatch the TRAC vehicle to predicted plume locations to measure tritium levels.

Tritium as water vapor (HTO or T_2O) is removed from the air stream using a column containing an alumina-based material. Heat is then used to drive the trapped moisture from the column into a collection vessel. A sample of this water is discharged into a liquid scintillation cocktail for tritium assay by one of the two Aston liquid scintillation counters onboard the TRAC. Tritium in the elemental form (HT or T_2) is an inert gas and therefore not effectively adsorbed on the alumina. To determine the elemental tritium concentration, the air stream is also passed through a palladium-coated sieve. The palladium catalyzes the oxidation of the elemental tritium to tritium oxide. Any tritium oxide generated by the presence of elemental tritium is then retained on the sieve and can be analyzed as described above.

The emergency response protocol established for the TRAC vehicle calls for the unit to collect and analyze air samples from nearby population centers as soon as possible after the onset of the release. Elemental and oxide tritium concentration data can be produced within 30 minutes of TRAC's arrival at a sampling location. This information, along with plume location data, is then relayed back to the WCAL for interpretation and communication to emergency management personnel operating from the Technical Support Center.

Appendix 2. References and Bibliography

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Appendix 3. Physical and Chemical Characteristics of Tritium

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Physical and Chemical Characteristics of Tritium

Tritium is an isotope of hydrogen that was discovered in 1939 by Rutherford. The three known isotopes of hydrogen are:

Protium - $^{1}_{1}H$ Stable
Deuterium - $^{2}_{1}H$ Stable
Tritium - $^{3}_{1}H$ - Radioactive

Tritium is the rarest of all known natural isotopes, occurring only one time in 10^{18} parts of $^{1}_{1}H$

Tritium is colorless, odorless, and tasteless and has a mass of 3.0260 mass units.

It exists as a gas or an oxide (T_2, HT, HTO, and T_2O where T = tritium and H = hydrogen).

Tritium is formed artificially as follows:

$^{6}_{3}Li + {}^{1}_{0}n \rightarrow {}^{3}_{1}H + {}^{4}_{2}He + 4.8\ \text{MeV}$

$^{2}_{1}H + {}^{1}_{0}n \rightarrow {}^{3}_{1}H$

Ternary Fission

The probability of deuterium capturing a neutron depends on the cross section measured in barns. Deuterium has a cross section of 0.00057 barns.

Tritium is also produced naturally in the upper atmospherte from nitrogen by reactions with cosmic-ray neutrons.

$^{14}_{7}N + {}^{1}_{0}n \rightarrow {}^{12}_{6}C + {}^{3}_{1}H - 4.3\ \text{MeV}$

and

$^{14}_{7}N + {}^{1}_{0}n \rightarrow 3\ {}^{4}_{2}He + {}^{3}_{1}H - 11.5\ \text{MeV}$

Tritium emits a weak betra particle that has a maximum energy of 18.6 KeV and an average energy of 5.7 KeV.

The physical half-life of tritium is 12.35 years and the mode of decay is by the emission of a beta particle to form $^{3}_{2}He$.

$^{3}_{1}H \rightarrow {}^{3}_{2}He + {}^{0}_{1}e$

Activity-mass relationship:

T_2 gas - 9,700 curies/gram; 2.6 curies/cc at S.T.P.
T_20 liquid - 2,650 curies/gram
HTO liquid - 1,460 curies/gram

$^{3}_{1}H$ interchanges with and replaces $^{1}_{1}H$ in many materials under certain temperatures and pressures.

END

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