CHAPTER 2

BRIEF HISTORY OF FACILITIES AND OPERATIONS RELEVANT TO THE RELEASE OF RADIONUCLIDES

ABSTRACT

The Savannah River Site (SRS) Dose Reconstruction Project, a research effort sponsored by the Centers for Disease Control and Prevention (CDC) is a study of historical releases, doses, and risks to members of the public living offsite during past operations. *Radiological Assessments Corporation* (*RAC*) has performed Phases I and II of the dose reconstruction. During Phase I, *RAC* gathered the records necessary for a dose reconstruction. During Phase II of the project, *RAC* staff have used that information to estimate historical radionuclide and chemical release rates (the source term) from the SRS. Also during Phase II, environmental monitoring records, map-based information and other records have been collected and evaluated. Information from these additional records is presented in this report and its associated document and data sets. This chapter provides background information in support of the subsequent source term development and environmental monitoring information chapters. It contains a brief history and description of the SRS, then presents SRS reactor and reprocessing data collected by *RAC* during the study and used in later chapters during source term development efforts.

The first section of this chapter discusses key areas and processes at the SRS to help the reader understand the factors contributing to offsite releases and potential public health impacts. The most likely scenarios for offsite impact involve releases of particulate and gaseous materials to the air, with subsequent atmospheric transport offsite, and releases of liquids to surface streams that flow offsite. The SRS areas and processes, organized by location, are described in detail in "History and Descriptions of Key Processes at SRS," in the SRS dose reconstruction Phase I, Task 3 report (Meyer 1995).

The second section of this chapter discusses the methods used by *RAC* to identify, locate, extract and declassify monthly reactor and reprocessing canyon records for use in the study. Some of these data have not previously been released to the public domain.

HISTORY AND DESCRIPTION OF THE SAVANNAH RIVER FACILITY

Creation and Development of the Savannah River Site

With the signing of the Atomic Energy Act of 1946, the Congress provided for the Atomic Energy Commission (AEC) to take over the nation's nuclear programs that had been administered by the Manhattan District of the United States Corps of Engineers. Early in 1950, a study group of Du Pont personnel who had been involved in the Hanford work in the late 1940s, began considering the design, construction, and operation of new production facilities. Of nearly one hundred possible sites, four sites were identified as favorable, including a site on the Red River in Texas, a site on the Wabash River in Indiana/Illinois, a site on the shore of Lake Superior in Indiana, and the current Site in South Carolina below Augusta, Georgia (Figure 2-1) (Joseph and Bannick 2000).

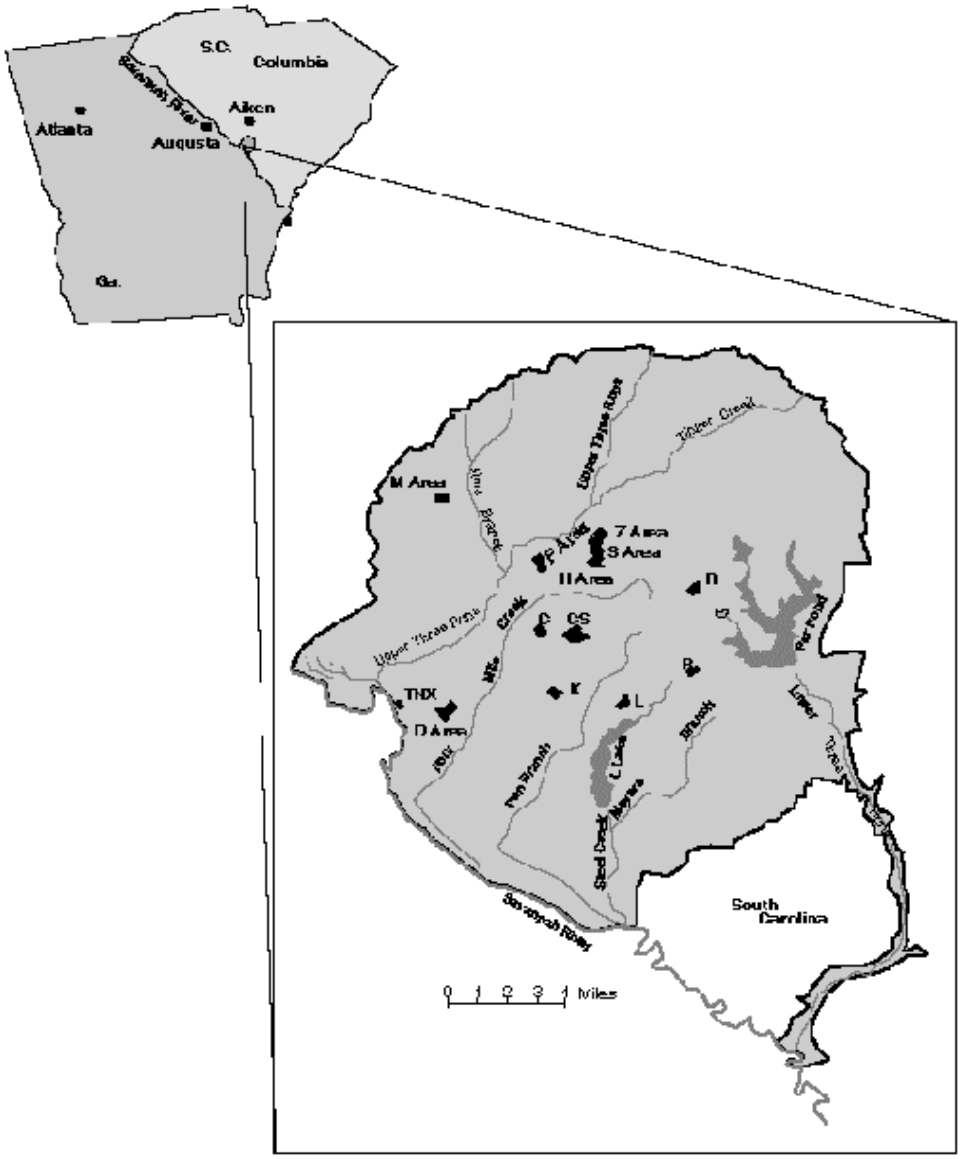

Figure 2-1. The Savannah River Site, showing its location in South Carolina on the Georgia border. Five Site streams flow into the Savannah River to the southwest. The Site occupies approximately 300 square miles. Figure 2-3 shows the Site in more detail.

The SRS, known as the Savannah River Plant (SRP) until 1989 when Westinghouse took over operations, was chosen because of its proximity to the Savannah River, a large source of water needed to remove the heat generated in the reactors, and a source for heavy water extraction. The large 300-mi^2 tract allowed builders to space production facilities at distances that would ensure security and safety (Bebbington 1990). Five major streams on the SRS feed into the Savannah River: Upper Three Runs Creek, Four Mile Creek, Pen Branch, Steel Creek, and Lower Three Runs Creek. Chapter 5 of this report presents detailed information on these streams and their involvement in releases from the SRS.

Figure 2-2 is a sketch of SRS processes and waste flows. Although SRS is divided into six major operational areas, each having a specific function, the key areas for our study were the set of five nuclear production reactors (100-R, -P, -L, -K and -C); the two chemical separations plants (200-F and -H) and their associated tritium production and waste management facilities; M-Area, where fuel and target elements were fabricated and cleaned; and D-Area, where heavy water was produced and processed. These process areas, spaced 2 to 3 mi apart along a rough circle centered within the Savannah River Plant (SRP) Site, were constructed in the early 1950s. They supported the primary industrial operations at SRS. The main activities were

- Fuel and target fabrication
- Operation of large-scale gas and liquid processes to extract and purify heavy water
- Reactor operation to create plutonium and tritium
- Production and purification of plutonium and tritium.

