CHAPTER 6

OTHER SOURCES OF CONTAMINATION IN THE ENVIRONMENT

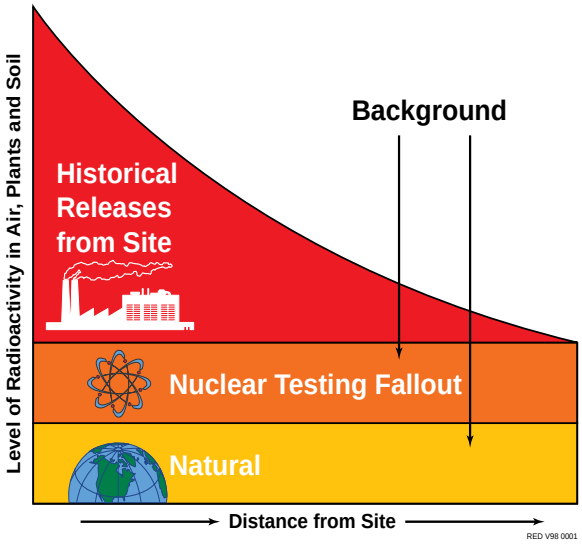
ABSTRACT

This chapter provides information about sources of radioactive contamination other than the Savannah River Site (SRS). This topic is important to dose reconstruction because other sources contribute to the total amounts of contamination measured by environmental monitoring programs. Definitive identification of the source of contamination is sometimes difficult. The most important non-SRS source of radionuclide contamination has been the aboveground testing of nuclear weapons in the 1950s and 1960s. Data from the Health and Safety Laboratory of the Atomic Energy Agency, the U.S. Geological Survey, and a Canadian fallout-monitoring program are provided to illustrate trends over time and space. In March 1955, a high deposition of radioactivity occurred in the vicinity of the SRS that appears to have resulted from rainout of debris from a nuclear test several days earlier in Nevada.

INTRODUCTION

The term contamination usually refers to unwanted radioactive or other material in the environment or other place where it may make surfaces or equipment unsuitable for some specific use. In this chapter we use the term contamination in a more general sense to denote the presence of certain radionuclides and chemicals in the environment. Some radioactive materials occur naturally in the environment, and others are produced by human activities. In Phase I of this study, other local man-made sources of contamination in the area of the SRS were identified (Stetar et al. 1995). However, the most significant contributor to radioactive contamination of the United States in the 20th century has been the detonation of nuclear weapons, which produced airborne radioactive debris called weapons fallout.

The term background often refers to amounts of materials that occur naturally in the environment, without input from human activities. Some radionuclides (such as tritium) have multiple sources: they occur naturally, are a component of weapons fall-out, and are also released from facilities such as the SRS. For the purposes of this chapter, "background" radionuclide concentrations in the environment around the SRS are defined as those levels occurring from *sources other than the SRS* (see schematic, right). Some background concentrations have changed over time and space, mainly because of trends in the deposition and decay of weapons fallout.



The first section of this chapter provides a general overview of weapons fallout, including the time trend of fallout deposition. The next section reviews a contamination incident that occurred in the SRS area in 1955, which has been determined to be most probably a hot-spot fallout deposition event. Natural, accidental, and other facility sources for radionuclides of interest are discussed next. Background levels of nonradiological chemicals of interest and associated monitoring data are presented in other chapters.

WEAPONS FALLOUT

Fallout is the radioactive debris that is subsequently deposited on the earth from a nuclear weapon that is detonated above ground. Weapons fallout has been distributed worldwide, sometimes into the upper layers of the atmosphere, gradually depositing to the earth and/or decaying to stable elements that are no longer radioactive. Some of the most important components of fallout have relatively long half-lives of 30 years or more.

Fallout was detected by historical environmental monitoring at the SRS. Environmental measurements conducted by SRS personnel are discussed in other chapters of this report, and the reader is referred to those sections to examine trends in the data. Separating radioactivity contributed by releases from the SRS from weapons fallout is difficult for some radionuclides.

It is not within the scope of this project to reconstruct the regional doses from weapons fallout in the region of the SRS. However, an understanding of the general trends in weapons fallout over time and space is necessary to interpret historical monitoring data.

Spatial and Temporal Trends

The first nuclear explosion occurred in 1945 in New Mexico. Fallout became recognized as a possible public health problem in the mid-1950s. In 1958, the U.S., United Kingdom (U.K.), and the Soviet Union, who were all conducting aboveground testing, declared a moratorium. However, in 1961, without advance warning, the Soviet Union unilaterally broke the moratorium agreement and exploded about 50 devices. The U.S. responded and major escalation of testing occurred. In early 1963, the U.S., U.K., and the Soviet Union signed a test ban agreement. France and China continued to conduct aboveground tests (particularly in 1968–1970) but not on as large a scale as the other countries had before 1963. In general, the highest levels of weapons testing fallout in air and deposition samples in the U.S. occurred during the years 1962 through 1964.

Spatial trend refers to how a material is distributed in the environment, for example, with distance away from the facility. Temporal trend refers to how the concentration of a material changes over time.

Nuclear fallout was injected both into the troposphere (lower atmosphere) and stratosphere (upper atmosphere). These two layers of the atmosphere circulate somewhat independently, with material injected into the stratosphere being distributed globally. The size of the explosion and the height of the detonation are the primary factors in whether fallout occurred close or far away from the bomb test location. The larger megaton bombs injected a large fraction of their fallout into the stratosphere. Some fallout debris stayed in the stratosphere for many months, coming down into the lower atmosphere during seasonal mixing of the atmospheric layers. Essentially all the debris

from smaller (kiloton) bombs was deposited within a few months following injection into the atmosphere because most fallout from these bombs was confined to the troposphere.

A long-term view of fallout deposition is provided by measurements made by the Health and Safety Laboratory (HASL) of New York City. This laboratory is now called the Environmental Measurements Laboratory. Operated by the U.S. Department of Energy (DOE) and its predecessors (the Energy Research and Development Administration and the Atomic Energy Commission), HASL was not independent of the DOE complex, but it was not involved in operating the SRS. HASL was known for its high-quality research and was instrumental in developing many techniques for radiochemical analyses. As opposed to a DOE production site's compliance-based monitoring program, the objective of the HASL environmental measurements program was to study the spatial and temporal distribution of natural and man-made radionuclides in surface air, deposition, and soil. Therefore, their historical results are very relevant to a dose reconstruction study.

In 1977, HASL provided a final tabulation of monthly monitoring of the fission product strontium-90 (^{90}Sr) deposition from a global network of stations started in 1954. During the early periods of nuclear weapons testing, ^{90}Sr was singled out as the most critical long-lived fission product produced by weapons testing, from the standpoint of dose to man. A gummed-film collector was operated by HASL from 1952 through 1959, and total beta radioactivity was measured. Because a more direct isotopic measurement was considered necessary, deposition collectors were added, first at HASL in New York City in 1954 and later at other locations. The collector was a high-walled stainless steel pot with an exposed area of 0.076 m^2. Collected precipitation and fallout material was transferred from the pot to laboratory glassware for evaporation and analysis for ^{90}Sr. A more practical method for other locations was developed that involved a funnel and ion-exchange column system with an exposed area of 0.072 m^2. With this collector, HASL was able to enlist the help of civilian and military weather installations and other government facilities throughout the world. This column system was used in Columbia, South Carolina, between April 1957 and June 1976. In all, 177 stations were established under the monthly radiostrontium fallout program. By 1976, 105 sites were operating; infrequent atmospheric testing and a subsequent decline in the stratospheric reservoir resulted in barely detectable levels of ^{90}Sr. In anticipation of a reduction in the number of stations and a longer collection time, the entire history of monthly strontium deposition data was presented in a summary report (HASL 1977).

Figure 6-1 shows the fallout depositions of ^{90}Sr in Columbia, South Carolina and New York City for 1954 through 1976. Table 6-1 provides the annual totals; individual monthly data are also available in HASL (1977). The monitoring record at New York City is quite complete; the only month of missing data was January 1954. At Columbia, missing data were more frequent (Table 6-1). Total deposition in Columbia for the years 1959, 1963, 1970–71, and 1973–1976 was estimated by assuming that deposition in months of missing data was the same as the average of the months that were monitored in the same year (Table 6-1). These data can be accessed directly in the Excel® workbook in the spreadsheet tab called "annual" by clicking on the following hyperlink: sr90dep.xls.

The years 1962 through 1964 were the highest for fallout deposition in the U.S. The total deposition at New York City was about 50% higher than that measured in Columbia. The fallout deposition relative to the highest year (1963) is given in Table 6-1 for the Columbia location. This relative trend is useful for interpreting time trends in environmental measurements collected by the SRS program.

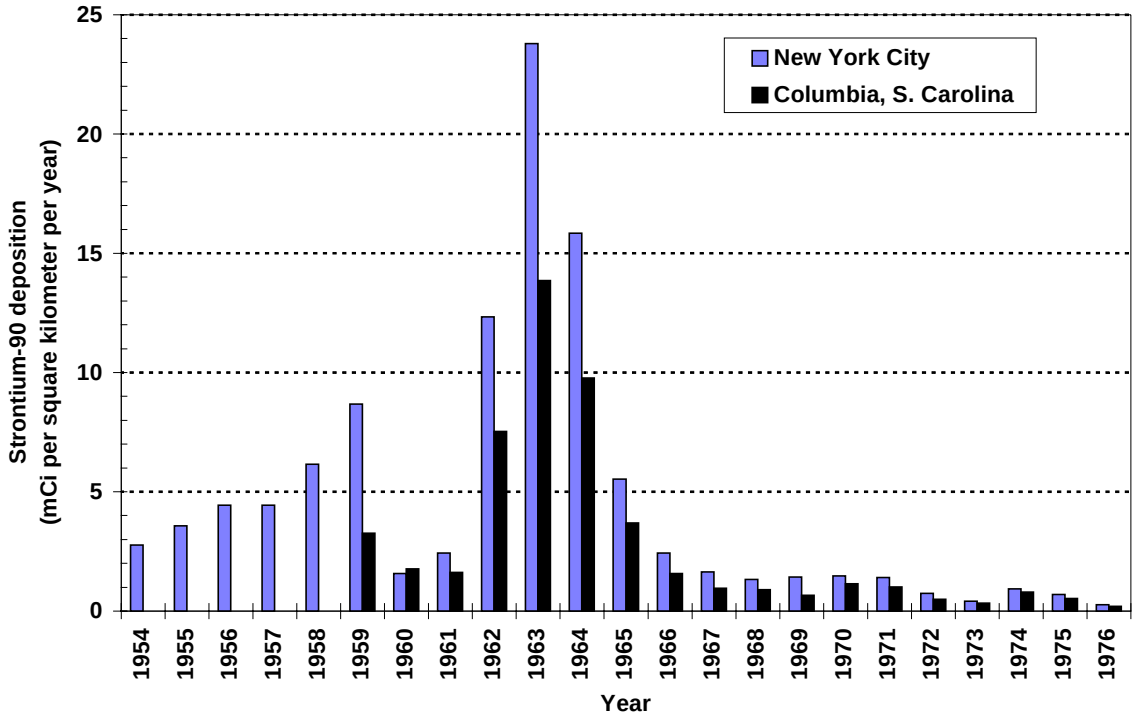


Figure 6-1. Deposition of the fallout radionuclide ^{90}Sr in New York City and Columbia, South Carolina (HASL 1977). Data in spreadsheet sr90dep.xls.

In the air monitoring chapter of this report (Chapter 8), the gross beta activity concentrations in particulate air samples within a 100-mi radius of the SRS are presented for a time interval that includes the peak fallout years (Figure 8-3). The highest monthly average concentrations of gross beta activity in air are observed in the spring of 1963, decrease about seven-fold in the fall of 1963, and increase again slightly in the spring of 1964. SRS monitoring data are compared with those from the Public Health Service monitoring of air in Columbia, South Carolina. The vast majority of beta activity in offsite air during these years is attributed to fallout from weapons testing.

