Deposition of ^{131}I on the Ground

Contents: The data used to estimate the activities of ^{131}I deposited per unit area of ground for each county of the contiguous United States following each nuclear test of interest are described. There are limited data available from the time during which the tests were carried out. In the absence of environmental radiation measurements, a meteorological transport and wet deposition model was used. The estimated amounts of ^{131}I released into the atmosphere by each test are tabulated. The available measurements are described in **Section 3.2.** *Detailed mathematical descriptions of the procedures used to estimate daily depositions of ^{131}I are in* **Section 3.3.** *Comparisons of the results obtained using different procedures are presented in* **Section 3.4.** *In* **Section 3.5***, the nuclear weapons tests are subdivided according to the procedures used to estimate ^{131}I deposition. A detailed listing of all tests considered in this report is provided as is the rationale for selection of those tests.* **Section 3.6** *provides summary estimates of ^{131}I deposition throughout the country from weapons testing in Nevada.*

3.1. INTRODUCTION

The amount of ^{131}I deposited in each county of the contiguous United States[1] for each shot was estimated using one of three methods. The method chosen depended upon the extent and type of environmental measurements available.

The activity of ^{131}I deposited on the ground was not measured directly in the 1950s because most measurements of environmental radioactivity at that time were of gross beta (β) activity; specific measurements of ^{131}I in the environment were not performed to a significant extent before 1960. Since the half-life of ^{131}I is about 8 days, the activity of ^{131}I present in the samples collected more than thirty years ago has now completely decayed, and therefore cannot be analyzed. Because few ^{131}I measurements were made at that time and because ^{131}I present at that time cannot be measured today, the estimation of the amount of ^{131}I deposited on the ground at that time cannot be based on unequivocal measurements of ^{131}I. It is possible, however, to estimate the amounts of ^{131}I deposited on the ground from some of the measurements (e.g., exposure rates, total β activity in air or deposited on sticky surfaces) which were systematically made after most of the tests as part of environmental monitoring programs. Although most of the measurements were made in the vicinity of the Nevada Test Site (NTS), one of the environmental monitoring programs collected samples at up to 95 sites located throughout the United States.

Three procedures are used for the determination of the deposition of ^{131}I in the counties of the contiguous United States for which no monitoring data are available. First, where there are enough measurements of deposition of gross β activity that can be converted to estimates of ^{131}I deposition, these, together with precipitation data, are used to interpolate estimates of ^{131}I deposition for all counties of the contiguous United States. A statistical technique, kriging, described in **Section 3.3.1.3,** is used to make these estimates. Second, where the kriging procedure is unlikely to be satisfactory due to an insufficient number of ^{131}I deposition estimates based on the analysis of gross β activities, a less complex method is employed. For a county without monitoring data, the ^{131}I deposition is estimated using the deposition estimate from the nearest county with monitor-

1 Data on the name, location, area, and population of each county of the contiguous United States are provided in **Appendix 2.**

ing data and the precipitation data for those counties **(see Section 3.3.1.2.4).** Those two procedures constitute what is called the *"historical monitoring data approach"* in this report. Finally, if estimates of surface deposition values of ^{131}I are not available, calculations of the wet deposition of ^{131}I were based upon a meteorological model **(Section 3.3.2 and Appendix 1).** This is called the *"meteorological transport approach"* in this report.

3.2. AVAILABLE MEASUREMENT RESULTS FROM THE TESTING PERIOD

A limited number of environmental radiation measurements are available from the period of testing in the atmosphere at the NTS. They are:

(a) measurements of exposure rates above ground, which were obtained near the NTS after each test using survey meters and are called "close-in measurements of environmental radiation,"

(b) measurements of deposition of fallout on gummed film. This systematic monitoring of fallout deposition was carried out for sites within the contiguous U.S. and also for sites throughout the rest of the world. For the purpose of this report, only the sites within the contiguous U.S. and, occasionally, a few sites in Canada, have been considered. This fallout deposition network is called "national network of deposition measurements,"

(c) measurements of individual radionuclides in the radioactive cloud, allowing the determination of the activity distribution of the radionuclides to be made. These measurements, called "radiochemical data," were necessary to establish the correspondence between the exposure rates above ground, or the fallout depositions, and the ^{131}I depositions per unit area of ground,

(d) measurements of exposure rates aboard aircraft, and

(e) other, less extensive measurement programs in the temporal or spatial dimensions, such as the measurements of ground-level air activity by the Public Health Service (PHS) and by the Naval Research Laboratory (NRL), or the measurements of activity in precipitation by the PHS.