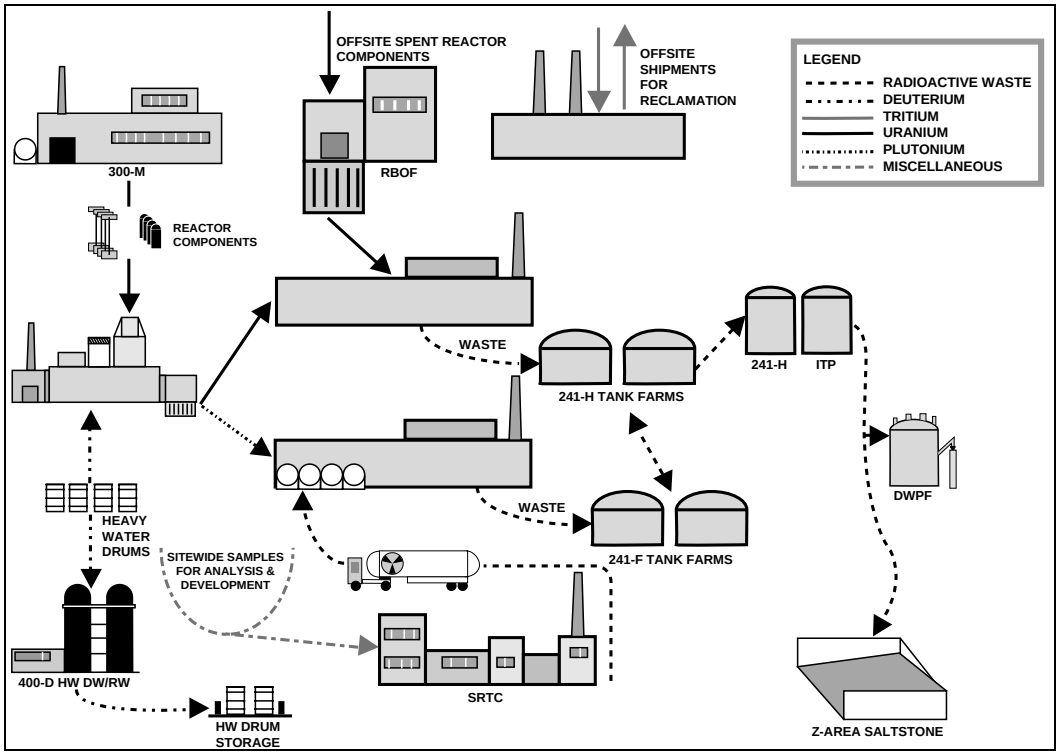

Figure 2-2. Process flow summary diagram of the SRS. The heart of the Savannah River Plant was the group of five nuclear production reactors and the F-Area and H-Area chemical separations plants (221-H Canyon and 221-F Canyon). The 400-D or Heavy Water (HW) area provided deuterium oxide or heavy water as a moderator to the reactors; its also was used to reconcentrate diluted heavy water. Fuel and target components, fabricated in the 300-M Area, were sent to the reactors. Cleaning solvents and wastes from the M-Area work remain as subsurface contamination problems. Fuel and target elements irradiated in the reactors were sent to H-Area and F-Area to be dissolved and the products extracted. Liquid waste was transferred to various tank farms, seepage basins, the Defense Waste Processing Facility (DWPF), or the Z-Area saltstone depending upon the level of radioactivity in the waste (Meyer 1995).

Table 2-1 provides a general overview of the key operational areas at the SRS and important release points, and more detailed descriptions of key SRS areas follow.

Table 2-1. Overview of SRS Facilities[a]

Facility	Dates of completion or operation	Notes
Heavy Water Plant-400-D Area	First of 24 GS units operating by Oct 1952; all by May 1953	Concentration of heavy water, and reconcentration after contamination in reactors with light water. Large quantities of H_2S were used at high pressure in the GS process; consequently, H_2S monitoring procedures were in place early because of its corrosive and toxic nature. Some potential for tritium release.
Fuel and Target Fabrication - 300-M Area	Jan 1953	Produced reactor fuel and target assemblies. Reactor assemblies became more complex as different products were desired and power levels were increased. M-Area used about 13 million pounds of chlorinated solvents to degrease items since mid-1950s. Uranium releases.
CMX and TNX technical development facilities. Savannah River Technical Center (SRTC)	1953	Technical support and pilot plant data and training.
Test “pile”; graphite-moderated reactor	Dec 1952	The reactor was used to calibrate monitors and to assay fuel and target slugs; dismantled in 1980
R-Reactor (100 Area)	Dec 1953–1964	First SRS production reactor; first fuel discharged June 1954; plutonium and tritium production. Liquid effluent to Lower Three Runs Creek, Par Pond, one seepage basin. Airborne releases, primarily gaseous, from all five reactors.
P-Reactor (100 Area)	1954–1988	Plutonium and tritium production. Liquid effluent to Steel Creek, Par Pond and three seepage basins
C-Reactor (100 Area)	1955–1985	Plutonium and tritium production. Liquid effluent to Four Mile Creek and three seepage basins
K-Reactor (100 Area)	1954–1988	Plutonium and tritium production. Liquid effluent to Pen Branch and two seepage basins
L-Reactor (100 Area)	1954–1968; 1985–1988	Plutonium and tritium production. Liquid effluent to Steel Creek, L Lake and a seepage basin; L Lake built in early 1980s by damming Steel Creek
H-Area and F-Area Canyon Buildings (200 Area)	November 1954, July 1955	Reactor products were separated chemically in the reprocessing canyons. Very large quantities of solid, liquid, gaseous wastes produced.
Waste Management Areas	1953	Includes various seepage basins, disposal pits; tanks and burial grounds.

[a] Source: Stetson et al. (1963), Bebbington (1990), Du Pont (1957), Meyer (1995), Wahl (1967).

Heavy Water Production and Reprocessing: D-Area

A heavy water production plant, in D-Area, began operation early in SRS history to concentrate heavy water from Savannah River water to moderate and cool the Site's reactors. The first of 24 girdler sulfide (GS) units was installed in October 1952, with all in place by May 1953. Tremendous quantities of hydrogen sulfide (H_2S) were used at high pressure in the GS process, which concentrated heavy water (D_2O) from its natural 0.015% level in river water (Bebbington 1990). Detailed procedures to monitor for H_2S gas in and around the operations areas were developed because of its corrosive, toxic nature and the possibility of accidental releases (French 1975). The facility stopped production in 1981 because there was a sufficient supply of heavy water. A heavy water reprocessing facility (built to reconcentrate heavy water that had become contaminated with light water during use in the reactors), a coal-fired power plant, and a laboratory to analyze process effluent samples were also located in D-Area. The concentration of tritium in heavy water was a function of the neutron flux in the reactor and the length of the irradiation, with tritium concentration is the moderator building up slowly over the years. Some of the tritium was lost to air and to liquid effluents by evaporation of moderator leaks and carry over of tritium oxide on fuel and target elements during reactor discharge. Chapter 4.1 discusses significant release points for tritium to the atmosphere at the SRS. Any tritium releases to the atmosphere resulting from heavy water processing were measured as stack effluent and are reported in Chapter 4.1. Chapter 5 discusses tritium releases to surface water.

Reactor Materials: 300-M Area

The facilities called the 300-M Area, the 300 Area or M-Area, produced fuel and target elements for the reactors. Control rods and other reactor components were manufactured here as well.

Over time, changes in the fuel rods and target elements were made to support higher levels of production, increased emphasis on tritium production, and the creation of other products for military, research, and satellite purposes (Pelfrey 1987). The reactor assemblies became increasingly complex as these different products were emphasized and higher reactor power was required. Since 1952, it is estimated that M-Area has used about 13 million pounds of chlorinated solvents to degrease the reactor components produced in the facility (Christensen and Brendell 1981). Much of this solvent material was disposed onsite, and it remains as underground contaminants. Chapter 15 discusses these materials in detail.

Reactor Areas

There are five nuclear production reactors located at the SRS; they are in the locations designated K-Area, L-Area, P-Area, C-Area, and R-Area. Plutonium and tritium—the primary products of the SRS reactors—were created in these reactors by uranium and lithium absorption of neutrons. The controlled fission process within the reactors produced those neutrons and enormous amounts of energy. The reactors were operated at relatively low temperatures (less than 100°C) and pressure (near 5 psi) for safety and to optimize product formation. These were heavy-water moderated reactors, which means that heavy water was circulated in a closed system

through heat exchangers to moderate and cool the reactors. The heavy water slowed fission neutrons, greatly increasing the number of additional fissions occurring. The energy produced was discarded as heat via the heavy water coolant/moderator flowing through the reactor cores. The moderator flowed through tubular heat exchangers, cooled by ordinary water. This heat exchange step greatly reduced the quantity of reactor radioactive materials directly entering the outside environment. The Savannah River and two onsite lakes provided cooling water for the heat exchangers. Reactor power levels were increased greatly during the early years.

During the construction of the SRS, the reactor tanks were fabricated by New York Shipbuilding Company at Camden, New Jersey, and shipped by barge via the Savannah River to SRS (Du Pont 1954; Bebbington 1990; Du Pont 1976–1984). All five reactors were operating by early 1955. By 1963, high-efficiency filters had been installed in the reactor ventilation systems to remove particulates, and charcoal beds had been installed to remove radioiodine (Wahl 1967). From 1956 through 1971, the reactors were also used to convert thorium to ^{233}U for the thorium breeder reactor program, as well as to produce numerous other special products (Stetson et al. 1963). Reactor shutdown began in 1964 with R-Reactor; C-Reactor was shut down in 1987. L-Reactor was shut down in 1968, restarted in 1985, then shut down again by 1988. K-Reactor and P-Reactor operated with few interruptions until 1988. A restart of the K-Reactor began in 1991, but it was not completed. All SRS reactors are now shut down.

F and H Separations Area, or 200 Areas

Products produced in the reactors were separated chemically in the F and H Separations Canyons, located in an 8 km^2 area near the center of the SRS (Figure 2-3). Operations in the separations area also include the unloading and storage of offsite fuel at the Receiving Basin for Offsite Fuel (RBOF).

The two chemical separations facilities, 200 F and 200 H, are very similar in construction. Each has two parallel lines of process cells, known as the hot and warm canyons, with a central system of corridors. Complex chemical and physical processes in the F- and H-Canyon buildings separated uranium, plutonium, and fission products. Processing capacities during the 1950s and 1960s were increased significantly.

The separated plutonium and uranium were transferred to other facilities in the F-Area and H-Area and processed into solid forms. Fission products were stored in high level waste (HLW) tanks in the separations areas. Detailed descriptions of the separations facilities, processes, and safety analyses can be found in Du Pont (1957). Bebbington (1990) contains a photographic history of Site construction.

Originally, the tritium received in the separations areas was a by-product of plutonium production. By 1955, greater production of tritium was required so reactor fuel rods and targets were modified, and a second tritium production line became operational in 1957. The key processes leading to tritium releases (detailed in Chapter 4.1) at the SRS included

- Production reactor operations
- Recovery of products in the separations facilities
- Recovery of tritium in the tritium facilities
- Laboratory research processes
- Heavy water rework facility.