Table 6-1. Deposition of ^{90}Sr in Columbia, South Carolina and New York City (HASL 1977)

Year	Reported deposition (mCi km^{-2})		Number of months of missing data for Columbia	Estimated deposition for Columbia (mCi km^{-2})	Ratio of annual deposition in Columbia to peak in 1963
	New York City	Columbia			
1954	2.76				0.12[a]
1955	3.57				0.15[a]
1956	4.43				0.19[a]
1957	4.44				0.19[a]
1958	6.16				0.26[a]
1959	8.68	2.17	4	3.26	0.23
1960	1.58	1.77	0	1.77	0.13
1961	2.43	1.62	0	1.62	0.12
1962	12.33	7.53	0	7.53	0.54
1963	23.79	12.71	1	13.87	1.00
1964	15.85	9.76	0	9.76	0.70
1965	5.53	3.7	0	3.70	0.27
1966	2.43	1.57	0	1.57	0.11
1967	1.64	0.96	0	0.96	0.07
1968	1.32	0.90	0	0.90	0.06
1969	1.43	0.67	0	0.67	0.05
1970	1.48	1.05	1	1.15	0.08
1971	1.41	0.93	1	1.01	0.07
1972	0.75	0.50	0	0.50	0.04
1973	0.42	0.30	1	0.33	0.02
1974	0.93	0.60	3	0.80	0.06
1975	0.69	0.49	1	0.53	0.04
1976	0.26	0.08	7	0.19	0.01

[a] Inferred from New York City measurements.

Tritium, a key radionuclide released from the SRS, has been increased well above its naturally occurring environmental concentrations because of nuclear weapons testing. A long-term perspective on this impact is provided by data collected by the Canadian Fallout Monitoring Program and published in Létourneau et al. (1994). These data can be accessed directly in the Excel® workbook in the spreadsheet tab called "data" by clicking on the following hyperlink: canada.xls.

Figure 6-2 illustrates the temporal trends in tritium concentrations in precipitation and in river water for 1955 through 1993 and shows the effect of weapons testing on environmental levels. As with the ^{90}Sr deposition data from Columbia, South Carolina, the peak year for tritium in precipitation was 1963, followed by 1964 (0.53 of 1963) and 1962 (0.33 of 1963). The tritium in river water shows a lag from the precipitation peak, with the highest levels measured in 1964–1965 in this Canadian valley at about 160 Bq L^{-1} (4300 pCi L^{-1}). Average concentrations in surface streams in the United States also reached about 4000 pCi L^{-1} in 1963 (NCRP 1979).

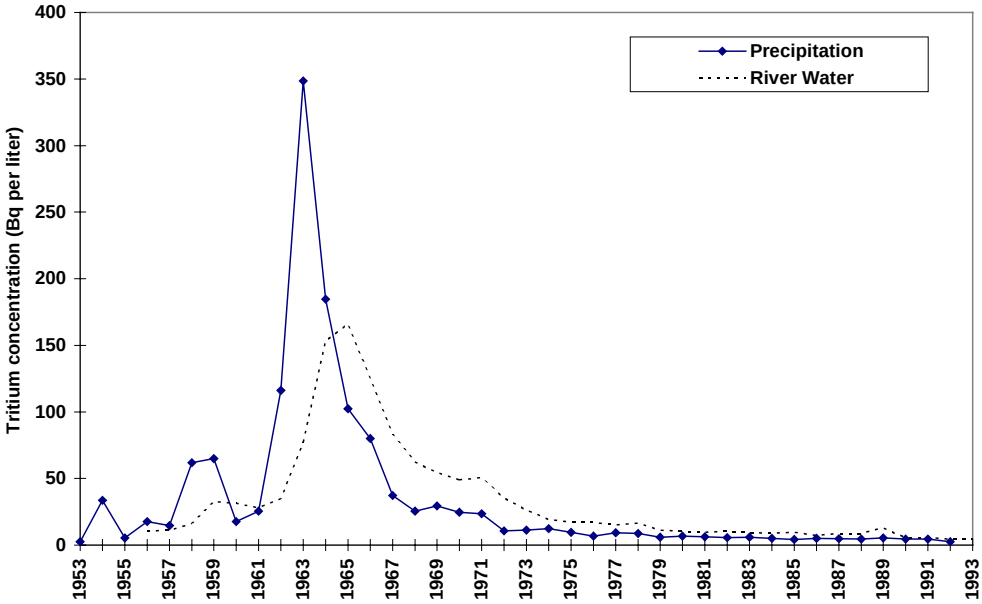


Figure 6-2. Annual average concentration of tritium in precipitation and river water from the Ottawa Valley, Canada (data from Létourneau et al. 1994, in spreadsheet canada.xls). The figure illustrates the effect of the injection of tritium into the atmosphere by the detonation of nuclear devices that increased concentrations in surface water by over 100 times the natural amounts in the early 1960s. Concentrations have gradually declined because of radioactive decay and mixing of atmospheric tritium into the oceans. Note the similar time trend as ^{90}Sr deposition in the U.S. shown in Figure 6-1.

Closer to the SRS, the U.S. Geological Survey monitored tritium in surface water of South Carolina streams, and others, since the early 1960s. The results and analytical procedures for this sampling program are tabulated in Wyerman et al. (1970). These data can be accessed directly in the Excel® workbook in the spreadsheet tab called "data" by clicking on the following hyperlink: streams.xls.

The data show the variations in stream tritium concentrations, caused principally by weapons fallout, as well as by seasonal, latitudinal, and continental effects. The four closest monitoring locations to the SRS are the Kissimmee River near Okeechobee, Florida; the Apalachicola River at Chattahoochee, Florida; the Savannah River near Clyo, Georgia; and the Neuse River near Vanceboro, North Carolina. The tritium content of surface waters varies greatly depending on the deposition of tritium as well as a variety of local hydrological factors. However, the impacts of weapons fallout as well as the SRS is clear (Figure 6-3).

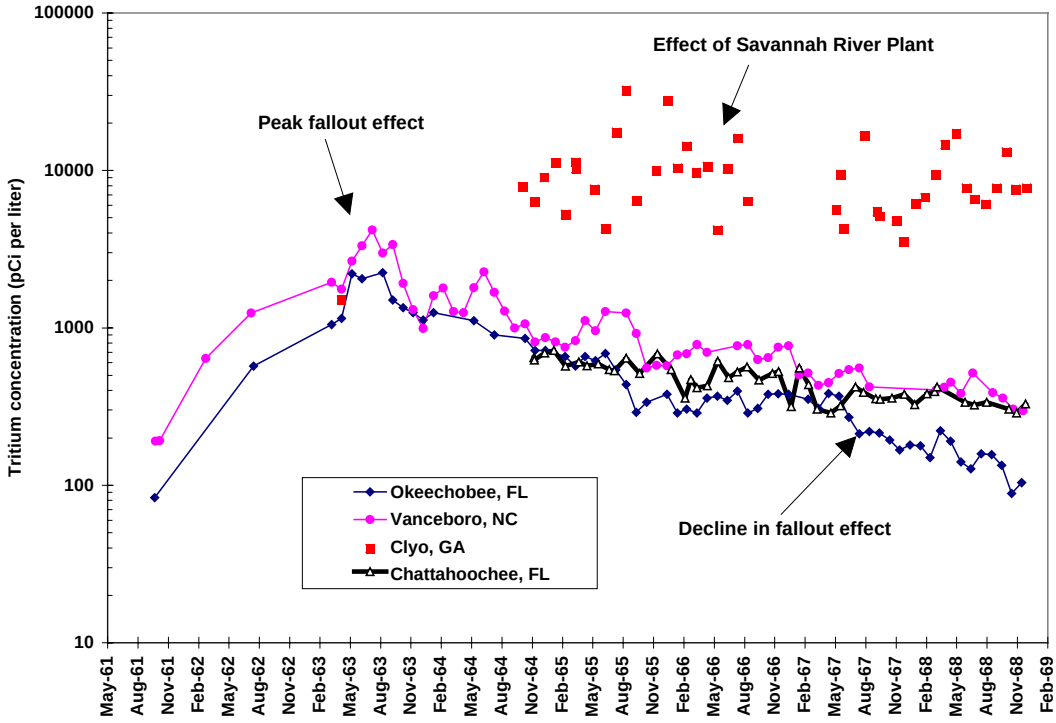


Figure 6-3. Tritium in four surface water streams in the southeastern U.S. Data collected by the U.S. Geological Survey (Wyerman et al. 1970), tabulated in spreadsheet streams.xls. The Clyo, Georgia, sampling location is downstream of the SRS.

The peak fallout years have been highlighted in the previous discussion. However, weapons fallout was detected into the following two decades, sometimes with better characterization of the material because of improved monitoring techniques. For example, the 1977 annual environmental report of the SRS (Du Pont 1978) notes an "extensive" special monitoring program undertaken in September following a Chinese atmospheric test. Fresh fallout was detected by a variety of devices 9 days after detonation. The 1978 annual report also noted that monitoring was conducted for additional Chinese tests.

In addition, the big-picture trends do not reflect the extensive spatial and temporal variability in fallout deposition, especially from the early lower-yield weapons tests that did not mix into atmosphere as extensively as later higher-yield tests. A contamination incident that illustrates the spotty distribution of weapons fallout, particularly in the 1950s and earlier, is reviewed in the next section. This incident has received much public scrutiny and interest. It also serves to underscore the importance of identifying other sources of radioactive contamination of the environment in any dose reconstruction study.

Contamination Incident at the Savannah River Plant, March 1955

Following a light rain between 2:00 and 3:00 p.m. on March 14, 1955, widespread ground contamination was detected at the Savannah River Plant (SRP, former name of Savannah River Site). The ground contamination was high enough that employees walking outside after the rain set off shoe monitors when they entered plant buildings (Sanders 1985). The Health Physics

Regional Survey Group completed an extensive survey the following day using portable radiation monitors.1 An oval area of radioactive surface contamination approximately 50 mi (80 km) long running generally from west to east, was deposited in the area of the SRP (Figure 6-4). Surface winds at the time of the deposition by light rain were from the north and northeast as reported by the weather station in Augusta (Marter 1985a).

The SRS environmental monitoring program detected high radioactivity in all media in the spring of 1955. The data were reported and analyzed in the semiannual report (Alexander and Horton 1956) and were discussed in the weekly environmental reports (Du Pont 1955b) as well as various internal memoranda (e.g., Mirshak 1983). Some of these SRS documents are discussed in more detail in a later subsection of this chapter. Additional original documentation for operational activities at this time was retrieved from archives of a senate investigation (Du Pont 1955a) and is reviewed later in this chapter.

Outside Scrutiny of 1955 Incident in the 1980s

In the 1980s, the 1955 contamination incident received additional scrutiny in a more public arena. This may have resulted partly because of the increasing declassification of historical documents. A brief chronology was outlined in an SRS internal memo titled "Mythical Reactor Accident at SRS on March 14, 1955" (Du Pont 1987):

- March 14, 1955 — Weapons test fallout arrives at SRS
- March 16, 1955 — Local media announcement of fallout
- 1956 — Arrival of fallout described in environmental monitoring semi-annual report for January–June 1955
- 1973 — Environmental monitoring reports declassified
- December 1984 — SRS learns about Alvarez and Franke paper
- January 1985 — Alvarez and Franke paper and Marter rebuttal presented at Health Physics Society meeting
- 1985 — Alvarez and Franke paper published in Ambio
- April 1986 — Chernobyl accident
- May 1986 — Formal rebuttal of Franke and Alvarez published in *Health Physics*
- May 1986 — Alvarez and EPA call for Federal investigation of "accident"
- May 1986 — Senator Thurmond requests an investigation by Armed Services Committee
- July 1986 — Senate probe finds no SRS accident.

[1] The type of radiation survey meter used for this special survey was a Thyac (Sanders 1985). These meters are sensitive to both penetrating beta and gamma radiation. Notes on radiation survey log sheets (Du Pont 1955) indicate that this instrument had a probe with a window that could be either open or closed, to shield out beta radiation. Routine ionization chambers used to detect penetrating radiation at various locations onsite and offsite were off-scale (14 mrep per week) when collected 1 week after the fallout. A survey made around 735-A with a gamma scintillometer 1 hour after the fallout showed a dose rate of 0.3 mrep per hour (Alexander and Horton 1956).