In addition, the spatial and temporal distribution of rainfall vis-à-vis that of the radioactive cloud, which played an important role in the determination of the deposition at the national scale, is available from historical records.

3.2.1. Close-In Measurements of Environmental Radiation

For counties near the NTS, the primary data are exposure-rate measurements using portable survey instruments. An extensive program of exposure rate measurements was carried out in a few counties near the NTS for several days following each test. These exposure-rate measurements, together with other, less extensive, monitoring data, were evaluated and archived by the Offsite Radiation Exposure Review Project (ORERP) of the Department of Energy. From these data, a Town Data Base (Thompson 1990) and a County Data Base (Beck and Anspaugh 1991) were derived:

(a) The Town Data Base (TDB) lists the time of arrival of the radioactive cloud produced by each test and the exposure rate normalized at 12 hours after detonation (H + 12) at 173 stations, representing inhabited locations, in 4 counties of Nevada (Clark, Esmeralda, Lincoln, and Nye) and in Washington County, Utah. In order to provide a uniform basis of comparison, the pertinent literature has used H + 12 as the standard time to report exposure rates; fallout may have been deposited on the ground before or after H + 12.

(b) The County Data Base (CDB) lists the estimated times of initial arrival of the radioactive cloud and the estimated exposure rates normalized at H + 12 in 24 subdivided areas of nine counties in Arizona, California, Nevada, and Utah, along with similar information for 120 additional counties (which were not subdivided) in Arizona, California, Colorado, Idaho, New Mexico, Nevada, Oregon, Utah, and Wyoming.

The geographical areas included in the Town and County Data Bases are shown in *Figures 3.1 and 3.2,* respectively.

3.2.2. National Network of Deposition Measurements

Monitoring of long-range fallout deposition in the United States in the 1950s was carried out primarily by the Health and Safety Laboratory (HASL) of the Atomic Energy Commission in cooperation with the U.S. Weather Bureau (Beck 1984; Harley et al. 1960). The HASL deposition network evolved gradually, beginning in the fall of 1951 with the Buster-Jangle test series. The original monitoring technique consisted of collectors which were trays of water; these were soon replaced by gummed paper for the 1952 Tumbler-Snapper test series. The gummed paper was replaced by an acetate-backed rubber-base cement gummed film in 1953, and this medium was used until the program ended in 1960.

A 1 square foot (0.093 m^2) exposed area of gummed film was positioned horizontally on a stand 3 feet (0.9 meters) above the ground. Usually two replicate films were exposed during a 24-h period beginning at 1230 Greenwich Mean Time (GMT) for the Upshot-Knothole, Teapot, Plumbbob and Hardtack-II series and at 1830 GMT for the Buster-Jangle and Tumbler-Snapper series. Daily high volume air samples also were collected at many of the gummed-film sites.

The number and types of monitoring sites in operation in the United States changed from one test series to another.

Figure 3.1. Geographical coverage of the Town Data Base of the ORERP study of the U.S. Department of Energy: each of the 173 stations is marked with its code number. The approximate center of the Nevada Test Site is marked with a star.