Administration Area, or A-Area, and the TNX/CMX Areas

Organizations that supply direct support for SRS operations, including the U.S. Department of Energy (DOE) office for the Site, the Savannah River Ecology Laboratory (SREL), the Savannah River Laboratory (SRL), and other administrative offices are located in the Administration Area.

Although not located in the A-Area, the TNX and CMX Semiworks were considered a part of the SRL, and were some of the first facilities to operate at SRS. CMX and TNX were code designations and had no logical derivation according to Bebbington (1990). CMX investigated problems associated with using Savannah River water for cooling, and it housed the river water pumps and a pressure facility for the testing of reactor elements. CMX was shut down in 1984. The TNX facility, one of the first to operate at the Site, provided technical support, pilot data, and personnel training. In later years, the facility was involved in waste processing research and development.

Waste Management Areas

SRS operations generated hazardous, radioactive, and mixed (radioactive and hazardous) wastes that were handled in a number of ways. Methods included the use of seepage basins for liquids, disposal pits and waste piles for solids, and burial grounds for solid radioactive wastes. Site records report that the historical disposal of waste materials occurred at over 150 individual waste sites, at over 100 areas around the plant. Over 100 of the waste sites contain nonradioactive waste materials, and 20 have been used as disposal sites for radioactive wastes. Fifteen sites have been used as disposal locations for mixed wastes (Christensen and Gordon 1983; Looney et al. 1986).

Waste management facility development was part of the initial construction phase at the F-Area and H- Area. Twelve underground carbon steel tanks were initially built to hold fission products separated from the irradiated uranium (Thomas and Robnett 1981a, 1981b). The tanks were located in reinforced concrete vaults, which had 5-ft-high steel liners. Three other series of tanks were installed in the mid-1950s (Goslen and Mcguire 1981, 1983a, 1983b). The first HLW tank was full in June 1955 (Bebbington 1990). Additional HLW tanks were constructed into the 1980s.

Two burial grounds in the separations area have received radioactive waste since 1953. Although most of the waste in the burial ground originated from onsite operations, a number of other facilities sent waste to the SRS, including

- Knolls Atomic Laboratory—the Naval Reactors Program
- Los Alamos National Laboratory
- Mound Laboratory
- Shippingport Atomic Laboratory
- Westinghouse—Bettis Atomic Laboratory
- Plutonium-contaminated debris from two U.S. military airplane accidents that occurred in other countries.

By the end of the first 5 years of SRS construction and operation, all of the basic production facilities were in operation and the products (plutonium metal and tritium gas) were being delivered. Following the division of the AEC into the Nuclear Regulatory Commission and the

Energy Research and Development Administration (ERDA), the SRS was operated for ERDA, then for the DOE.

Production Data Needs

While reconstructing facility releases during Phase II of the SRS dose reconstruction project, the CDC and *RAC* decided it was necessary to develop a detailed history of reactor and reprocessing facility production during the years of SRS operations. These data have been used to develop estimates of certain types of radionuclide and chemical releases linked to reactor and reprocessing canyon production rates, where more accurate rate data are not available. While partial information related to production was available from various sources, *RAC*'s discussions with SRS staff did not identify a complete source of data for all key facilities for all years of operation. Therefore, in 1997, we undertook an additional records review to create the following production history. While this research has been summarized in a project newsletter and during public meetings and presentations to the CDC Health Effects Subcommittee, it has not been published in full detail elsewhere.

SRS REACTOR POWER, CANYON, AND TRITIUM PRODUCTION DETAILS

Introduction

A key element of the Phase II research involves estimating releases from the SRS. Most of these releases occurred from a few major facilities onsite: the five reactors and the reprocessing and tritium production areas. Figure 2-3 maps the location of these facilities. To assist in developing an understanding of the historical operation of these key areas and to provide data necessary to estimate routine releases of radionuclides and chemicals, we developed a history of reactor and fuel processing at SRS. Detailed data in spreadsheet format are supplied with this report.

Details: Reactor and Reprocessing Area Power/Production History and Data Compilation

On December 28, 1953, the R-Reactor went critical and began producing plutonium. Scrams (unplanned reactor shutdowns) because of various problems averaged one per day for the first 2 months, one per 3 days in March 1954, and one every 15 days by June. In June, the first irradiated fuel was removed from the reactor. After a cooling period, plutonium was extracted from this fuel in the 221-F reprocessing canyon beginning in November 1954. The 221-H reprocessing canyon began operating in July 1955. Tritium was extracted from LiAl targets in a small facility in the 200-F Area beginning in October 1955 (Stetson et al. 1963).

Initial Production Levels

From 12/28/53 to 2/3/54, R-Reactor power was raised in steps to its initial rating of 375 megawatts (MW). Continuing modifications (described later in this section) increased reactor power ratings; near the end of its first fuel cycle, R-Reactor was operating at about 640 MW. By March 28, 1955, all five reactors were in operation. After initial startup and adjustments to processes and equipment, the 221-F Canyon design throughput of 3 metric tons of uranium per day was reached. The 221-H Canyon operated at 7 tons per day during this period. Figure 2-3, created by *RAC*, displays the rough circle within which the primary production facilities at SRS were located (Stetson et al. 1963).

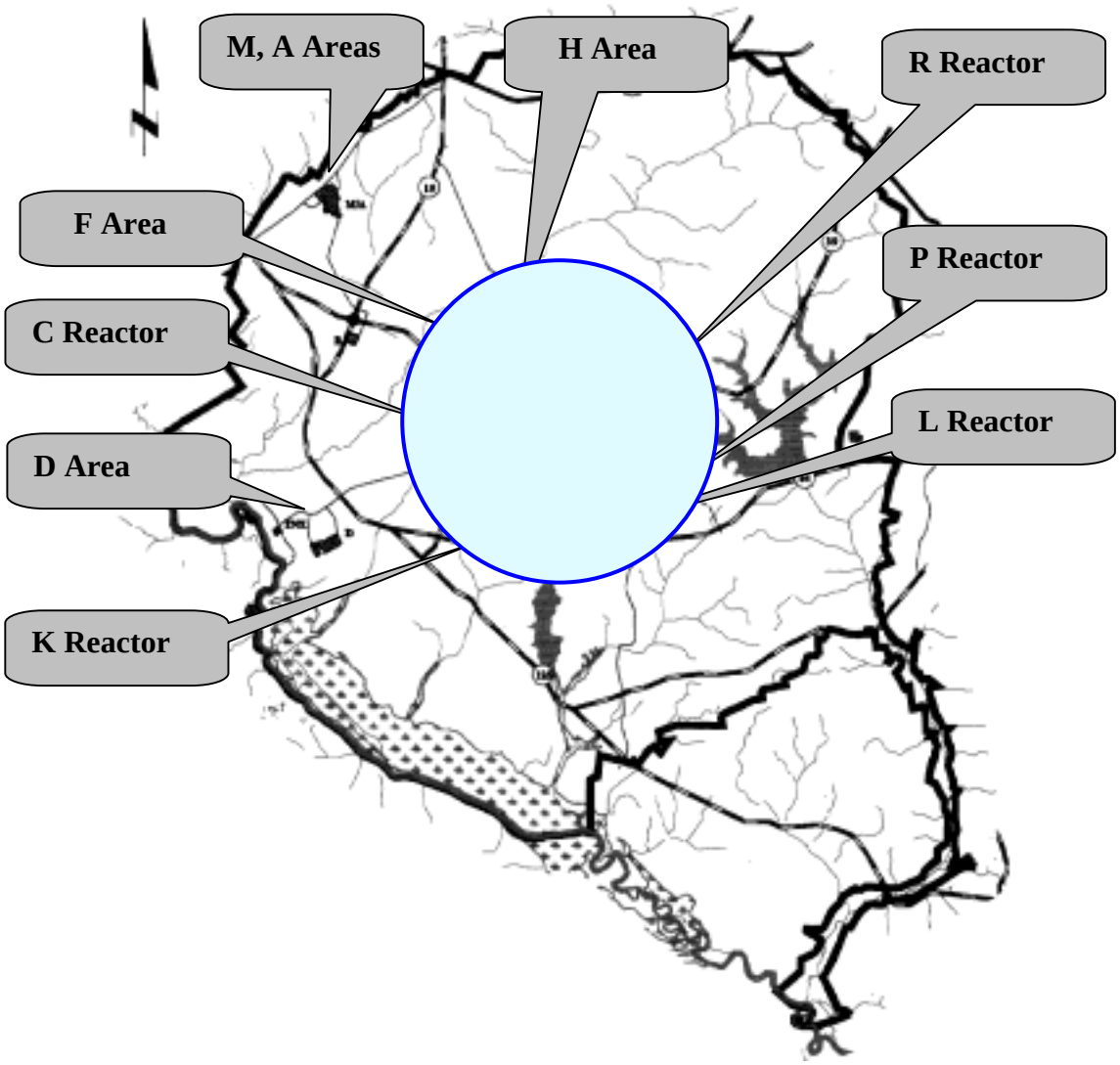

Figure 2-3. The SRS showing the reactor (C-, K-, L-, P-. and R-Reactors) and processing areas (F-Area and H-Area) in a rough circle toward the center of the Site, and D-Area and M-Area near the Site perimeter (Meyer et al. 1995).