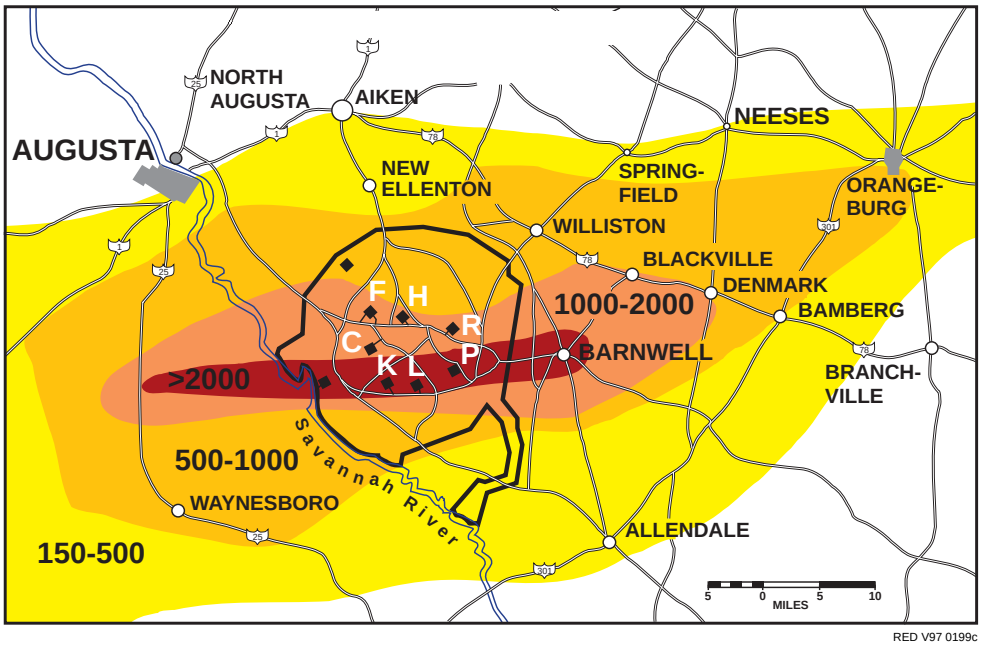


Figure 6-4. Radiation levels (counts per minute, cpm) measured with portable Thyac survey instruments on March 15, 1955 (redrawn from map in Alexander and Horton 1956). The darkest zone in the figure represents a region where measurements were more than 2000 counts per minute. Other zones are 1000–2000 cpm, 500–1000 cpm, and 150–500 cpm. Original documentation for this field survey was not located during our document search.

Alvarez and Franke Allegation and SRS Rebuttal. In a paper presented at a poster session on January 8, 1985, at the Health Physics Society midyear meeting and published in the proceedings, Drs. Bernd Franke and Robert Alvarez (1985a) claimed that the radioactive contamination in March 1955 around the SRS had resulted from an SRS reactor accident. In addition, the authors claimed that elevated offsite radiation levels for the 1954-1969 period were caused by atmospheric releases of radioactive materials from SRP (Franke and Alvarez 1985a). The first point will be discussed in this section.

With regard to the March 1955 incident, Drs. Franke and Alvarez (1985a) summarize the extent of contamination measured by SRS personnel that was documented in the SRS semiannual environmental report (Alexander and Horton 1956). However, Franke and Alvarez maintain, "As the center of the contamination was located around the reactors K, L, and P they could be considered as a more likely source of the contamination rather than rainfall deposition of a Nevada weapons test." The decay characteristics of the contamination, although consistent with fresh fission products, could also be explained by a release of 69% of ^{133}I (half-life 20.8 hours) and 31% ^{131}I (half-life 8.04 days). They claim that these nuclides "would be standard for a reactor incident. In all likelihood a major reactor accident happened at SRP on March 14, 1955."

An SRS critique of the first Franke and Alvarez paper (Marter 1984) was distributed at the same Health Physics Society midyear meeting, and a discussion session was held with conference attendees. According to McEnroe (1985), overwhelming support was demonstrated by the professional health physics community for the SRP position on the Franke and Alvarez paper. Numerous technical inaccuracies were noted.

A slightly expanded version of the Franke/Alvarez paper was published in the journal *Ambio* (Franke and Alvarez 1985b). There were some additions to the section that addressed the March 1955 contamination incident. A cumulative dose of 12 mrem was estimated, based on an exposure rate of 0.3 mR h^{-1} measured 1 hour after the rainfall (Alexander and Horton 1956) and (presumably) the observed rate of decay. In this article, they stated that the observed decay could be attributed to "halogens (iodine and bromium isotopes) from SRP reactor fuel at about 100 hours after unloading from the reactor." The authors point out that detailed records held by the SRS that might indicate if an unusual incident had occurred during this period were not publicly available.

Some review of the Teapot Hornet atmospheric nuclear test conducted at the Nevada Test Site is included in the *Ambio* article (Franke and Alvarez 1985b), probably in response to the arguments made by the SRS. Citing List (1956), which is reviewed later in this chapter, Franke and Alvarez (1985b) notes that the southern-most trajectory of radioactive debris from Teapot Hornet actually passed over North Carolina. Highest contamination measured from a gummed-film monitoring network was in Louisville, Kentucky, whereas levels in Atlanta, Georgia, and Charleston, South Carolina, were over three times less. Applying a ratio of empirical measurements at different locations, the authors calculated that more than 1.5% of the total fission products from the Teapot Hornet test would have to have been deposited in the vicinity of the SRS, which would be unlikely. Only 0.4% of the total fission products from the Upshot-Knothole weapons tests in 1953 had been deposited over the entire U.S. by the second day after the shots.

The SRP has always maintained that the gross contamination in March 1955 was not from the SRS, providing a formal rebuttal in the journal *Health Physics* (Marter 1986).

The main points made by the SRS personnel were

- Radiation monitoring data from the reactors (moderator monitors, process monitors, and continuous exhaust-stack air monitors) indicated no unusual activity during the month of March 1955. Investigations at other SRS facilities showed no unusual release of radioactivity.
- Recordings made by continuously operating environmental air monitors showed deposition of the activity in widely separated areas of the SRP site within a 30-minute period (Sanders 1985). This is not consistent with a site release from a single location. Surface winds of 10 mph were insufficient to disperse the activity that widely if a plant reactor were the source of the activity. The winds did not change direction 180 degrees, which would have been necessary to distribute the activity from the SRS in the observed pattern.
- The probable source was fallout from an atmospheric nuclear weapons test called Teapot Hornet that occurred in Nevada at 0820 hours, eastern standard time (EST), on March 12 (Carter and Moghissi 1977).
- The radioactive decay of activity was very consistent with fresh weapons test fallout at 2 days post-detonation. A mixture of 31% ^{131}I and 69% ^{133}I isotopes theorized by Franke and Alvarez is not supported by physical or chemical processes, and other short-lived radionuclides of iodine would be present if the source were an SRP reactor. Accidental iodine release from an SRS reactor, or from the chemical processing plant (as occurred

in 1961), would be expected to occur over a number of days. Radionuclides like ^{99}Mo and ^{239}Np, which were identified in precipitation from the March 1955 hotspot, would not be released from an SRS reactor except in a major fuel meltdown. In that case, long-lived radionuclides would have also been released, and these were not detected in the March 1955 fallout.

- Greater than 80% of the beta radioactivity measured in vegetation and rainwater following the fallout deposition was from nonvolatile beta-emitting radionuclides and less than 20% was radioiodine.

In response to a media request, Marter prepared an additional explanation (Marter 1985a) including a reference that documented numerous other fallout hot spots at other times (Sanders 1985) and an early attempt to identify the contributing radionuclides in the March 1955 fallout (Kinard 1955). Sanders shows that fallout hot spots were not uncommon, tabulating 31 incidents between 1951 and 1958 that illustrate localized surface contamination caused by atmospheric precipitation of nuclear fallout from weapons testing. These localized contamination incidents became less frequent after 1957 with the testing of larger yield bombs that carried radioactivity to higher elevations where it remained longer and became more evenly distributed.

Apparently the Marter (1986) rebuttal had already been submitted to the journal *Health Physics* when the *Ambio* article appeared. Marter (1985b) addresses some additional points in the *Ambio* article that had not been made in the previous Health Physics symposium paper. Marter (1985b) states that the high deposition on gummed film in the other states (Illinois and others) was primarily dry deposition from surface winds, which followed a different trajectory than winds at 18,000 ft.2 The deposition around SRP was caused by a short rainfall originating at high altitudes. Marter (1985b) does not address the additional magnitude issues raised by Franke and Alvarez (1985b), that is, that the contamination levels and initial dose rates measured near the SRS were quite high.

Senate Armed Services Committee Investigation. In July 1986, the Senate Armed Services Committee released the report of a staff investigation, conducted at the request of Senator Strom Thurmond, relating to the allegations of an unreported nuclear accident at the SRP on March 14, 1955 (Bott 1986). The investigation included discussions with U.S. Department of Energy officials, past and present employees of E.I du Pont de Nemours, Inc., and Bernd Franke and Robert Alvarez, as well as a thorough review of classified and unclassified documents. These documents, many recovered from archive facilities and not previously examined in this context, included health protection records (such as daily radiation survey logs, air sample logs, shift logs, and special work permits) and weekly operating reports. The report stated that there was no reason to conclude that an unreported nuclear accident at the SRP was responsible for the

[2] Marter is not entirely correct here. The highest depositions were associated with a different trajectory (see fallout maps later in this chapter). However, the high depositions in the midwestern states *were* associated with rainfall. In addition, recent reevaluations have shown the historical gummed-film monitors did intercept and retain both wet and dry deposition, although the collection efficiency was less with heavier rainfall (Beck et al. 1990). The estimated collection efficiency for dry deposition is believed to have been 20%. For a combination of dry and wet deposition, the collection efficiency of gummed-film ranged from 7 to 30% for high (>25 mm) and low (<0.75 mm) precipitation amounts in a 24-hour period, respectively.

radiation levels detected on March 14, 1955. This conclusion resulted from the following major findings:

1. The trajectories of the fallout from the Teapot Hornet test at the Nevada Test Site on March 12, 1955 were examined; one trajectory could have placed fallout over the vicinity of the SRP on March 14. Although the trajectory data for fallout from the test indicated passage several hundred miles north of the SRP, the Committee felt this did not discount the probability that fallout from the test was deposited at the SRP. The trajectories were not based on high altitude sampling of air, and the width of dispersion was not indicated.3
2. The direction and velocity of surface winds on the date in question were inconsistent with SRP as the source.
3. Monitoring at the SRP operating facilities did not indicate any release. There was no indication in any classified or unclassified documents of any unusual activity at the SRP on or about the date in question. There was an aggressive effort on the part of health physics personnel to determine the source of the contamination, although there was a presumption that it was related to a recent weapons test.
4. Increased radioactivity was not recorded on continuous air monitors until the rain began. Radioactivity from a SRP source would have been detected in the air before being deposited on the ground by rainfall.
5. The radioactivity decay pattern was consistent with fallout of approximately 2 days after detonation.
6. Other hot spots of this type have been measured in other parts of the country during the period of aboveground nuclear testing (e.g., see Sanders 1985, and gummed-film data reviewed later in this chapter).

The Senate Armed Services Committee noted that considerable resources had been expended in answering questions and in retrieving the documents and that further expenditure of government resources on this issue was unwarranted. They noted that the circumstantial evidence pointed to the possibility of an SRS release and that direct documentary evidence to the contrary had not been made available to the public. Consequently, they recommended that the unclassified record reviewed during this investigation be available for public review.

Since the investigation, those records have been maintained on a set of 14 microfilm cartridges, labeled “US Senate Investigation,” in the public reading room at the University of South Carolina in Aiken. An index to the contents of the microfilm is available in paper form (Anonymous 1986). We reviewed the entire set of microfilms during two visits in November 1997 and February 1998, made in conjunction with other travel for this project. The films contain many hundreds of pages of SRS logbooks and onsite health physics monitoring records from the time period before, during, and after the March 1955 contamination incident. Most of the pages

[3] The meteorological trajectories are subject to error, particularly over regions of sparse data or in areas of variable or complex flow patterns. In general, over the U.S. for trajectories of the order of 1000 miles, the errors average 10–20% of the length of the trajectory (List 1956). The SRS is roughly 2000 mi from the Nevada Test Site. Thus, an error of 200 to 400 mi in the location of the trajectory might be expected at this distance from the detonation.

were routine operational monitoring records listed below for the following SRS areas: K-Area, L-Area, P-Area, R-Area, F-Area, H-Area, D-Area, and M-Area.

- Air sample log
- Monthly report
- Shift log
- Special work permit
- Special permit log time sheets
- Weekly report

These records were useful in documenting the arrival and extent of contamination that was deposited around and tracked into buildings on the SRS in March 1955. Each page of a logbook is numbered sequentially, so it can be confirmed that a record series is complete. For example, on microfilm roll number 1, the Radiation Survey Log Sheet pages numbered 3601 through 3800 contain surveys conducted between 3/12/55 and 3/23/55 in K-Area. Some of the key pages on these microfilms had been found previously during RAC's document search for this project. In addition, we made copies of 60 key pages from the microfilms that were particularly revealing as to the facts and the staff's interpretations of the March 1955 contamination event. These pages were assembled and given a SRS Phase II Database number (Du Pont 1955a). More detailed observations on the content of the microfilms are included in a later section of this chapter titled, "SRS Monitoring Relating to 1955 Incident."