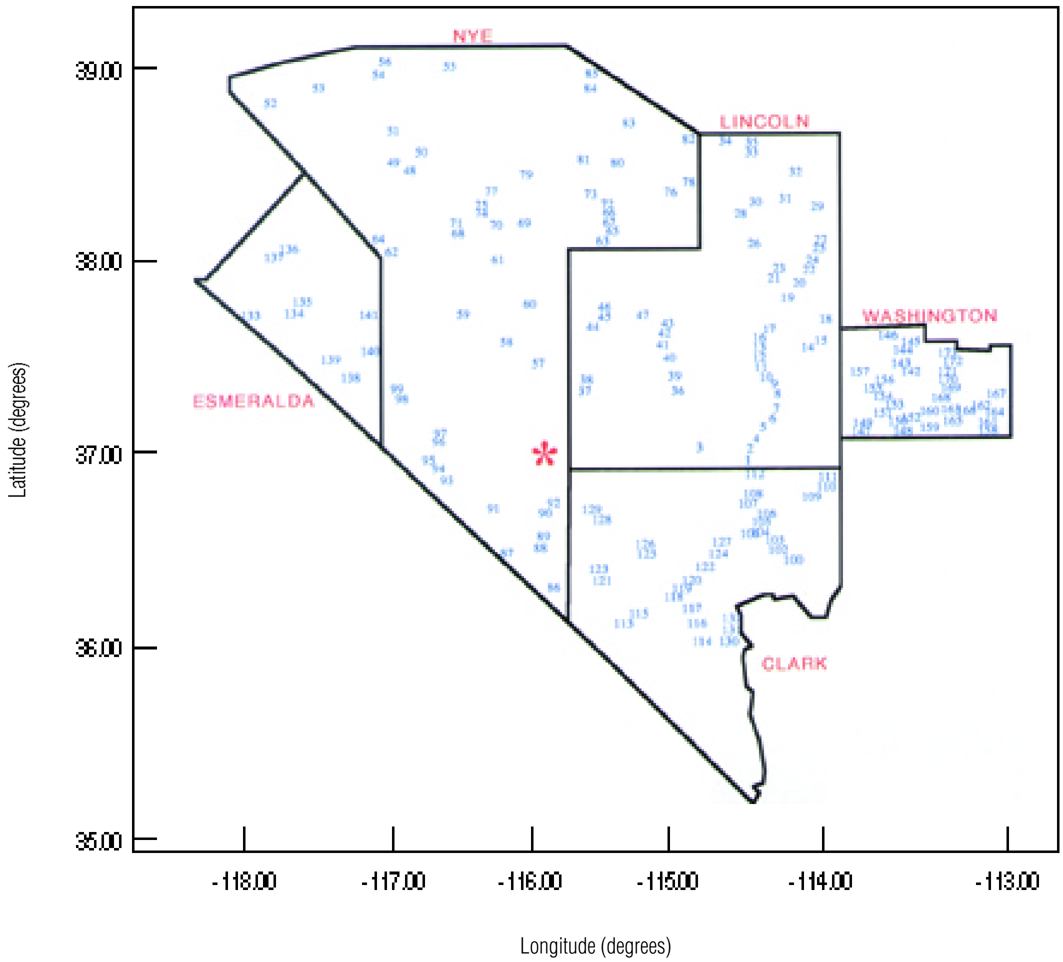


Figure 3.2. Geographical coverage of the County Data Base of the ORERP study of the U.S. Department of Energy: the 9 counties in solid colors are those that were subdivided while the 120 counties hatched in blue were not subdivided. County boundaries for the remainder of the states in which the County Data Base is located also are shown. The approximate center of the Nevada Test Site is marked with a star and the 5 counties covered by the Town Data Base are shown in white.

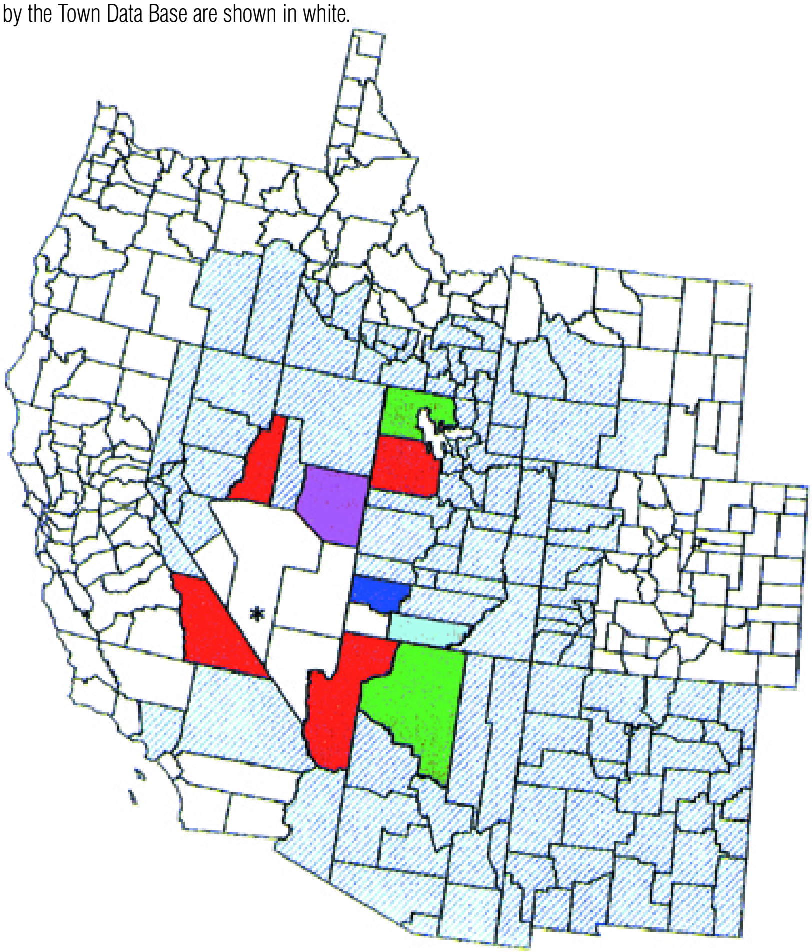


Table 3.1. Number of contiguous U.S. sites of fallout monitoring by HASL, for which data are available, by test series (Beck 1990).