Reactor Operations, Modifications, and Incidents

The heat output of a reactor is proportional to the rate of fission and, thus, to the creation of fission products in the fuel. Heat output is also proportional to the rate of production of ^{239}Pu and tritium for a given reactor/fuel configuration. Reactor thermal output at SRS was gradually increased beginning in 1954. In 1955, the first enriched (5% ^{235}U) uranium fuel was used to allow increased loadings of LiAl for tritium production, with LiAl rods inserted into fuel spaces (earlier only in control rod spaces). Solid enriched uranium slugs alternated with LiAl slugs in the four-element tubes (Bebbington 1990).

C-Reactor power was increased from 378 to 877 MW by December 1955. Various factors contributed to reactor increased power capacities. The allowable upper limit for fuel slug surface temperature was raised from 80 to 160ºC without harm to the cladding. Additional heat

exchangers were added as the supplier's production capacity permitted; in 1956, the number of heat exchangers for the R-, P-, L- and K-Reactors was doubled (C-Reactor was provided with 12 exchangers before startup). Reactor water flow distributions were adjusted and river water pump impellers were increased in size. A peak of 1400 MW was reached in R-Reactor by the end of 1956. Higher-capacity heavy water circulating pumps were installed in L-, K-, and C-Reactors in 1957. By the end of the year, peak power in C-Reactor had reached 2250 MW (Stetson et al. 1963; Meyer et al. 1995; Bebbington 1990).

Construction of Par Pond was completed in 1958; it received all R-Reactor cooling water. Water from the pond was pumped to R- and P-Reactors, making more river water available to L-, K-, and C- Reactors. The overall effect increased cooling water flow from 650,000 to 775,000 gpm, increasing total five reactor power by 850 MW. In 1960, larger impellers in the river pump house and the addition of three pumps at Par Pond raised cooling water flow to 900,000 gpm. This raised peak power in C-Reactor to 2575 MW (Du Pont XX)[a].

Fuel slugs evolved as well. Beginning in January 1960, hollow slugs to improve cooling capacity were being produced at SRS. Hollow slugs were used as early as 1955, produced elsewhere by Sylvania. Longer and more complex fuel elements were developed to increase power levels and neutron availability for tritium production. In 1963–1964, reactor powers were increased 100–200 MW by increasing pressure within the reactor tanks by 5 psi (Stetson et al. 1963, Du Pont XX).

In 1964, after 10 years of operation, R-Reactor was shut down; L-Reactor shutdown followed in February 1968. Both were shut down because of reduced production requirements; R-Reactor also had longstanding leakage problems. L-Reactor was later refurbished for operation. The C-Reactor peaked at 2915 MW in 1967, the maximum power level reached by an SRS reactor. This is comparable to the thermal output of a commercial electric power reactor. Figure 2-4 shows peak power levels from 1954–1989 (Bebbington 1990).

The SRS reactors operated near atmospheric pressure and the normal boiling point of water, precluding the explosive release of latent energy during an accident. Ventilation of reactor buildings was continuous, with air passing around the reactors and out to the atmosphere through tall stacks. Tritium from deuterium neutron capture and ^{41}Ar from neutron activation of natural ^{40}Ar were detected at low concentrations in the reactor building air as early as 1956 (Hall and Coombs 1956; Hoy 1962).

[a] The SRS vaults onsite contain several series of records with monthly reactor and canyon production data. These records are identified as SRS CXXIX-XX-X from 1955, as DPSP-XX-717 in 1962, and as DPSP-XX-307 beginning in 1963. Beginning in June of 1979, reactor monthly reports were deleted from the 307 series and reported separately as DPSP-XX-14-XX. This series remained classified through May 1982, then was published monthly, internally, as unclassified reports. These records have been extracted and deleted/declassified as necessary, and are in *RAC* and CDC possession offsite. They are referenced throughout this document as Du Pont XX.

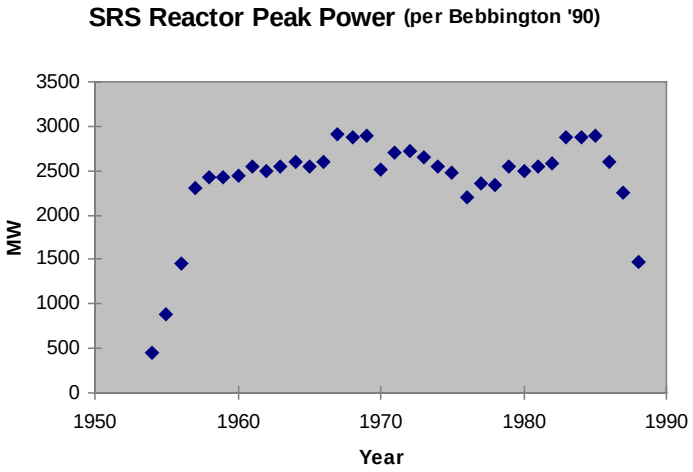

Figure 2-4. SRS reactor peak power (in MW) (Bebbington 1990).

The potential for the dropping and melting of a fuel element during fuel handling, with consequent release of volatiles such as ^{131}I, lead to installation of deluge sprays in the reactor rooms and filters and activated carbon adsorbers installed ahead of the stacks in the R-Area, P-Area, and K-Area in 1962. In 1963, similar facilities were installed in L-Area and C-Area. In the following 3 years, retention basins were constructed to contain water from the deluge systems. Later, 500,000-gal tanks were added in these basins to catch deluge runoff. These systems were never used according to Bebbington (1990).

In 1964, the first process-control computer was given a trial run in K-Area, monitoring some 3600 sensors of process variables. By the end of 1966, similar first-generation computers were installed in all four operating reactors. They scanned the sensors, compared observations with allowable limits, and presented analyses to the operators. Scram capability linked to over-temperature was added to the computer system in late 1966. Additional new controls and capabilities were added over the years (Bebbington 1990).

From 1954 to 1974, Advisory Committee on Reactor Safety reactor physicists and engineers performed 30 reviews of SRS reactor operations. In January 1960, the most serious SRS reactor incident occurred, when a rapid restart of L-Reactor (following a scram) resulted in over-temperature and the potential for fuel melting within 40 seconds if shutdown had not been performed. Rapid restarts were prohibited in all SRS reactors following that incident (Stetson et al. 1963). A 1970 incident involving a neutron source held too long without cooling after removal from K-Reactor, resulted in significant contamination inside the reactor building. Personnel dose during cleanup totaled 600 person-rem, with a maximum dose of 3.3 rem and an average dose of 0.7 rem. The reactor was down for 3 months for cleanup. In 1982, a new Reactor Safety Advisory Committee was formed.

Stress cracking of stainless steel welds at complex shape locations on the reactor vessels eventually led to leaks. The first was discovered in R-Reactor in 1960 after about 7 years of operation. This leakage problem was chronic but controlled. Only R- and C-Reactors were found upon detailed inspections to have developed serious cracks. R-Reactor cracks were related to early welding fabrication technology (largely inadequate thermal stress relief). C-Reactor cracks were associated with a curved transition section (the knuckle) with high residual stresses. Smaller

cracks discovered in C-Reactor in 1985 were caused by helium embrittlement in stainless steel; repair attempts were not successful (Bebbington 1990).

Reactor heat exchanger tube cracks and leakage appeared as early as 1956; modification of water chemistry controlled the problem by 1961. Disassembly basin operations, involving fuel elements with failed cladding, regularly resulted in fission product escape to basin water then to seepage basins. Redesigns later reduced releases, particularly of ^{137}Cs.

A 15-year program was initiated in 1956 to produce ^{233}U for the thorium breeder reactor program. Some 630 kg of ^{233}U was eventually produced at the SRS (Bebbington 1990). The ^{232}U daughter high-energy gamma radiation eventually made the program unattractive.

About 66 million curies of ^{60}Co was deliberately produced, beginning in 1955, for potential use in food sterilization programs. Some 275 kg of ^{238}Pu was produced from 1959–1978 for various heat source and related programs. Other production programs, including creation and extraction of ^{252}Cf during the period 1965–1970, were also conducted at the SRS (Stetson et al. 1963; Du Pont XX). During this period, SRS produced a variety of radionuclides ranging from tritium to ^{252}Cf in a series of reactor campaigns. The program to produce ^{252}Cf, which was used mainly for research purposes, required the modification of the reactor core because the heat generated per foot of fuel element was about three times normal. During these high-flux operations, over 250 target capsules, comprised of 150 nuclides of 66 chemical elements from nine research laboratories for Oak Ridge National Laboratory, Brookhaven National Laboratory, the University of Illinois, and Denmark, were irradiated (Meyer et al. 1995).

Determining Reactor Power and Canyon Production Levels

During Phase II of the Dose Reconstruction Project, researchers determined that detailed reactor and canyon operational data would be useful to estimate radionuclide and chemical release data for periods when measurements were unavailable. Monthly F- and H-Canyon input and production data were not available from SRS staff in summary form, and monthly reactor power data summaries were not found during an extended search by *RAC* and Site staff. *RAC* then examined the detailed monthly production summaries to collect these data. Tritium production data remains classified, but *RAC* and CDC were able to reach a compromise with SRS and DOE staff allowing the declassification of an adequately detailed history of tritium production, discussed below. *RAC* and CDC research to access the reactor power and canyon production data included the following steps:

- A Search of the *RAC/CDC* Phase I document database for records of potential value
- Discussions with SRS staff to identify potential data sources
- An SRS visit in April 1997 to inspect records, conduct interviews, and search for data
- Conferences with SRS declassifiers to format data to allow release to the public domain
- Extraction of key data from classified and unclassified records
- Declassification review by SRS staff
- Conversion of declassified data to spreadsheet format
- Quality assurance review; graphical analysis of results
- Additional Site visits to locate more records
- *RAC* report preparation, including internal and external reviews.