Supporting Documentation for Evaluation of Source of Contamination

In our review of the 1955 contamination incident, the key references that documented the facts of the nuclear testing were obtained and reviewed. Operation Teapot, in the spring of 1955, was a series of 14 atomic detonations at the Nevada Test Site (List 1956). The fifth burst in the series, conducted on March 12, was named Hornet. Teapot Hornet was a 300-ft tower burst occurring at 13:20 Greenwich civil time (GCT), or 8:20 a.m. eastern standard time. The height of the top of the cloud was 37,000 ft above mean sea level. Only 4 of the 14 detonations in the Teapot series produced higher clouds of radioactive debris than the Hornet test on March 12, 1955. Trajectories for the atmospheric transport of the resulting debris were computed and compared to the fallout observed by gummed film at 87 locations in the continental U.S., 12 stations in Canada, and 6 stations elsewhere in North America (List 1956).

The immense heat from a nuclear detonation in the atmosphere produces a bubble of intensely hot gases. This buoyant bubble carries not only the debris resulting from the nuclear fission and the disintegration of the bomb casing and auxiliary equipment, but also great amounts of soil and dust, much of which becomes radioactive, that are drawn into the cloud. The term fallout refers to the deposition, on or near the surface of the earth, of radioactive particles resulting from the detonation of a nuclear device. It includes deposition from direct gravitational fallout of large particles, vertical currents and eddies in the atmosphere, and particles scavenged from the atmosphere and deposited by falling precipitation (which is referred to as rainout).

The movement of the atomic cloud is determined by the wind field, which can produce rapid dispersion or carry concentrated patches of debris for long distances in the upper atmosphere. The

deposition of particles from the atomic cloud is dependent on their size and density; these factors were not well known when the initial trajectories of atomic bomb debris were produced.

Meteorological Trajectories. The trajectories of the atomic cloud from weapons tests were computed from meteorological data from more than 150 stations in the U.S. and Canada. These stations reported the direction and speed of the winds every 6 hours. About one-half of these stations were equipped with electronic devices enabling soundings to be made at 6- or 12-hour intervals to very high altitudes even in the presence of clouds and also to measure the pressure, temperature, and relative humidity. The trajectories were prepared from maps from the National Weather Analysis Center (supplemented by additional site-specific wind reports).

For the March 12, 1955 burst, the trajectories indicate that the debris was carried eastward and fanned out to cover most of the central and eastern U.S. (Figure 6-5). A large precipitation area in the central states on March 14 resulted in deposition of debris from the Gulf states northward to the Great Lakes, and radioactivity continued to be associated with the precipitation area as it moved eastward on the following day.

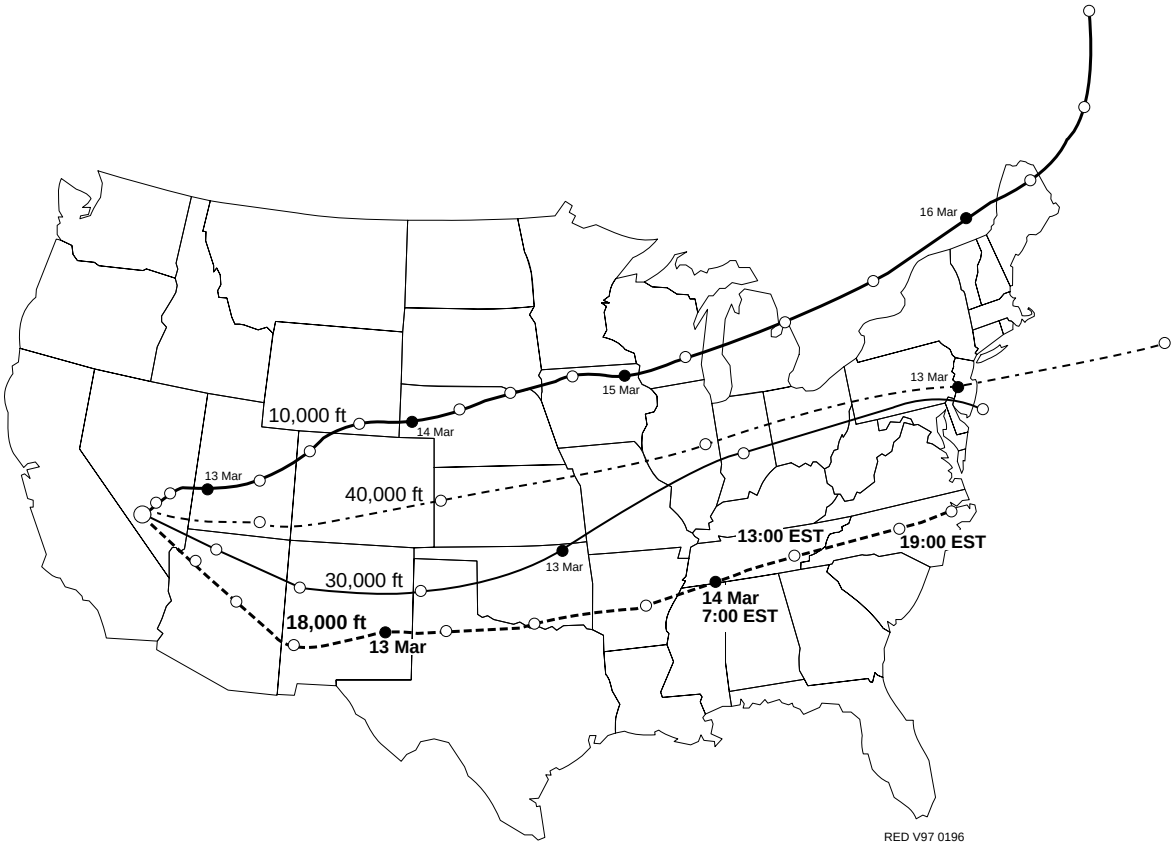


Figure 6-5. Trajectories of radioactive debris produced by the March 12, 1955, nuclear test Teapot Hornet (redrawn from figure in List 1956). The four trajectories represent the directions that atmospheric debris from the test traveled at different heights in the atmosphere. The center of the 18,000-ft trajectory passed over North Carolina between 1:00 and 7:00 p.m. EST on March 14 (shown as 13:00 and 19:00, in military time, on the figure). An error of several hundred miles is associated with the trajectory position at this distance from the blast. Rain occurred at the SRS between 2:00 and 3:00 p.m. EST.

Gummed Film Network. A simple and inexpensive monitoring technique was used in the 1950s to measure fallout of radioactivity to ground surfaces. A 1-ft square of gummed cellulose-acetate film was placed on a horizontal stand. Duplicate films were exposed at most stations on stands about 6 ft apart. The film was exposed for a 24-hour period and then mailed with a field data collection card to the Atomic Energy Commission's Health and Safety Laboratory (HASL) in New York City. At the HASL, the film was ashed and counted for beta activity. For the Teapot series, the average time between collection and analysis was about 3 weeks (List 1956). Even in the 1950s, the limitations and uncertainties of the gummed-film monitoring techniques were recognized. For example, List (1956) mentions

- Unknown efficiency of film during rain and snow
- Uncertainty in how film represents deposition on natural surfaces
- Possibility of concentration and re-deposition in dusty regions.

For the Teapot series, 18 of the northern stations were equipped with heated stands to melt the snow that might fall on the film. The closest stations to the SRS were located at Atlanta, Georgia, and Charleston, South Carolina.

Monitoring of weapons test fallout with gummed film led to the conclusion that precipitation was a major factor in depositing debris that was more than a day or two old. About 10 times more activity was found on film exposed during precipitation as on dry days. In general, the heavier the rainfall, the more material collected (List 1956). Although wet deposition was a scavenging process for fallout particles, recent reevaluations have shown that the collection efficiency of gummed-film monitors was less with heavier rainfall (Beck et al. 1990). The estimated collection efficiency for dry deposition is believed to have been 20%. For a combination of dry and wet deposition, the collection efficiency of gummed film ranged from 7 to 30% for high (>25 mm) and low (<0.75 mm) precipitation amounts in a 24-hour period, respectively.

Fallout Maps. List (1956) presents maps showing daily gummed-film fallout data at each location for 24-hour periods beginning at 12:30 GCT (7:30 EST); the map for March 14, 1955 is reproduced here as Figure 6-6. The units are millicuries (mCi) deposited per 100 mi^2. Areas with more than a trace of precipitation are shaded on the map. All radioactivity measurements were corrected to the expected radioactivity remaining on January 1, 1956, according to Equation (6-1):

$$A_t = A_0\, t^{-1.2} \qquad (6\text{-}1)$$

where

A_t = the activity on January 1, 1956

A_0 = the activity extrapolated to 1 day after the most recent blast

t = the time in days between blast and January 1, 1956.

On March 14, 1955, the highest depositions of beta activity were recorded in the midwestern states of Illinois, Indiana, Michigan, and Wisconsin. These deposition data and the resulting map (Figure 6-6) do not include or consider the survey monitoring conducted by the SRS. The closest HASL gummed-film monitoring stations to the SRS were in Atlanta, Georgia, and Charleston, South Carolina.

Table 6-2 lists the daily fallout measured in Atlanta and Charleston in March of 1955. The data are from maps in List (1956). Values from only one station in Atlanta were presented; however two replicate results are given for Charleston during this period. There were seven separate bursts (No. 3 through 9 of the total series) in March of 1955, occurring on the 1st, 7th, 12th, 22nd, 23rd, and 29th (two bursts) of the month. All extrapolations of radioactivity remaining by January 1, 1956 were made by assuming that the fallout was from the most recent burst (List 1956).

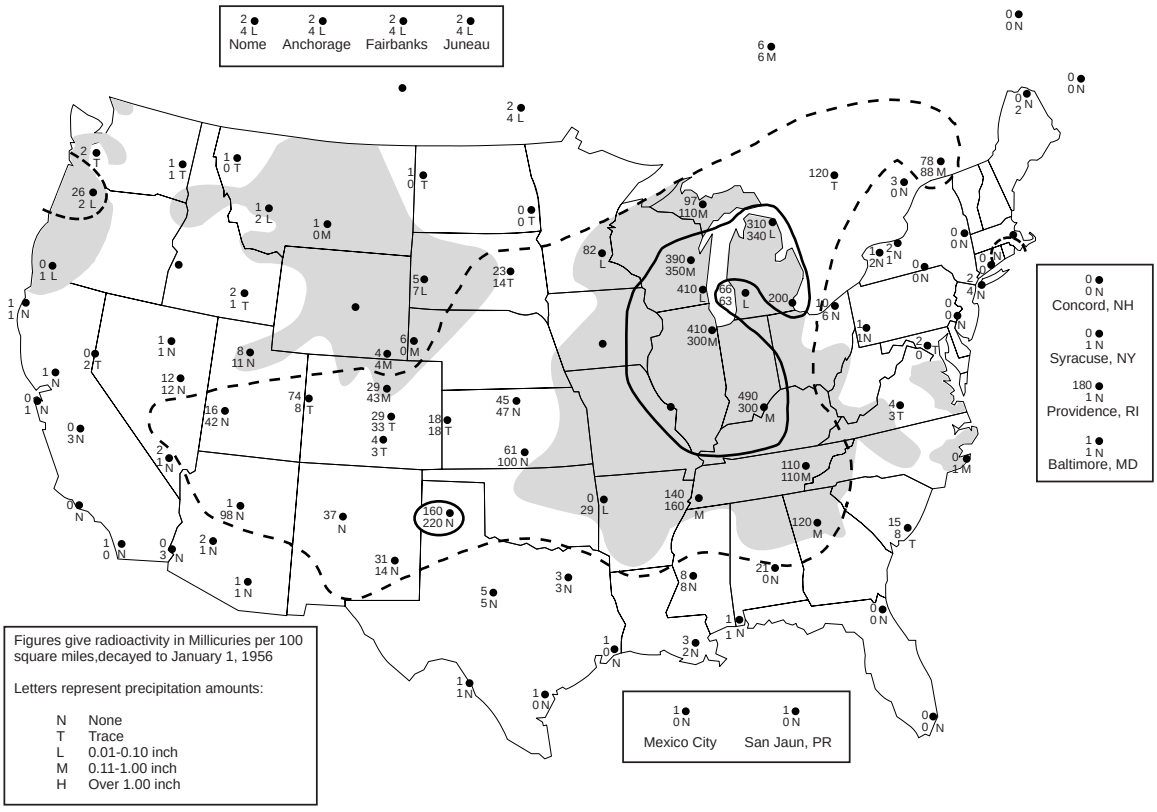


Figure 6-6. Radioactive fallout in the U.S. on March 14, 1955 (redrawn from figure in List 1956). The solid line outlines areas with more than 200 mCi/100 mi^2 on the most active film from each station in the area. The dashed line similarly outlines areas of more than 20 mCi/100 mi^2.