Test Series	Year	Number of sites
BUSTER-JANGLE	1951	51-61[a]
TUMBLER-SNAPPER	1952	93
UPSHOT-KNOTHOLE	1953	95
TEAPOT	1955	89
PLUMBBOB	1957	42[b]
HARDTACK-PHASE II	1958	40

[a] The number of sites of fallout monitoring varied from one test series to another.

[b] Estimates of ^{131}I deposition also were derived from 25 sites at which measurements of β activity in air and in precipitation were carried out by the Public Health Service.

Although only about 40 sites operated continuously throughout the atmospheric testing era, the number generally was increased during the testing periods and reached a maximum of 95 in 1953 (Upshot-Knothole series) (*Table 3.1*).

Figure 3.3 illustrates the geographical coverage of the network during the Upshot-Knothole series. *Figure 3.4* shows the reduced available coverage during 1957, which was the last year of substantial atmospheric testing at the NTS; during that year, however, estimates of ^{131}I deposition also were derived from 25 sites from the PHS network (described in **Section 3.2.5**).

The gummed-film samples were sent to HASL where they were processed and total beta activity counts were made. The measured beta activities were extrapolated to the middle of the sampling day, using the assumption that the total beta activity decreased with time after detonation t, expressed in hours, according to a power function ($t^{-1.2}$). These fallout results, as well as the amount of precipitation recorded at the sampling location that day, were published in joint reports by HASL and the U.S. Weather Bureau (List 1953, 1954, 1956; NYO 1952, 1954).

The HASL network effectively fulfilled its purpose of indicating quickly where and when fallout occurred. Although this network was not designed to derive radiation exposures, it represents the only data set available on a daily basis over the entire United States during most of the atmospheric testing period. Therefore, it was extensively used to derive deposition estimates of ^{131}I (or of any other radionuclide from fallout) at the national scale.

3.2.3. Radiochemical Data

Measurements of individual radionuclides in the radioactive cloud were conducted after many events (Hicks 1981a). These measurements, called "radiochemical data", were used to establish the relative amounts of radionuclides in the radioactive cloud, immediately after detonation.

On the basis of the radiochemical data, the correspondence between external gamma radiation exposure rate and radionuclide ground depositions, as a function of time after detonation, has been published by Hicks (1981a) for all tests that resulted in off-site detection of radioactive materials. The tabulated results include 30 decay times, grouped in three time periods following detonation: 10 decay times between 1 and 21 hours, 10 decay times between 1 to 300 days, and 10 decay times between 1 to 50 years. For each of these times, Hicks calculated: (a) the exposure rate from external gamma radiation, (b) the deposited activity per unit area of ground of specified individual radionuclides (including ^{131}I), and (c) the total deposited activity per unit area of ground of all radionuclides. Thus, given a measurement of the exposure rate, one can derive the ^{131}I and total deposition on the ground. Similarly, if the total deposition is known, the ^{131}I deposition and the exposure rate can be determined.

3.2.4. Aircraft Measurements

Aircraft measurements were used: (1) to track the movement of the radioactive cloud and sample its contents, or (2) to estimate off-site radiation fields .

Aircraft sampling of radioactive clouds was obtained at high altitudes in 1951 (Machta et al. 1957). In general, flights were made along the 80th and 95th meridians, at elevations between 2.5 and 9.2 km. The aircraft were equipped with two filters, which were changed alternately every 15 min, so that each filter was exposed for 30-min periods. After sufficient time for decay of the natural radioactivity, the filter was measured with a Geiger counter. The conversion of the counting rates into activity concentrations in air was not attempted because of inadequate information on the efficiency of the filter, the counting geometry of the Geiger counters, etc. (Machta et al. 1957).