Searching the Phase I Document Database

During Phase I of the SRS Dose Reconstruction, *RAC* and CDC devoted a great deal of effort to a hands-on review of records stored onsite and offsite. To document this record location and review, *RAC* developed an electronic database to track boxes and individual documents as they were reviewed and to categorize their likely value to the study. Documents determined to be potentially useful to the study were copied and sent through the SRS classification review process. The declassified or unclassified records and the *RAC* database describing their contents are available at the University of South Carolina public reading room in Aiken.

The Phase I database reflects the results of our review of more than 40,000 boxes of records, including material found in all formal repositories located onsite. The search for these records was comprehensive, involving hundreds of interviews and many dozens of Site visits.

To locate Phase I database records related to Site production levels, we searched the Phase I database for the words “reactor,” “power,” “production,” “canyon,” “tritium,” and “plutonium.” Additional keywords were applied based on the results of the initial search. The resulting sets of document descriptions were printed for use during the initial Site visit. Approximately 200 documents of potential interest were identified via this search.

Discussions with SRS Staff

Dr. Robert Meyer of *RAC* contacted Mr. Greg Peterson, the SRS onsite coordinator for *RAC*’s research, and asked for assistance in identifying historical reports on reactor and canyon production levels. Other SRS staff members were contacted to determine whether existing summaries of reactor and canyon production levels were available in sufficient detail. No detailed summary documents were found during these discussions, and *RAC* proceeded to review detailed classified and unclassified records in Buildings 773A and 773-52A to create such a summary, published here.

Site Visit - April 13–18, 1997

RAC spent the week onsite, initially searching for records and interviewing SRS staff, then focusing on extracting data from the pertinent records. A key *RAC* Category 1 record was located during research in the 773A classified vault. This document led to a series providing monthly reactor and canyon production data of adequate detail. These records are identified as SRS CXXIX-XX-X in the earlier years, as DPSP-XX-717 in 1962, and as DPSP-XX-307 beginning in 1963. Each classified monthly summary consists of 20 or more pages detailing the canyon, tritium area, and reactor production record for the month. A great deal of production information is available in these reports; only a subset was necessary for the purposes of this specific research project. Data sheets were used to collect that subset, and about 250 pages of data were extracted from the reports during the week. Copies of all document pages used during creation of this SRS production history were declassified as necessary by SRS staff, are now held offsite by *RAC*/CDC, and are available for public review.

In June 1979, the classified report series previously containing both reactor and canyon data was converted by SRS to a classified, canyon-only production summary. The reactor power summaries were continued as separate, unclassified monthly reports. Reactor power data for the

period April 1982 through the end of 1987 were located during the summer of 1997 and are presented in this chapter. *RAC* continued to search for monthly reactor power data for the period June 1979 to March 1982, eventually discovering the final data sets under a new report title. All necessary data, with minor exceptions, were eventually located during this research.

Tritium Data Declassification

After several discussions, SRS staff determined that all needed data could be declassified, with the exception of tritium exact production data. To circumvent this remaining problem, tritium production data were sorted by *RAC* into 15 "bins," consisting of ranges of tritium monthly production rates. This approach obscures the data, allowing Site declassifiers to treat the results as unclassified, while maintaining sufficient accuracy for the purposes of dose reconstruction. The results of this conversion are reported here as "estimated" tritium production data. As is the case with all records of value to the dose reconstruction, the original monthly report sections were submitted by *RAC* to the SRS declassifiers and were eventually released to the public domain as "deleted versions" (with classified information removed).

Extraction of Key Data

The monthly SRS DPSP reports contain estimates of future production, actual reactor power and production data, and information related to specific campaigns at SRS to produce other products, including ^{233}U, ^{238}Pu, ^{252}Cf, and ^{60}Co. Most of this information was not needed for our purposes. For the records period January 1955 through October 1967, *RAC* extracted peak power, average power, megawatt-days per month, estimated ^{239}Pu production, estimated tritium production, and heavy water accumulated losses for each reactor. For the same period, *RAC* extracted F-Canyon and H-Canyon uranium-to-dissolver, tritium, and plutonium production. For H-Canyon after mid-1959, "U235 tubes to dissolver" data (enriched uranium fuel element data), were extracted. These fuel elements were used to enhance reactor tritium production beginning in June 1959. On the data sheets, *RAC* also captured notes concerning certain campaigns, reactor heavy water inventory, error corrections, and SRS production of additional radionuclide products. For the period following October 1967, we reduced the amount of data extracted, capturing reactor megawatt-days per month, heavy water accumulated losses, uranium to dissolver, ^{239}Pu production, tritium production, and U235 tubes to dissolver. The *RAC* data sheets were declassified by SRS staff, and they are available for public review (Du Pont XX). The tritium production estimates and actual tritium production data were deleted from the *RAC* data sheets by the SRS classifiers (as agreed), but the "binned" tritium production data were cleared to the public domain and are reported within this chapter. These data have not been previously released.

Transcription of Declassified Data to Spreadsheet Format: QA Review

RAC received the declassified data sheets after our Site visits, and we transcribed power and production data into an Excel® spreadsheet. The data entries were reviewed and corrected during a second pass through the data sheets. (Time onsite did not permit similar review of the data extracted during the Site visit.) These data are available offsite now, in the declassified records held by *RAC*/CDC. The plotted data were inspected for outliers and trends. A change in trends

observed for the heavy water accumulated releases after July 1974 indicated the need to correct for a units change from pounds to kilograms at that point. Later data retrieved from SRS validated this correction.

Report Preparation and Review

A *RAC* Technical Memo detailing the power and production study was transmitted for review by additional *RAC* researchers and to evaluate the adequacy of the data collected. Several report versions were prepared over time to incorporate reviewer comments and to add late-discovered reactor power data sets. *RAC* asked SRS declassifiers to additionally review the potentially sensitive information. Results of the power/production study were presented to the CDC's SRS citizens' Health Effects Subcommittee in August 1997; they were updated at a later meeting.

Reactor Power Output

The following graphs reflect monthly reactor power output data for the five SRS reactors. Reactor power for each month is presented below in thousands of megawatt-days. This is a measure of the reactor's thermal power output daily average during the month, in millions of watts, times the number of days in the month. A reactor averaging 2000 MW thermal power output for 30 days would produce 60,000 megawatt-days (MWd) of power in that month. Thermal power levels reached by SRS production reactors are similar to those reached by commercial electric power reactors. On the following plots, zero power for a month means that the reactor was not operating for that month, except for March and April 1985. We could not locate data reports for that 2-month period. P-, K-, and C-Reactors were operational at that time. Detailed data supporting the following graphs are available in an associated spreadsheet.

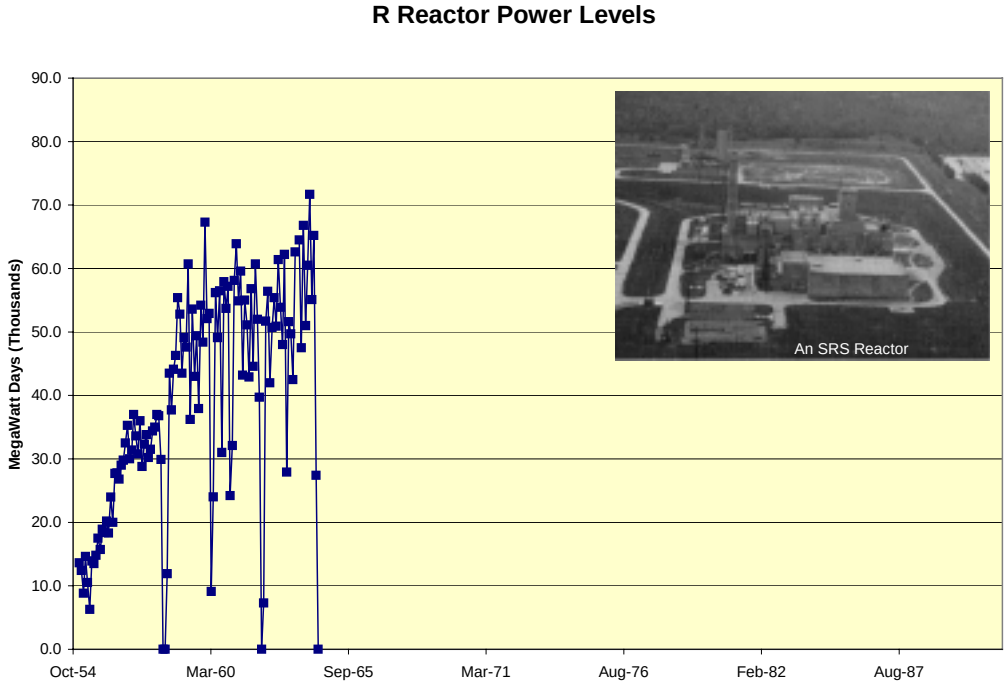

Figure 2-5. R-Reactor operated from December 1953 to June 1964, initially reaching 375 MW thermal power. Modifications increased power levels over time. R-Reactor reached its maximum of 71,700 MWd in March 1964. The reactor developed significant vessel cracks, discovered in mid-1960 (Du Pont XX).