Table 6-2. Daily Radioactive Fallout (Beta Activity) in Atlanta, Georgia and Charleston, South Carolina in March 1955 (data from List 1956)

	Atlanta		Charleston		
Date in March[a]	Deposition (mCi/100 mi^2)[b]	Precipitation[c]	Replicate 1 (mCi/100 mi^2)[b]	Replicate 2 (mCi/100 mi^2)[b]	Precipitation
1	3	low	na[d]	na	na
2	3	none	2	1	none
3	1	trace	0	0	none
4	0	trace	0	0	none
5	na	na	0	0	none
6	na	na	4	3	trace
7	na	na	0	0	none
8	2	none	3	9	low
9	4	moderate	1	0	none
10	4	trace	0	1	none
11	na	na	2	1	none
12	1	moderate	0	0	none
13	12	low	0	0	none
14	120	moderate	15	8	trace
15	2	trace	na	na	na
16	0	moderate	na	na	na
17	1	none	0	0	none
18	na	na	3	4	low
19	2	moderate	5	3	high
20	na	na	88	0	none
21	9	low	6	5	trace
22	25	low	9	4	low
23	0	moderate	0	0	none
24	15	none	15	31	none
25	55	low	na	na	na
26	3	none	na	na	na
27	1	none	na	na	na
28	3	none	57	65	low
29	9	none	2	3	none
30	3	none	1	10	none
31	2	none	1	1	none

[a] Twenty-four hour period beginning 7:30 EST.
[b] Millicuries beta activity per 100 mi^2, corrected to activity on January 1, 1956.
[c] Low = 0.01 to 0.10 in.; moderate = 0.11 to 1.00 in.; high = over 1.00 in.
[d] na = not available.

Figure 6-7 plots the daily deposition data tabulated in Table 6-2. The highest deposition rate at these two stations occurred on March 14 in Atlanta. This was the same day of the observed

contamination at the SRS. The timing of the arrival of fallout in the area is also consistent with the predicted arrival based on trajectories from wind field data. Fallout at the 18,000-ft level was projected to occur at the longitude of the SRS between 1:00 p.m. and 7:00 p.m. EST on March 14. The light rain, which is believed to have carried the contamination to the ground, occurred between 2:00 and 3:00 p.m. on March 14 at the SRS.

High beta activity was seen in deposition at Atlanta, Georgia, on the same day in March 1955 that contamination was observed near the SRS.

The highest measured depositions of beta radioactivity from this test were recorded at locations in Kentucky, Illinois, Wisconsin, and Michigan. Two monitoring stations closer to the latitude of the SRS (at Amarillo, Texas, and Memphis, Tennessee) showed elevated depositions probably associated with the test. With the exception of the Texas station, all of the areas of highest deposition in the U.S. on March 14, 1955 were associated with low or moderate rainfall (Figure 6-6).

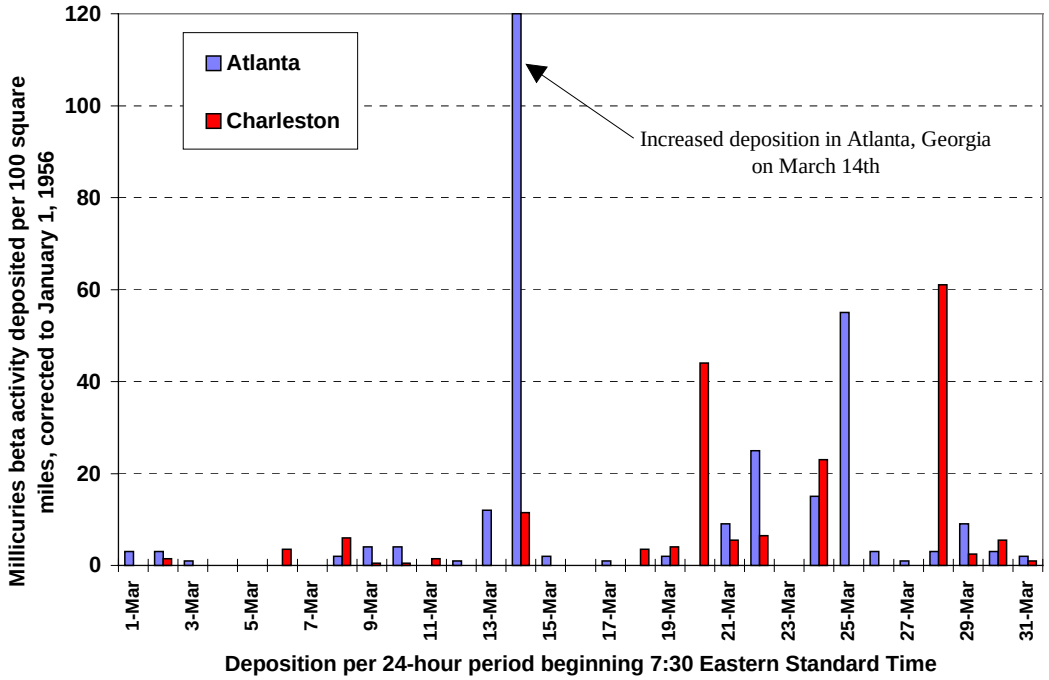


Figure 6-7. Daily deposition of beta activity in Charleston, South Carolina, and Atlanta, Georgia, in March 1955. Data taken from maps in List (1956) and presented in Table 6-2. The Charleston value plotted is the average of two replicates shown in Table 6-2.

Isotopic Composition of Fallout from Operation Teapot. The deposition measurements that were made on the gummed-film collections in the 1950s were all gross beta activity. The radiation survey conducted by SRS personnel measured total penetrating radiation, which would have included both gamma and beta-emitting radionuclides.

There are many different individual radionuclides that make up fresh weapons fallout; the composition varies with the type of nuclear test and with the time after detonation. Relatively recently, individual weapons tests have been analyzed, and an estimate of the various radionuclides produced has been published. The relevant report for the Teapot test series is Hicks (1981). For 30 times after the blast (10 times from 1 to 21 hours; 10 times from 1 to 300 days, and 10 times from 1 to 50 years), the following data are presented:

- The external gamma radiation exposure rate normalized to 1 mR per hour at 12 hours after the event, 1 m above the surface of the ground
- The deposition of each radionuclide in TCi m^{-2}
- The total deposition for all radionuclides in TCi m^{-2}.

Hicks (1981) presents the data for 128 radionuclides for the time interval of 1 to 300 days. By 1 year post-detonation, many of these radionuclides have decayed. At 1 year and beyond, the data are presented for 37 remaining radionuclides. Table 6-3 includes the data for the 33 radionuclides that contributed most to the external gamma exposure rate from widespread debris from the Teapot Hornet test. This list includes all radionuclides contributing at least 2% of the total exposure rate at 2 days or 5 days post-detonation. In addition, some longer-lived radionuclides were added to show those radionuclides making up 95% of the exposure rate after 1 year. The familiar long-lived radionuclides from weapons fallout, such as $^{137}Cs/^{137m}Ba$, $^{106}Ru/^{106}Rh$, and $^{144}Ce/^{144}Pr$, are relatively insignificant contributors to the total exposure rate at 2 days post-detonation. The data illustrate how the decay of short-lived radionuclides results in a rapid decrease in the total exposure rate from the debris in the first few days after the blast. The exposure rate versus time relationship for this blast is illustrated in Figure 6-8. The gamma exposure rate a week after the deposition around the SRS would have been less than one-half that observed on the third day after the blast when the survey was conducted.

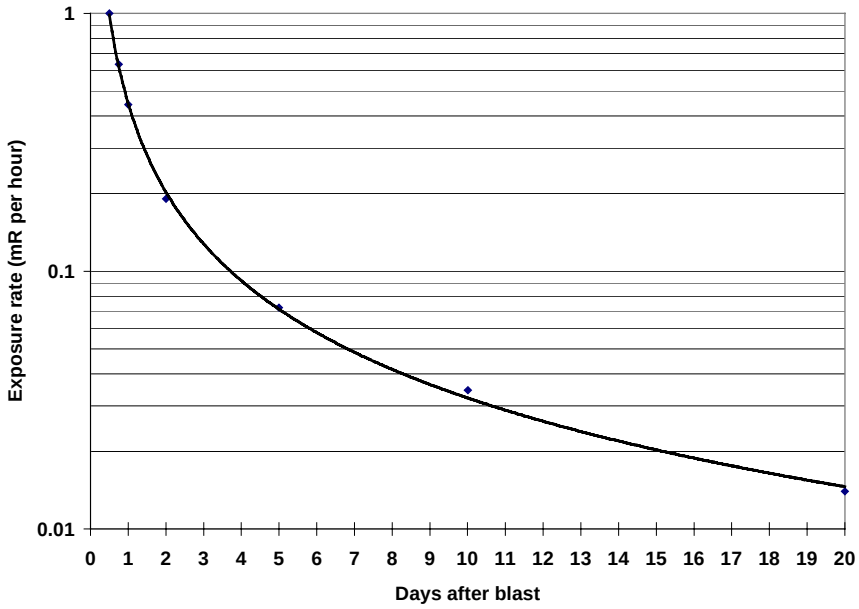


Figure 6-8. Exposure rate versus time after blast for the Teapot Hornet weapons test in Nevada (data from Hicks 1981). The curve shows the time trend for a hypothetical location at which the exposure rate was 1.0 mR/h at 12 hours after detonation.

Table 6-3. Isotopic Composition of Debris from the Teapot Hornet Test (Hicks 1981)

Nuclide	Time post-detonation					
	2 days		5 days		1 year	
	μCi m^{-2}	%	μCi m^{-2}	%	μCi m^{-2}	%
^{64}Cu	2.14	7.5	0.0435	0.4		
^{89}Sr	0.101	0.4	0.0971	1.0	0.000801	2.2
^{90}Sr	0.000692	0.0	0.000692	0.0	0.000674	1.9
^{90}Y	0.000281	0.0	0.000504	0.0	0.000674	1.9
^{91}Y	0.105	0.4	0.105	1.1	0.0015	4.1
^{95}Zr	0.0723	0.3	0.07	0.7	0.0015	4.1
^{95}Nb	0.0028	0.0	0.0067	0.1	0.00323	8.9
^{97}Zr	0.926	3.2	0.049	0.5		
^{97m}Nb	0.889	3.1	0.0473	0.5		
^{97}Nb	0.929	3.3	0.0493	0.5		
^{99}Mo	1.13	4.0	0.537	5.5		
^{99m}Tc	1.07	3.8	0.514	5.3		
^{103}Ru	0.193	0.7	0.183	1.9	0.000334	0.9
^{103m}Rh	0.193	0.7	0.183	1.9	0.000335	0.9
^{105}Rh	1.55	5.4	0.386	4.0		
^{106}Ru	0.0116	0.0	0.0115	0.1	0.00584	16.1
^{106}Rh	0.0116	0.0	0.0115	0.1	0.00584	16.1
^{131}I	0.701	2.5	0.563	5.8		
^{132}Te	1.62	5.7	0.854	8.7		
^{132}I	1.67	5.9	0.878	9.0		
^{133}I	2.64	9.3	0.245	2.5		
^{133}Xe	1.42	5.0	1.27	13.0		
^{135}Xe	1.91	6.7	0.0109	0.1		
^{137}Cs	0.000958	0.0	0.000958	0.0	0.000936	2.6
^{137m}Ba	0.000894	0.0	0.000894	0.0	0.000878	2.4
^{140}Ba	0.566	2.0	0.479	4.9		
^{140}La	0.333	1.2	0.461	4.7		
^{143}Ce	1.11	3.9	0.245	2.5		
^{143}Pr	0.183	0.6	0.236	2.4		
^{144}Ce	0.0126	0.0	0.0125	0.1	0.0052	14.4
^{144}Pr	0.0126	0.0	0.0125	0.1	0.0052	14.4
^{147}Pm	0.000219	0.0	0.0005	0.0	0.00145	4.0
^{239}Np	2.7	9.5	1.12	11.5		
Total of nuclides in this table	21.5	84.9	7.56	88.9	0.0343	95.0
Total of all nuclides in Hicks	28.5		9.77		0.0362	

Total Fallout from Teapot Series. Figure 6-9, from List (1956), shows the total fallout deposition from the Teapot series between February 18 through May 20, 1955, corrected to activity remaining on January 1, 1956. Most of the debris was carried by prevailing westerly winds. In general, fallout deposition decreased with distance from the Nevada Test Site. Total deposition in South Carolina, around 20 mCi/mi^2, was 5 to 10 times less than that deposited over large areas of Oklahoma, Colorado, and Utah. The Atomic Energy Agency estimated that less than 5% of the total beta activity released during the Teapot series was deposited in the U.S., exclusive of close-in fallout, from February 18 through May 20. This finding was consistent with that from two previous Nevada test series. Consequently, the residual activity remained in the atmosphere, either to decay over time or to be deposited to the ground with precipitation or with seasonal mixing of the layers of the atmosphere.