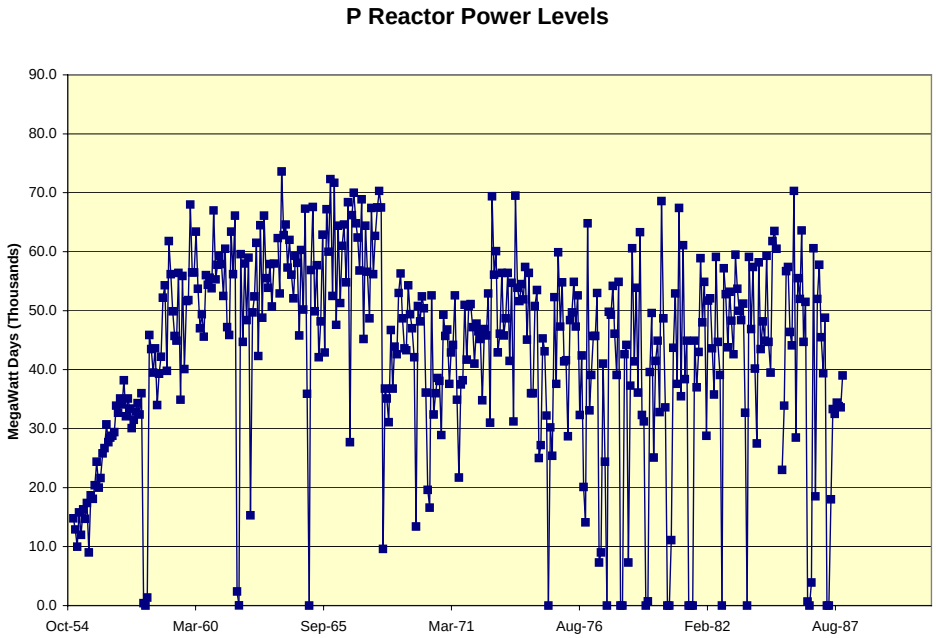

Figure 2-6. P-Reactor operated for nearly 35 years, reaching its maximum monthly power output of 73,600 MWd in December 1963 (Du Pont XX).

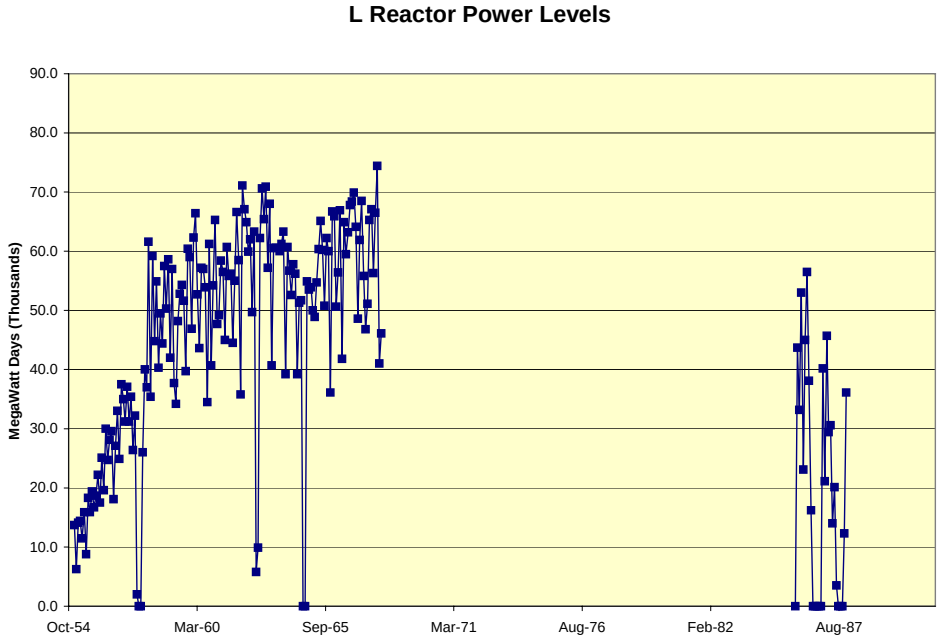

Figure 2-7. L-Reactor operated from 1954 through February 1968, reaching its maximum monthly output of 74,400 MWd in December 1967. It operated again from November 1985 through December 1987. A January 1960 rapid restart lead to a serious incident in which fuel temperatures could have reached the melting point. SRS procedures were modified to prohibit rapid restarts as a result of that incident (Du Pont XX).

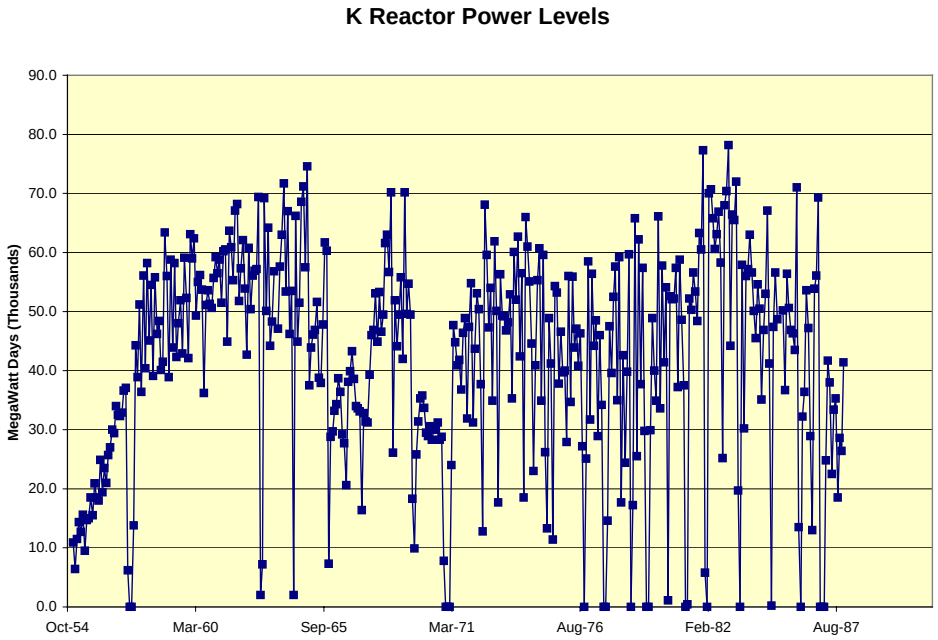

Figure 2-8. K Reactor operated for more than 30 years, reaching its peak monthly power output of 78,200 MWd in January 1983 (Du Pont XX).

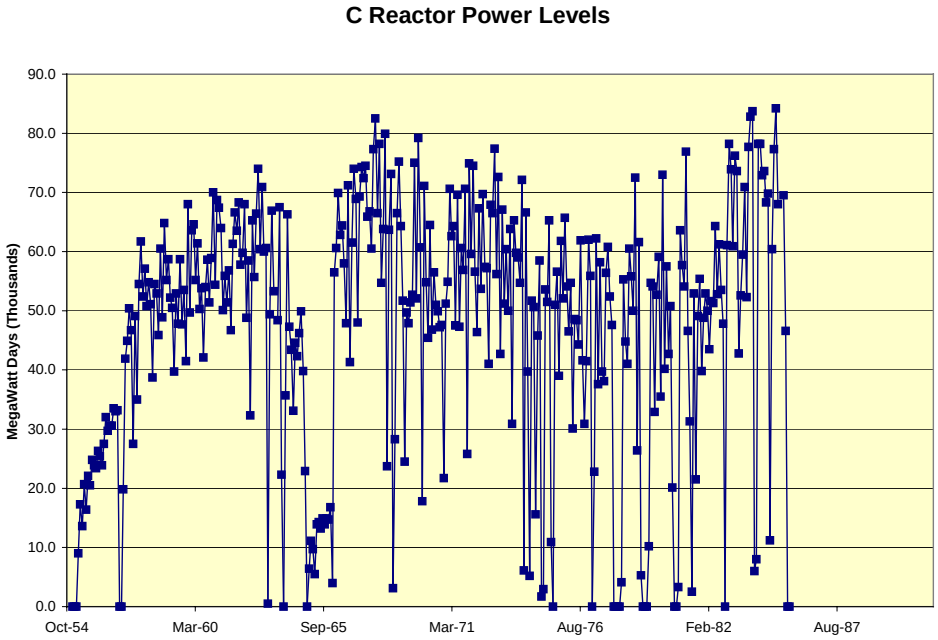

Figure 2-9. C-Reactor also operated for more than 30 years, reaching a peak monthly power output of 84,200 MWd in January 1985. Inspections in the early 1960s indicated cracking in a highly stressed section of the vessel. In 1985, additional cracks caused by helium embrittlement were found (Du Pont XX).

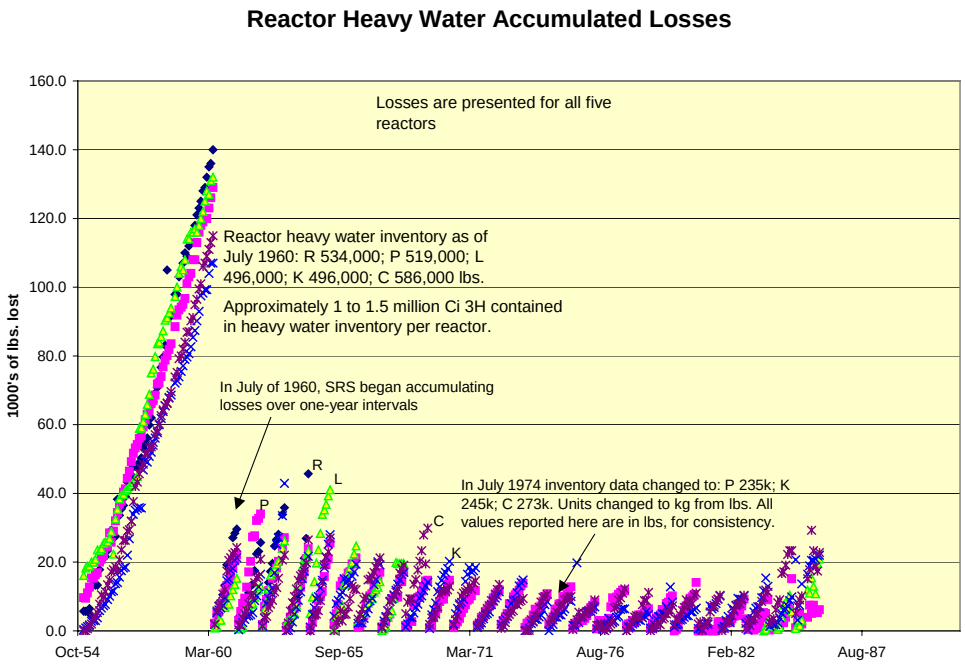

Figure 2-10. Because reactor heavy water moderator was an expensive SRS product, its loss rate was monitored routinely. Tritium (as tritiated water) was present in the moderator and was released offsite via moderator leakage. Routine tritium loss from the reactors may be estimated using records of moderator loss (Du Pont XX).

Canyon Processes, Modifications, and Incidents

Bebbington (1990) notes that early in 1955 efforts were concentrated on increasing F-Canyon throughput to work off the accumulation of irradiated fuel in the reactor cooling basins. Throughput increased from 1.6 tons uranium per day at the beginning of 1955 to 4 tons per day by May. The cooling time of stored fuel had by then been reduced to 118 days. The throughput increase was managed by increasing the amount of uranium in solutions entering solvent extraction and increasing the tributyl phosphate concentration in the solvent. Dissolver batch size was increased from 5.9 to 9.4 tons uranium. Less than 0.2% plutonium and 0.1% uranium were being lost to HLW. The first carbon steel, underground HLW tank was full in June 1955. Following this event, reagent concentrations were more carefully controlled, reducing the amounts sent to HLW by 22%. By the end of 1956, H-Canyon was up to 6.6 tons per day input and F-Canyon to 4.5 tons per day. Rates were then limited by the available quantity of adequately cooled fuel. By the end of 1956, a second tritium production line in 232-H was operating.

At the end of February 1957, F-Canyon was shut down for enhancements. New mixer-settlers as large as could fit into the canyon cells replaced the existing units. After beginning tritium recovery in 232-F in October 1955, in July 1957, a larger tritium facility began operation in 232-H. Uranium processing was moved to the H-Area where 8 tons per day throughput was soon attained. The 232-H capacity was doubled in 1958. In 1958, plutonium demand slumped and H-Canyon operation dropped to three shifts, 5 days per week. Hollow (Mark VII) fuel slugs dissolved much more rapidly but with some increase in waste (Meyer 1995; Wahl 1967).

Also in 1957, SRS began compressing tritium into steel reservoirs, components of enhanced nuclear weapons. The 234-H facility began operation in August 1957 to produce these filled (high-pressure) tritium reservoirs. These were regularly returned to SRS over the years to extract ingrown ^{3}He, the tritium decay product. Equipment to separate ^{3}He was installed in 234-H in August 1958. Reservoir recycling was added subsequently in a new building, 238-H.

Two of the three large heavy water plants in D-Area were shut down and scrapped in 1957–1958. Adequate supplies of heavy water were in place by then, and D-Area reconcentration equipment was used to recover from dilution of reactor moderator (Bebbington 1990; Wahl 1967).

In August 1958, tritium processing began in 232-H-2 (plus existing processing in 232-F and 232-H). In October 1958, the F-Area tritium facility was shut down permanently.

A new plutonium-finishing facility, the JB line, was built on the roof of 221-F in the late 1950s. In March 1959, Purex operations resumed with hollow slugs as feed. Process capacity in 221-F was then 14 tons of uranium per day. Plutonium processing in H-Area then ceased; Building 221-H was shut down for 3 months in 1959 and converted to process the enriched uranium tubes (U-235 tubes; the HM process) used to enhance tritium production. That operation began in May with a throughput of 25–53 fuel tubes per day. During the preceding 3 years, these tubes had been processed at the Idaho Chemical Processing Plant for uranium recovery. The 221-H dissolver was extended to handle long fuel tubes, and neutron-sensing instruments were added to monitor ^{235}U concentrations to prevent criticality. Processing and upgrading were done remotely using the canyon cranes. Operations in H-Canyon were suspended from May to October 1960, limited by irradiated fuel availability. From 1961–1965, F- and H-Canyons were operated alternately (Du Pont XX).

In 1959, the high-neutron-flux potential of SRS reactors led to the production of high atomic weight research and industrial materials, including ^{252}Cf and isotopes of curium and berkelium. Stepwise, recirculating ion exchange processes were developed to first produce precursors of these high atomic weight particles and then final products. Solvent extraction was eventually added to this process. About 2 g of ^{252}Cf was eventually produced in the SRS reactors. Both ^{244}Cm (a heat source) and ^{241}Am were produced/extracted at SRS, with the major production activity in the 1970s.

The Multipurpose Processing Facility (MPPF) was completed in 1972, but it was not operated until 1978 when it converted a stock of ^{241}Am to oxide for shipment to Oak Ridge National Laboratory. SRS produced americium/beryllium neutron sources, and some ^{241}Am was used in smoke detectors produced elsewhere. Some ^{252}Cf was used in well logging, industrial radiography, and activation analyses. About 2 g ^{252}Cf still in its target elements was eventually shipped to Oak Ridge National Laboratory for storage (Bebbington 1990).

Beginning in 1964, SRP increasingly reprocessed uranium fuels from experimental power reactors and research reactors at universities and AEC laboratories. Early Candu (Canadian power reactor) fuels were included in this program. The RBOF was built to inspect and prepare these variously encapsulated fuels. An electrolytic dissolver (enhancing corrosion/dissolution rates) was built to deal with stainless-steel-clad offsite fuels. This dissolver operated through 1979.

Neptunium-237 was purified and converted to ^{238}Pu in SRS reactors. Recovery of neptunium began in 1960, first by ion exchange but later, in 221-H, by solvent extraction. Neptunium was purified and converted to oxide in the HB line, which was no longer being used for plutonium finishing. To enhance ^{238}Pu production, uranyl nitrate solution returned to Oak Ridge for reenrichment in ^{235}U was kept segregated for return to SRP so that the concentration of ^{236}U built up (^{236}U is part of the ^{237}Np creation chain). Building 235-F, never used for production of weapons shapes, was converted in 1961 to producing neptunium oxide-aluminum target slugs for irradiation. Building 235 was modified further to produce neptunium oxide-aluminum billets for extrusion in Building 321-M. The 321-M Building extruded powders into target tubes later. The first separation of ^{238}Pu was done in the SRP High Level Caves. The process was then scaled up and transferred to the 221-H-Canyon. The Plutonium Fuel Facility (PUFF) was constructed in Building 235-F in 1978 to produce ^{238}Pu oxide spheres, about 1.5-in. diameter, sealed in iridium shells. These each were capable of producing 7 W electrical. Several hundred spheres were produced between the late 1970s and the mid-1980s (Bebbington 1990; Meyer 1995).

The first of several Thorex campaigns was run in 221-H beginning in late 1964. This work continued intermittently through 1969. Some of the ^{233}U produced was used in the Navy's Shippingport, Connecticut, experimental light-water breeder reactor.

Solvent deterioration lead to the need to separate solvent purification stages early in the canyons' processing years. First stage solvent eventually deteriorated to the point that it was burned in an open pan in the low-activity waste burial ground. A great deal of smoke was produced, but the process "did not release significant radioactivity to the air" (Bebbington 1990, p. 120). Changing from ultrasene (highly refined kerosene) to the more stable hydrocarbon adakane in 1962 ended most of the solvent degradation problems. Contact time was reduced by developing a centrifugal contactor in F-Canyon—this reduced solvent damage and startup and shutdown time.

One of the "more serious" F-Canyon incidents occurred in 1960. About 5000 Ci of "radioactivity" (Bebbington 1990) escaped from the HLW evaporator and flooded down a

stairwell and through normally nonradioactive sections of the building. Contamination in the corridor was reduced to operable levels in about 3 months; some lower-level spaces were out of service for several years.

In 1969, after 15 years of operation, the H-Canyon sand filters failed because of concrete corrosion by acidic vapors. New sand filters were installed in H-Area and F-Area, this time with steel support structures under the filter beds to reduce further collapse. In 1975, a chemical explosion in the A-line of F-Area (uranyl nitrate solution processing) caused no injuries, but the facility was shut down for about 6 months. Refer to the dose reconstruction Phase I report for additional details concerning the reprocessing canyons (Meyer 1995). Detailed data supporting the following graphs are available in an associated spreadsheet.