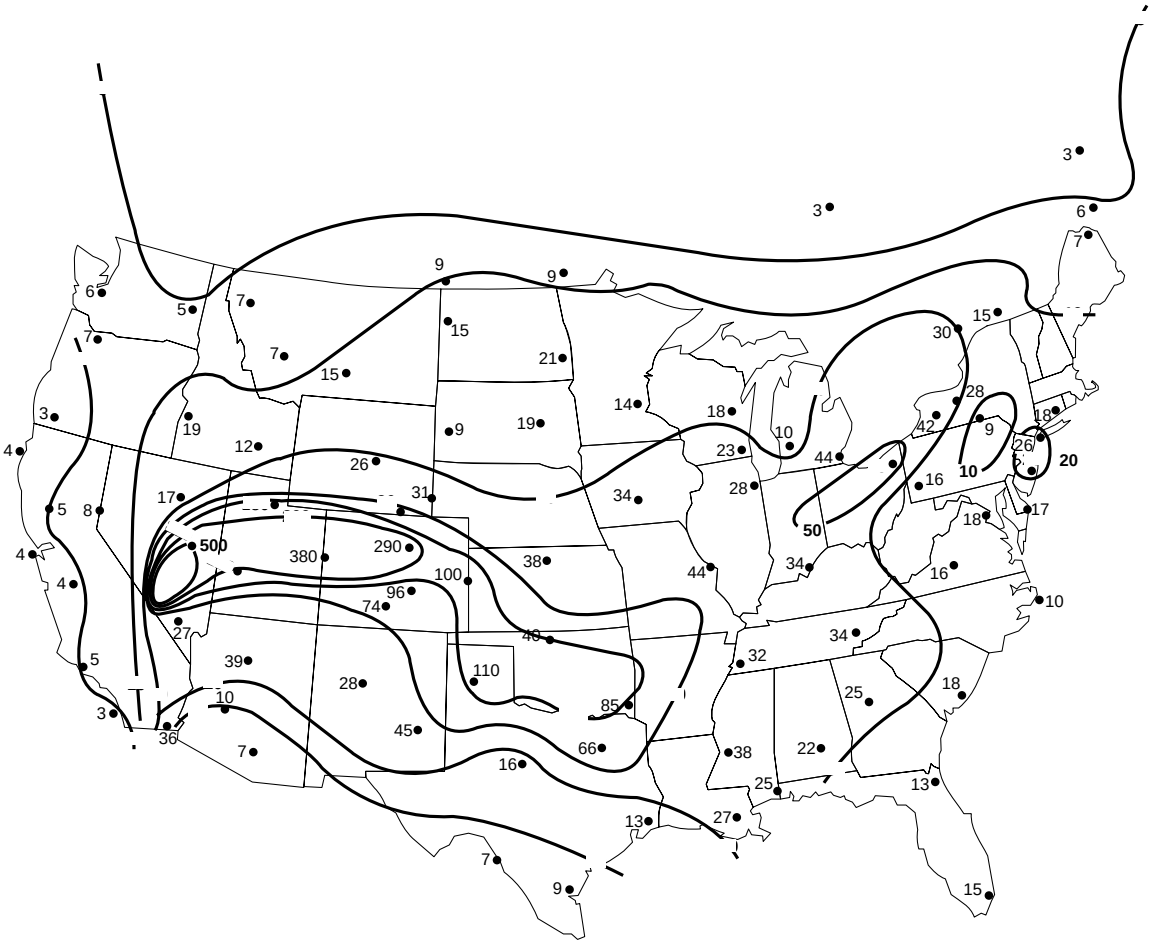


Figure 6-9. Total deposition of beta activity from the Teapot series, February 18–May 20, 1955. Each data point represents the measured total millicuries deposited per square mile, corrected to the amount of radioactivity that would have remained on January 1, 1956. The solid lines approximate equal deposition rates ranging from 5 to 500 mCi/mi^2. This figure was redrawn from one in List (1956).

The total deposition in March 1955 was roughly 0.3 mCi/mi^2 in Atlanta and 0.2 mCi/mi^2 in Charleston, or about 1/10 of the regional deposition from the entire test series (20 mCi/mi^2 or 2000 mCi/100 mi^2). Therefore, relatively significant depositions must have occurred at other times. Table 6-4 lists the deposition rates for these two locations for all days having a deposition of at least 10 at either location. Dates having a deposition of 100 or greater at either location are highlighted in bold. There are 9 such days over this 3-month period. Only one very high deposition day occurred in March; the remainder were in April and May.

The variation in daily deposition rates is apparent. In addition, regional hot spots of activity deposition from Teapot tests are evident from the maps in List (1956) for some days. For example, on May 7, 1955, the activity deposition at Jacksonville, Florida (south of the SRS) was around 200 mCi/100 mi^2 (with replicates of 170 and 250 mCi/100 mi^2). At St. Louis, Missouri, and Louisville, Kentucky (north of SRS), depositions were around 1350 mCi/100 mi^2 (with replicates of 1300 and 1400 mCi/100 mi^2). Yet, at Atlanta and Charleston on that day, depositions were 33 and 17 mCi/100 mi^2, respectively. It is not known whether significant ground contamination occurred at the SRS as a result of depositions of Teapot series fallout on days other than March 14, 1955. It does seem likely that this would have been the case.

SRS Monitoring Relating to 1955 Incident. The HASL fallout maps discussed in the previous section did not incorporate any data produced by the SRS environmental monitoring program. The isoactivity map reproduced earlier in this chapter (Figure 6-4) was published by the SRS in the semiannual environmental report (Alexander and Horton 1956) along with other site monitoring data. Alexander and Horton stated that the deposition of 1×10^{-7} Ci/ft^2 of beta activity in this area from bomb fallout between late February and the end of June obscured radioactivity releases from plant operations. All types of samples collected contained unusually high quantities of beta activity. Daily variations in the amount of fallout were determined by collecting particulate fallout on flypaper, collecting fallout in a water-filled tray, and from constant air monitors.

Alexander and Horton estimated that 68–77% of bomb fallout deposited on the plant site in the first half of 1955 was deposited on March 14. However, charts of the monitoring data illustrate many elevated concentrations at other times, including during April and May when contamination was also observed at the non-SRS gummed-film monitoring stations (Table 6-4).

More original documentation for these environmental monitoring results was not found during our document search. However, the weekly environmental monitoring reports for the first half of 1955 were located and reviewed (Du Pont 1955b). These reports have the title “Weekly Report – Control” followed by the date. They are typically three pages in length for each week and contain the number of samples collected by Regional Survey for routine monitoring and special problems; as well as notes on the week’s activities from the Health Physics Control Laboratory, the Development Group, and Bioassay. In general, what was accomplished is described, but few data are presented. The weekly report ending February 4 indicated that statistical analysis of the environmental data had begun for a bomb fallout report. The report ending February 18 stated that the regional survey group had made preparations for collecting data on fallout from the current Nevada tests. Similar general statements were made throughout the first quarter of 1955. For the week of March 14 through March 18, 1955, the regional survey group “surveyed surrounding territory to determine extent of fallout in rain on March 14.” Reference is also made to rain samples collected from five onsite locations that contained “unusually large quantities of short half-life radioactive fission products.”

Table 6-4. Daily Deposition Amounts for Days with at Least 10 Millicuries per 100 Square Miles at Atlanta, Georgia, or Charleston, South Carolina, for the Period February 18 through May 20, 1955[a]

Date	Deposition (mCi/100 mi^2)[b]	
	Atlanta	Charleston
March 14	**120**	12
March 20	na	44
March 22	25	6
March 24	15	23
March 28	3	61
April 1	**210**	0
April 2	65	18
April 3	24	4
April 4	17	2
April 5	62	**170**
April 6	21	58
April 7	4	44
April 9	10	1
April 10	36	10
April 11	26	15
April 13	17	5
April 14	1	26
April 19	8	28
April 20	2	10
April 21	9	11
April 22	18	0
April 24	12	6
May 1	10	6
May 7	33	17
May 8	**170**	**230**
May 9	22	72
May 10	88	16
May 11	9	**290**
May 12	**300**	43
May 13	**150**	**102**
May 14	na	17
May 15	na	16
May 16	80	6
May 18	**400**	0
May 20	**130**	98

[a] Source: List (1956).

[b] Dates having a deposition rate of 100 or greater at either location are presented in bold type.

In these weekly reports, the notes of the Bioassay group include actions taken for all significant internal exposures of personnel to radioactive materials. If an accident had occurred during the week of March 14, 1955, some description of personnel overexposures would be expected to show up in this section of the weekly report. Instead, the following observations are made for that week: "After the above average fallout was reported Tuesday morning, shoe covers were required for all people entering the laboratory. The Area Survey group made smears of the area. Activity was found on the floor of the offices and outside halls, but none in the laboratory. A fission product analysis was also made on a composite urine sample collected Tuesday. No activity could be found due to excretion or contamination of equipment." Shoe covers were discontinued the following Monday. During May 9–13, two surveys to determine ground contamination due to bomb fallout showed negligible contamination as determined with a Thyac instrument.

Kinard (1955) attempted to determine the radioisotopes present by gamma spectroscopic analysis of an evaporated rain sample supplied on March 17, 1955. Because the sample was evaporated, little volatile activity would be expected to be remaining in this sample. A spectrum was obtained daily on this sample between March 17 and 28. The resolution of gamma energies possible with the technology available (a 1-1/2 × 1-in. sodium iodide crystal and photomultiplier) was not good by later standards. However, the energies, half-lives, and possible radionuclides are listed. There were two broad half-life groups: one about 70 hours and the other about 110 hours. Most probable nuclides identified were ^{99}Mo; ^{95m}Nb (daughter ^{95}Zr); ^{97}Zr (daughters ^{97m}Nb, ^{97}Nb); ^{132}Te (daughter ^{132}I); and ^{133}Xe.

Lapsley (1955) notes three abnormal changes that were observed in the pattern of local airborne alpha activity. The changes, which could not be explained by natural radon and thoron decay products, occurred after three recent nuclear weapons tests in Nevada. The dates of the tests were March 12, March 29, and May 15, 1955. Abnormally high alpha activity was observed at the SRS on the fourth night, the third night, and the fourth night, respectively, after these tests. The abnormal alpha activity had a longer half-life, with one component having an 8.5-hour half-life contributing about 3×10^{-5} dpm/cm^3 initially. Another decay curve indicated a component with about 2.4-hour half-life. A tentative evaluation of ^{234}Pu was made for the 8.5-hour half-life material. It is a possible product of the tests, being formed by alpha reactions with ^{233}U, ^{235}U, and ^{239}Pu. The half-life of the short-lived daughter of radon and thoron in the air of Building 773-A had been determined to be about 40 minutes (filterable alpha activity). Activity concentrations of the natural activity ranged from 10^{-5} dpm/cm^3 to about 10^{-3} dpm/cm^3.

The detailed operational records from the SRS, which were obtained and reviewed during the Senate Armed Services Committee investigation, are available for review on microfilm at the Aiken public reading room (Anonymous 1986). We examined the entire set at that location and made copies of about 60 key pages (Du Pont 1955a). Some of these records on the microfilms had been obtained by *RAC* previously as part of the overall dose reconstruction document review and retrieval process, for example, a radiation survey logbook from P-Area (Anonymous 1955a). The microfilms contain many hundreds of pages of SRS logbooks and onsite health physics monitoring records from the time period before, during, and after the March 1955 contamination incident. Most of the pages were routine operational monitoring records, of the types in the list below, for the following SRS areas: K-Area, L-Area, P-Area, R-Area, F-Area, H-Area, D-Area, and M-Area.

- Air sample log
- Monthly report
- Shift log
- Special work permit
- Special permit log time sheets
- Weekly report.

For the most part, these records deal with measurements and observations that were taken inside buildings during operations for routine safety purposes. A Thyac or Cutie Pie survey instrument was most often used for the radiation surveys. Typical background count rates with the Thyac instrument (open probe) were 150–200 counts per minute (cpm). The probe was held 1 in. from the surface in question (for example, a floor or table). Both penetrating radiation exposure rates and removable contamination levels (such as counts per minute of beta-gamma contamination on paper towel smears) were recorded on the log sheets. Following are notes from P-Area radiation surveys relevant to the March 1955 environmental contamination incident. All times are Eastern Standard Time. Unless noted otherwise, the P-Area surveys are contained within the document referenced as Anonymous (1955a). These notes are presented to give the reader an idea of the eyewitness observations made by a number of workers during the time of the ground contamination incident.