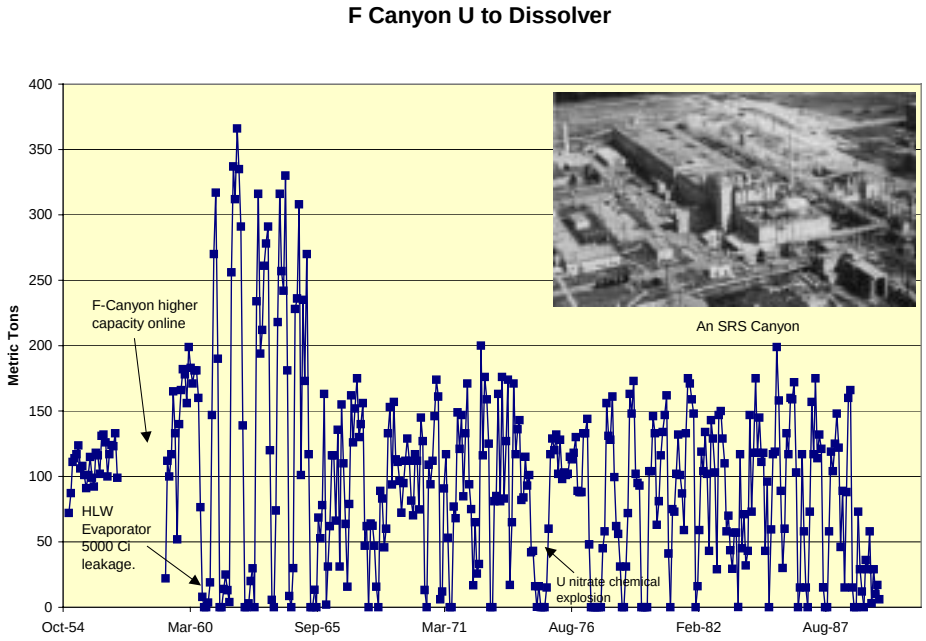

Figure 2-11. F-Canyon uranium to dissolver. The first plutonium extraction at SRS took place in November 1954 in the F-Canyon. The canyon reached its peak capacity in April 1962. A leak from a HLW waste evaporator in mid-1960 caused internal flooding and contamination (Du Pont XX).

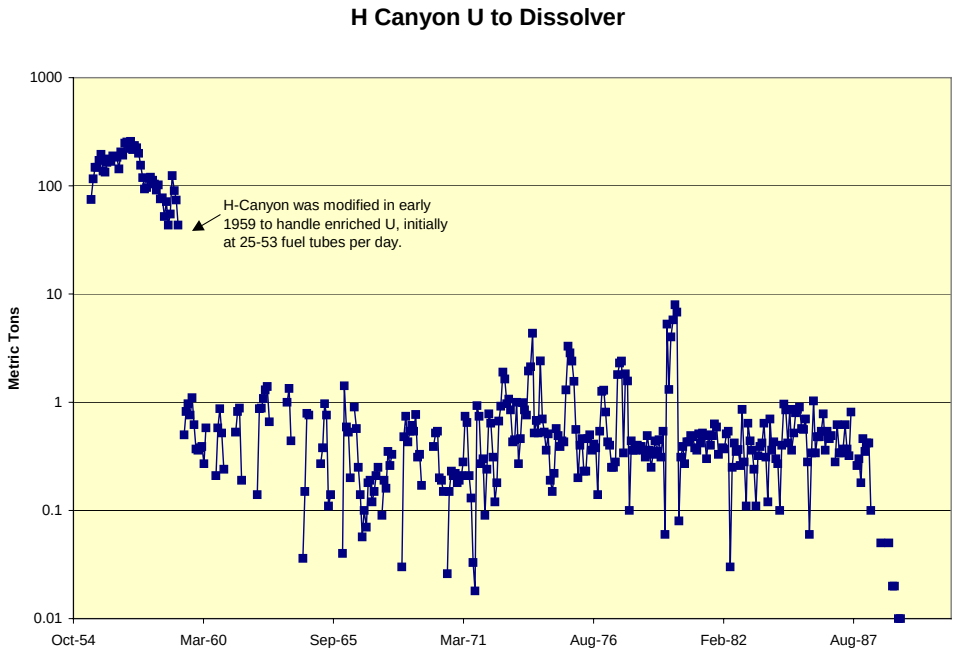

Figure 2-12. H-Canyon uranium to dissolver. In later years, H-Canyon throughput was reported both in metric tons of heavy metal (uranium) and as the number of (enriched) ^{235}U tubes charged to the dissolvers (Du Pont XX).

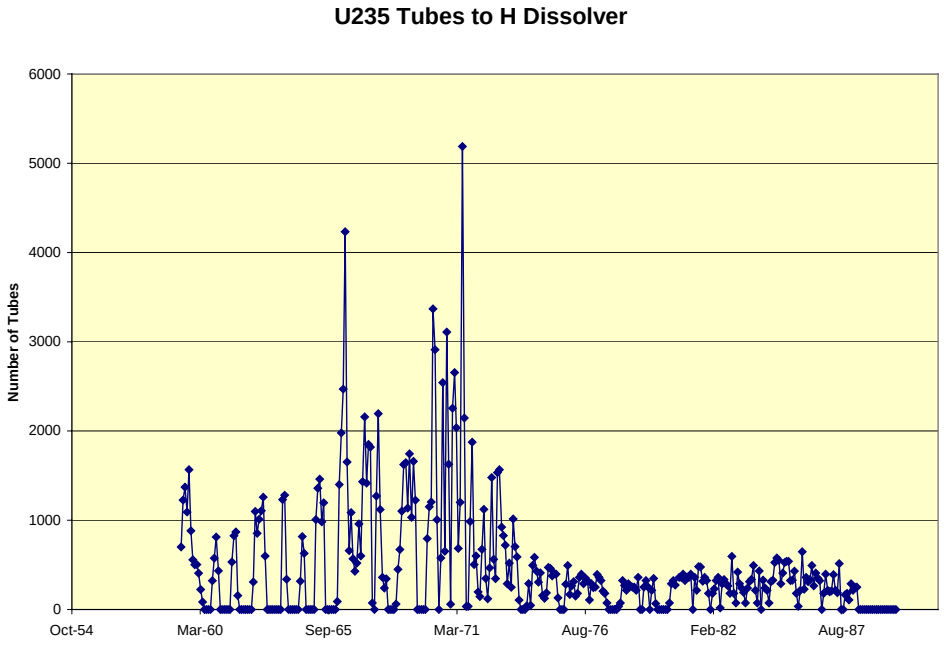

Figure 2-13. Uranium-235 tubes to the H-Canyon dissolver. Uranium-235 tube input peaked in June 1971 (Du Pont XX).

Estimated Tritium Production

Exact or "accurate" levels of tritium production at SRS remain classified. For purposes of dose reconstruction, ranges of production levels by month are adequate to estimate routine releases. The tritium production data were sorted into ranges as shown in Table 2-2, allowing presentation of the data in an unclassified document. The tritium production graph (Figure 2-14) plots these sorted data. These binned data are called "estimated" values here. Detailed data supporting the following graphs are available in an associated spreadsheet.

Table 2-2. Tritium Production Rate Data Sorted into Bins (Du Pont XX).

Production rate range (g mo^{-1})	Bin number	Average of range (g mo^{-1})
0—50	1	25
50—100	2	75
100—200	3	150
200—300	4	250
300—400	5	350
400—500	6	450
500—700	7	600
700—900	8	800
900—1100	9	1000
1100–1400	10	1250
1400–1700	11	1550
1700–2000	12	1850
2000–2300	13	2150
2300–2600	14	2450
2600–2900	15	2750

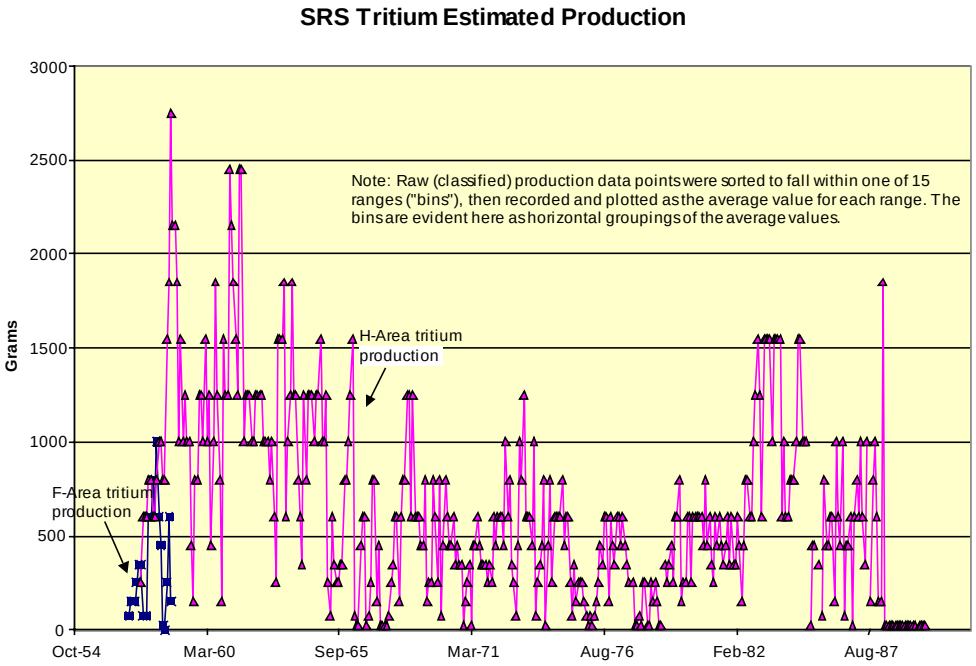

Figure 2-14. SRS estimated tritium production (Du Pont XX).

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