The description of survey number P11223 of the lunchroom, at 5:50 p.m. on March 14, was to make "routine and special check of tables, seats and entrance as result of fallout contamination." Survey number P11230 of the general area inside building 105-P at 6:30 p.m. on March 14 states, "contamination spread thru-out bldg. from fall-out." Survey number P11224 on March 14 detected 2.9×10^{-4} µCi/cc in rainwater as compared with 9.5×10^{-7} µCi/cc in water from the 186-1 basin and 2.4×10^{-7} µCi/cc in tap water. Survey number P11222 at 3:40 p.m. on March 15, 1955, was a survey of loading a scrap cask. High contamination (5000 counts per minute), which was reduced to 800 cpm after one washing with water, was "probably due to fall out as the casks were setting on the truck outside the transfer area during the rain and were put into the transfer area about 1535." Survey number P11230 at 6:30 p.m. on March 15 in Building 105-P remarks that there were "no unusual rad. levels found or shielding leaks. Contamination spread thru-out bldg. from fall-out." Survey number P11247 was of the "fall out on concrete in front of 105-P E side." Spots reading 4000 to 5000 cpm on the Thyac were smeared. Nine smears ranged from 412 cpm to 954 cpm beta-gamma. The fallout seemed to be equally distributed over this area of ground. A routine paper smear survey of the floor of the lunch room (survey P11273 on March 16) found that the "floor was found contaminated due to fall out." Survey P11321 of the Inst. Shop (Purif. Area) on March 18 showed "contamination found on floor attributed to fall-out. Personnel carried some into area on soles of their shoes." The routine smear survey of the 105-P lunchroom on March 19 (P11347) showed that "the floor is still contaminated from the fall out." By March 21 (P11396) the survey of the lunchroom showed <100 cpm beta-gamma, and <2 cpm alpha (alpha counts were never positive).

Similar radiation survey log sheets for F-Area, R-Area, K-Area, and L-Area were obtained from the Senate investigation microfilms (Du Pont 1955a). In L-Area, two lunchroom surveys (L5636, L5643) in building 105-L on March 12 showed no contamination; however at 2:10 a.m. on March 15, the lunchroom survey (L5681) showed beta-gamma "contamination on floor of

lunch room due to 'fallout.' Sign put up telling people to keep feet on floor." Levels were considerably less than those seen in P-Area. On March 16, no action was taken on floor contamination in the 704-L building cafeteria "due to conditions in area from radioactive fallout" (survey L5713). In R-Area, a sidewalk outside the cafeteria read 4000 cpm at 6:00 p.m. on March 14 (survey R15427). There was no contamination in lunchroom of 105-R at 6:45 p.m. on March 14 (R15363), but at 2:00 a.m. on March 15 there was contamination there (survey R15371). A survey of the shoes of two personnel at 8:20 a.m. on March 15 (R15385) showed Thyac readings up to 2000 cpm above background (200 cpm). The technician states, "The men had not been in an RDZ so it was decided the contamination was brought in from outside of the building." Over one-half of 42 smears of the floors of all levels of building 105-R on March 15 were contaminated (survey R15406). In F-Area, at 3:45 p.m. on March 14, the technician notes on survey F5799, "Survey made to verify reports of high activity fall out. Paper towel smears show contamination ranging from 1500 c/m4 to as high as 15000 c/m. There is doubt at the present time as to the source of the contamination. At the time of this survey it was raining." At 9:30 p.m. on March 14, at the railroad area west of the 221 stack, a Thyac reading was 2250 cpm at ground level on the ties and 500 cpm at 3 ft above ground level.

Thyac count rates at ground level (usually 1 in. from surface) were over four times higher than those made at a height of 3 ft above ground.

Over 97% of the radioactivity measured by the Thyac radiation monitors on March 15 was from beta-emitting radiation; the remainder was gamma radiation.

In K-Area, contamination was found over all the floor of the 704-K cafeteria at 9:00 p.m. on March 14 (survey 3652). The area was "not cleaned up since entire area (outdoors) was above the limits. The contamination was due from the radioactive fallout." At 5:30 a.m. on March 15 in K-Area, a survey was made of roads and walkways that showed up to 3000 cpm above background (K3657). Radiation survey K3661 was the only one found for this contamination event that showed the Thyac readings expressed both as beta-gamma and as gamma alone. The latter measurement would have been made with the instrument probe window closed. Fifteen locations outside 105-K building at 10:00 a.m. on March 15 had beta-gamma readings of 1500 to 4100 cpm whereas gamma-alone readings were 50 to 140 cpm. The average ratio of gamma:beta-gamma was 0.028 (range 0.016–0.067). This is an important finding that indicates that the wide area survey shown in Figure 6-4 represents mostly beta activity. These data can be accessed directly in the Excel® workbook in the spreadsheet tab called "survey K3661" by clicking on the following hyperlink: 100kwr.xls.

Dozens of radiation survey log sheets, produced by many different technicians at separate locations, illustrate clearly that contamination was widespread around the SRS on March 14 and 15, 1955, and originated *outside* the SRS buildings. The hundreds of survey log sheets reviewed show no indication of a large-scale accident at this time.

Another source of original data during the time period of interest for the March 1955 contamination incident is air sample log sheets. The data sheets in Anonymous (1954) record radioactivity in air collected within Building 105-P between 9/2/54 and 8/27/55. An initial 10-minute count of beta gamma activity is recorded as well as a 10-minute count taken 4 hours later, which allows short-lived natural radon and thoron products time to decay. The calculation

[4] c/m is counts per minute, also abbreviated as cpm.

showing the conversion from counts per minute to activity concentration for fission products and for plutonium and uranium is preprinted on the data sheets. There were no samples taken between March 10, 1955, at 7:15 a.m. (log sheet P2920) and March 15, 1955, at 3:45 a.m. (survey P-2921).

Similar Air Sample Log Sheets for K-Area (Anonymous 1955b) end with sheet number K1250 dated 4/11/55. A sample taken outside the window of the health physics office on March 15, 1955, (log sheet K1193) had a higher 4-hour count (160 cpm net of background) than observed at locations inside the building during that same general time period (approximately 20–40 cpm). We reviewed air sample log sheets from all areas from the microfilm record (Anonymous 1986) and copied key pages from P-Area, R-Area, K-Area, and F-Area (Du Pont 1955a). The location of the samples varies, there is not always a delayed (4-hour) count, and there are few comments. It does not appear that any insight can be gained from the Air Sample Log Sheets for the March contamination incident.

Shift logs give a verbal confirmation to notes from formal data sheets. The M-Area shift log notes for March 14, 1955 (Du Pont 1955a) state, "Building in normal operation. Large number of shoe contaminations due to radioactive rainfall. Made surveys at barricades and gate house." The F-Area shift log notes for March 14 contain the following:

> "Background has been high with RR cut reporting around 1000 cts/min. Background at 700 Area and 100 Areas has been 1000–1300 cts/min. It is presumed this is 'fall out' from atomic tests. A line vicinity showed 800 cts/min background Thyac, but 13,500 cts/min from paper towel smear of rails west of stack in clean area. (Illegible) near exclusion area fence west of A line read 7000 cts/min paper towel smear."5 "High background thought to be coming from stack or Nevada tests." "Today until 8:50 tomorrow morning let men go home on contamination of shoes up to 1000 cts/min, unless you can determine contamination is caused by the srp process, rather than Nevada." "Stack samples pulled at 3:30 p.m. to determine if activity of project was due to us: apparently not; sample read only 10–12,000 c/m (Thyac). This fallout is known to be project-wide & presumed to be a result of bomb tests."

On March 15, 1955, notes from the F-Area shift log relative to the contamination were as follows:

> "Shoe contamination due to yesterday's fallout remains common. Certain types of shoe soles absorb up to 3000 c/m. Procedure for release: at A-line, check for ∝, release if negative; at 211-F determine contamination level & base release on contamination history. In no case is plant-caused contamination to be released. Check of fallout indicates half-life in 30–36 hr range.6 Roadway reading maximum of 2000-2500 c/m, towel smearable contam. to 25000 on pipes, hand-rails, etc. Rubber gloves were required for work in outside areas where process contamination is posible [sic] as it is not determinable whether skin contamination is caused by fallout or process. No skin decontamination record is necessary for decontamination of personnel known to have been contaminated by non-process, i.e. fallout, material."

[5] Break in quotes indicates an area where unrelated text appears in the logbook.

[6] Shorter half-life than would be expected based on exposure rate decay curve from Teapot Hornet (Figure 6-8). No data were located to support this statement, so it is not known what isotopes were being measured. Some components of the fallout have half-lives in this range. (Table 6-3).

Weekly reports of reactor area activities were reviewed for the time period of interest. A brief mention of the contamination is made in Kauffman (1955a):

> "The fall out which occurred on the afternoon of 3/14/55 caused difficulty with contamination surveys such as the hand and foot checks. Lectures were given to a number of personnel on the nature of the fall-out. Decay and absorption studies are being made on samples of fall-out material. A special report will be issued on the fall-out incident in 100-P area."

The 100-P weekly report for March 21–March 27 (Kauffman 1955b) states, "On the morning of March 25, 1955 fall-out activity was observed for the second time during the month. Thyac readings ranging from 800 c/m to 1000 c/m, above background, were found by spot-checks outside of the 105-P building." No mention of contamination is made in the weekly reports from 100-L for March 1955. However, at 100-C, the weekly report ending March 20, 1955 (Catlin 1955) states:

> "Numerous cases of foot contamination from radioactive fallout were detected by the Hand and Foot Counters. One hand contamination case was also reported. Smear surveys outside the 105-C Building gave contamination levels as high as 5000 c/m. This material was tracked into the 105-C Building to give contamination levels as high as 500 c/m. Half-life of the fallout was found to be approximately 30 hours. Notices were posted at all Hand and Foot Counters to acquaint building personnel with the problem."

The next week, contamination was observed again on March 25, 1955. Smear survey spot checks outside the 105-C building revealed contamination levels up to 2000 cpm.

The 100-K weekly report for March 14 through 20 (Du Pont 1955a) contained fallout data for six areas outside the building. The original data were on Radiation Survey Log Sheet K3661. On March 15, Thyac readings were 3100–4000 cpm; five days later on March 20 they ranged from 650–1100 cpm at the same locations. On average, the March 20 readings were 24% of the March 15 readings, for both Thyac measurements and for removable contamination measured by smears (data in spreadsheet 100kwr.xls). This is in reasonable agreement with the decay trend illustrated for the Teapot Hornet test in Figure 6-8 of this chapter; between 3 days and 8 days after the blast, a somewhat smaller reduction of 30–35% in the exposure rate is expected. However, we do not know the precise time of day that the exposure rate measurements were taken at SRS. If taken early in the day on March 15 and late in the day on March 20, a decrease of around 25% is expected, based on Figure 6-8. In addition, some weathering of the contamination either surficially or into the ground would tend to further reduce the exposure rate beyond the theoretical amount based on decay alone. Therefore, we have concluded that the exposure rate reduction observed in K-Area between March 15 and 20 is consistent with the decay characteristics of the Teapot Hornet fallout event.

A monthly report of Miscellaneous Areas for March 1955 (contained in Anonymous 1986) states that "occurrence of fallout on 3-14-55 necessitated the use of shoe covers in the 735-A Bioassay labs and counting rooms." A summary of important items for 100-P area in March 1955 (Du Pont 1955a) contained the following comments:

> "The 'fallout' from the Nevada Tests proved to be one of the biggest problems during the month. For a number of days the Hand and Foot counters would indicate 'Decontamination Required' for all personnel in the building. Special checks had to be given to all personnel working in RDZ locations with a Thyac in the H.P. Office. A number a [sic] special indoctrination sessions on the fall-out were given to different groups in the area."

In general, we have found that internal documents reporting on SRS operations frequently note contamination incidents, personnel overexposures, unplanned releases, and other unusual incidents. There does not appear to be any attempt to hide this type of information. An example during the time period of interest is Radiation Survey Log Sheet F1917 from March 15, 1955 (Du Pont 1955a), in which an incident involving product from the FB line resulted in significant contamination within that working area as well as radiation exposure to personnel. The previous paragraphs of this section have reviewed original, primary records that confirm widespread radioactive contamination around the SRS buildings on March 14, 1955 and the days that follow. However, in the records of special work permits, weekly reports, and monthly reports contained in the Senate investigation microfilms (Anonymous 1986) as well as weekly reports of the control group (Du Pont 1955b), there was nothing to indicate that a major problem in SRS facilities caused this contamination.

Stephens and Ross (1984) summarizes sites of contamination on the SRP. It includes a list of many sites contaminated with radioactivity from SRS activities. There were 25 locations in F-Area between November 1954 and November 1978; 9 areas in H-Area between July 1956 and 1983; 28 areas in G-Area, M-Area, and A-Area between December 1953 and 1973; and 3 areas in the reactor areas between 1957 and 1983. This demonstrates that the personnel were cataloging areas believed to be contaminated by their operations. The sites listed for 1955 were small in extent relative to the March 1955 contamination area. No mention is made of any SRS event leading to significant environmental contamination in March 1955.

National Cancer Institute Report on Exposure of the American People to ^{131}I from Nuclear Weapons Tests. The National Cancer Institute (NCI) used the gummed-film monitoring data from the 1950s in a recent retrospective analysis of estimated exposures and thyroid doses received by the American people from ^{131}I in fallout following the Nevada atmospheric nuclear bomb tests (NCI 1997). A correction was made to estimate the fraction of iodine from each of the tests because the monitoring data were reported as total beta activity. The projected trajectories from the Teapot Hornet test were the same as shown in List (1956), reproduced in this chapter as Figure 6-5.

Our Conclusion About the 1955 Contamination Incident

We conclude that it is highly probable that the ground contamination measured at the SRS on March 14–15 came from deposition of debris from the Teapot Hornet test conducted on March 12 in Nevada. This conclusion is based on a number of factors reviewed in the previous sections, perhaps most importantly (1) the timing of the deposition relative to the predicted arrival of Nevada fallout, (2) the measurement of elevated radioactivity in Atlanta on the same date, and (3) the decay characteristics of the material. The main argument supporting an SRS accidental release is that localized contamination centered on the reactor areas at the SRS. However, there were no other nearby areas being monitored for radioactivity, so the complete extent of the contamination

will never be fully known. This incident underscores the difficulty in interpreting environmental monitoring data from the 1950s, when isotopic analyses were much less frequent than gross activity analyses, and when hot spots from fallout were more frequent than in the 1960s and later.

NATURAL, ACCIDENTAL, AND OTHER FACILITY SOURCES OF ENVIRONMENTAL RADIOACTIVITY

Although fallout from weapons testing has been the most important man-made contributor to radioactive contamination of the global environment, there are other sources. In addition, some radionuclides occur naturally in the environment. To focus our discussion, it is necessary to identify the radionuclides of interest for this dose reconstruction. In Phase I of this study, a screening calculation was conducted to identify the radionuclides that probably contributed the largest proportion of offsite doses from past SRS releases to air and water (Meyer et al. 1995, Table 25). There were 14 radionuclides in the most important group: ^{241}Am, ^{41}Ar, ^{60}Co, ^{137}Cs, ^{3}H, ^{131}I, ^{129}I, ^{32}P, ^{90}Sr, ^{35}S, ^{238}Pu, ^{239,240}Pu, ^{65}Zn, and ^{95}Zr/Nb. In Chapter 3 of this Phase II report, some of the radionuclides identified in Phase I are highlighted as prime candidates for future detailed source term work. Those eight nuclides, which should be evaluated further for their offsite release potential, are ^{3}H, ^{137}Cs, ^{131}I, ^{90}Sr, ^{60}Co, ^{32}P, ^{41}Ar, and ^{129}I.

Only two of these most important radionuclides, tritium, (^{3}H), and iodine-129 (^{129}I), are produced naturally in the environment.

Natural Sources

Natural tritium is produced by the interaction of cosmic rays with nitrogen in the upper atmosphere. The natural production rate has been calculated to be 4 million curies per year, leading to an inventory of 70 million curies (NCRP 1979). Since the mid-1950s, the global inventory of tritium from aboveground nuclear weapons tests has overwhelmed the natural inventory. This inventory from weapons tests was (within a factor of 2) 3100 million curies in 1963 (NCRP 1979).

The average concentration of tritium in environmental waters from natural tritium production is 3.2 to 16 pCi L^{-1} (NCRP 1979). Average concentrations up to 4000 pCi L^{-1} were measured in U.S. surface waters in the peak fallout years (see previous section).

Radioactive isotopes of iodine are produced naturally by the interaction of cosmic rays with the earth's atmosphere and by rare spontaneous fission of uranium and thorium in the earth's crust. Essentially the only radioactive isotope of iodine to survive the transit time between production in the atmosphere and deposition on the earth's surface is ^{129}I (with a half-life of 16 million years). The global inventory of ^{129}I accumulated over the lifetime of the earth is estimated to be 10 Ci in the terrestrial environment and 30 Ci in the oceans and atmosphere (NCRP 1983). Fallout from nuclear weapons testing has added about 10 Ci of ^{129}I into the atmosphere (NCRP 1983).

There are no other key radionuclides in this dose reconstruction that occur naturally except in rare instances. For example, ^{239}Pu and fission products such as ^{137}Cs can occur in minute quantities in some naturally occurring ores containing uranium or thorium. Based on the Phase I screening analysis (Meyer et al. 1995), another 11 minor radionuclides were selected that probably contributed between 0.1 and 1% to offsite dose from the SRS releases: ^{140}Ba,La,

^{141,144}Ce, ^{14}C, ^{51}Cr, ^{85}Kr, ^{239}Np, ^{106}Ru, ^{99}Tc, ^{232}Th, uranium, and ^{91}Y. Of these, ^{14}C, thorium, and uranium isotopes occur naturally in significant quantities. Minor amounts of ^{85}Kr are produced naturally.

Environmental measurements that do not distinguish individual radionuclides (gross beta, nonvolatile beta, external gamma, and gross alpha) always include some background level of naturally occurring radioactivity such as ^{40}K, ^{226}Ra, radon, and other radionuclides in the uranium and thorium series. The background radioactivity concentrations depend on the sample collected and how it is prepared and analyzed. When appropriate, background levels of gross radioactivity are discussed in other sections of this report that address the individual environmental media.

Accidental Sources

A significant source of ^{238}Pu in the global environment was the burnup of a satellite (SNAP-9A) in April 1964 (Hardy et al. 1972). This malfunction resulted in an estimated 17 kilocuries (kCi) of ^{238}Pu being released to the upper atmosphere. Although most of this material ended up falling out in the Southern Hemisphere, there were detectable amounts in the Northern Hemisphere that affected the ratio of ^{238}Pu to ^{239,240}Pu in fallout after that time.

Plutonium-238 from the April 1964 burnup of the SNAP-9A satellite was first detected by the HASL in ground-level air in Ispra, Italy in early 1966. In New York City, the elevated levels were first detected in April of that year. After 1970, HASL stopped reporting ^{238}Pu at many stations, because concentrations were barely detectable and soil sampling indicated that 95% of the SNAP-9A ^{238}Pu had been deposited by that time. Because of the low levels of ^{238}Pu in the air after October 1971, the errors associated with the measurements are large (Figure 6-10).

The Chernobyl Unit 4 nuclear reactor accident in April 1986 in the Ukraine released radioactivity to the atmosphere that was detected at locations throughout the U.S. Table 6-5 lists the amounts believed to have been released, for those longer-lived radionuclides having significant activity 10 years later. In addition to these, Bradley (1997) gives estimated release quantities for the following shorter-lived radionuclides: ^{133}Xe (45 million curies), ^{131}I (7.3 million curies), ^{85m}Kr, ^{140}Ba, ^{95}Zr, ^{103}Ru, ^{99}Mo, ^{141}Ce, ^{89}Sr, ^{132}Te, ^{239}Np, and ^{242}Cm. Based on ^{131}I/^{129}I isotope ratios measured by Paul et al. (1987), the accidental release of ^{129}I is estimated to be 0.2 Ci.

Other nuclear reactor accidents such as Three-Mile Island (in Pennsylvania, 1979); SL-1 (in Idaho, 1961); and Windscale (in the U.K., 1957) released smaller amounts of radioactivity that were essentially limited to their regions.

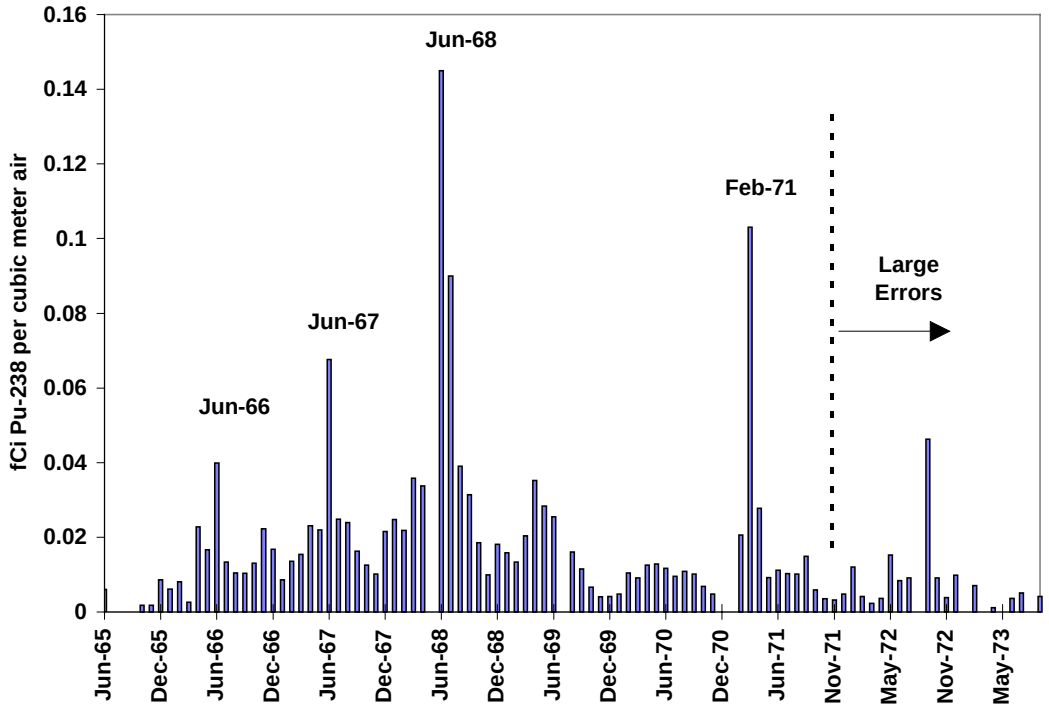


Figure 6-10. Plutonium–238 in air in New York City, measured by the Health and Safety Laboratory surface air-monitoring program (HASL 1975). Concentrations in the late 1960s were affected by the accidental burnup of a satellite that contained ^{238}Pu. These data can be accessed directly in the Excel® workbook by clicking on the following hyperlink: puair.xls.

Table 6-5. Estimated Release of Radionuclides from the Chernobyl Accident (Bradley 1997)[a]

Nuclide	Released Activity by May 6, 1986 (Ci)
^{137}Cs	1,000,000
^{85}Kr	950,000
^{90}Sr	220,000
^{241}Pu	140,000
^{134}Cs	500,000
^{106}Ru	1,600,000
^{240}Pu	1,000
^{238}Pu	800
^{239}Pu	700
^{144}Ce	2,400,000
^{242}Pu	2

[a] Estimated error ± 50%.

Other Facility Sources

Other facility sources of man-made radioactivity include commercial nuclear reactors, medical and industrial facilities, and other government sites in the weapons complex. Their contributions to environmental radioactivity levels usually can not be distinguished from ambient background conditions at distances very far from the facilities. They need not be considered as contributors to concentrations measured near the SRS.

RELATIVE CONTRIBUTIONS OF VARIOUS SOURCES OF RADIOACTIVITY

Some radionuclides identified in the screening analysis (see Chapter 3), if detected in the SRS regional environment (within about 10 km of the source), would be expected to have come almost exclusively from SRS releases. These include ^{85}Kr, ^{41}Ar, ^{32}P, ^{35}S, ^{60}Co, ^{129}I, ^{99}Tc, and ^{51}Cr. In addition, ^{238}Pu is mainly released to the environment from facilities that produce or process nuclear materials (such as the SRS), although lesser amounts have been contributed by weapons fallout. The accidental burnup of the SNAP satellite is an important contributor to atmospheric ^{238}Pu in the late 1960s.

Natural sources are unimportant contributors to environmental concentrations for the key radionuclides identified for this dose reconstruction. Similarly, other government and commercial facilities would not contribute significantly to environmental radioactivity levels near the SRS.

Radionuclides in weapons fallout such as ^{241}Am, ^{137}Cs, ^{3}H, ^{131}I, ^{90}Sr, ^{239,240}Pu, ^{65}Zn, and ^{95}Zr/Nb were also released in significant quantities from the SRS. A careful examination of source term amounts and trends as well as environmental concentrations and trends is necessary before an informed judgment can be made about the relative contributions for radionuclides produced from multiple sources.

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