Aerial surveys of off-site radiation fields began in 1953 and continued until 1970 with aircraft flying at altitudes of 50 to 500 ft (Burson 1984). The data from those aerial surveys were used extensively to assist in quickly estimating the fallout radiation patterns. In general, the aerial survey results were used to support the ground data, not vice-versa, since the aerial survey technique was still under development and many uncertainties existed in its application. In many locations, however, ground measurements were not made and the aerial survey results alone were relied on to extend the fallout patterns. This occurred particularly during the Plumbbob test series in 1957 and also in the 1960s when the aerial survey results were more reliable (Burson 1984).

The radioactive clouds from cratering and vented underground tests, beginning in 1960, were tracked by aircraft (usually two) (Anon. 1975, 1976; Crawford 1970; Placak 1962; Thompson 1966). The movements and speed of the radioactive cloud were determined by on-board exposure-rate meters and by visual observations of dust in the cloud. Many such clouds were tracked beyond the test site and a few were tracked into neighboring states to the north and east of NTS. High-volume air samples also were collected in the aircraft, depositing radioactive particles on special filters.

3.2.5. Other Measurement Programs

Other measurement programs, less extensive than those described above, were established in the 1950s with the purpose of monitoring fallout or man-made activity in air or in water (RHD 1960).

The Public Health Service operated several networks, among which:

(a) The Nationwide Radiation Surveillance Network, established in April 1956 consisted of about 40 stations in which sampling operations included: (a) the daily radioassay of beta-emitting suspended particulate matter with relatively long half-lives, collected on a filter from approximately 2,000 cubic meters of air, (b) two (or more) daily determinations of external gamma radiation levels with a portable survey meter, (c) the collection of radioactive fallout with gummed-film devices, (d) the collection of precipitation sam-

Figure 3.3. Geographical coverage of the gummed-film network during the Upshot-Knothole test series. The diamonds represent the gummed-film stations operated by HASL. The approximate center of the Nevada Test Site is marked with a star.

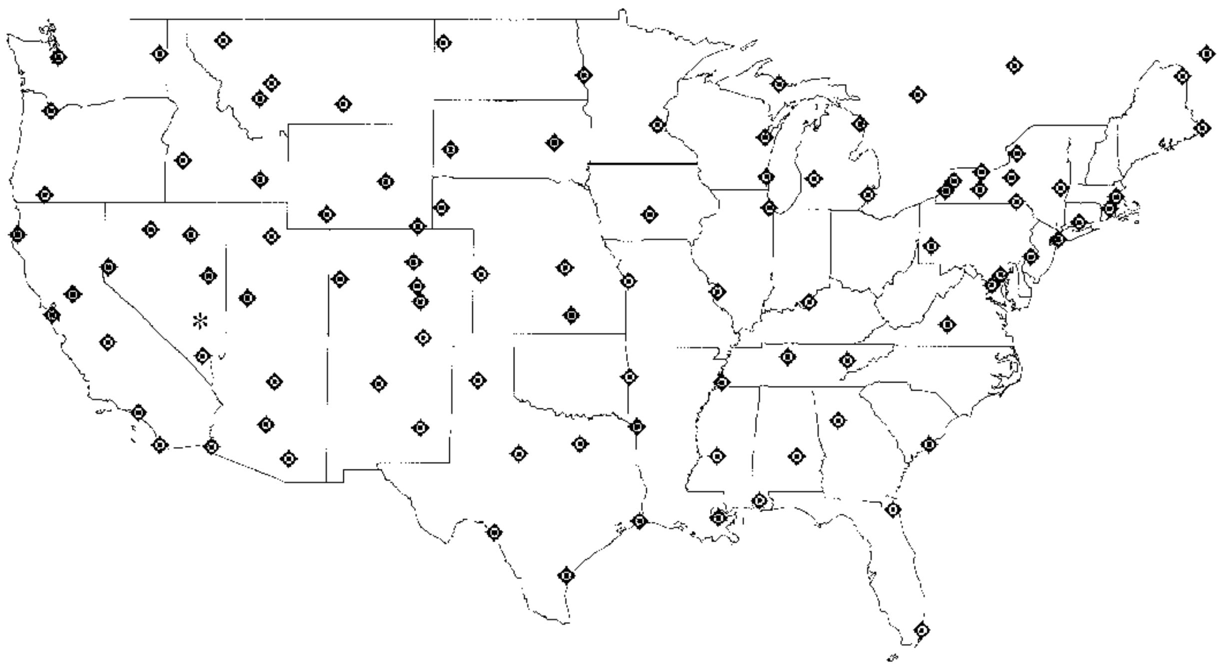
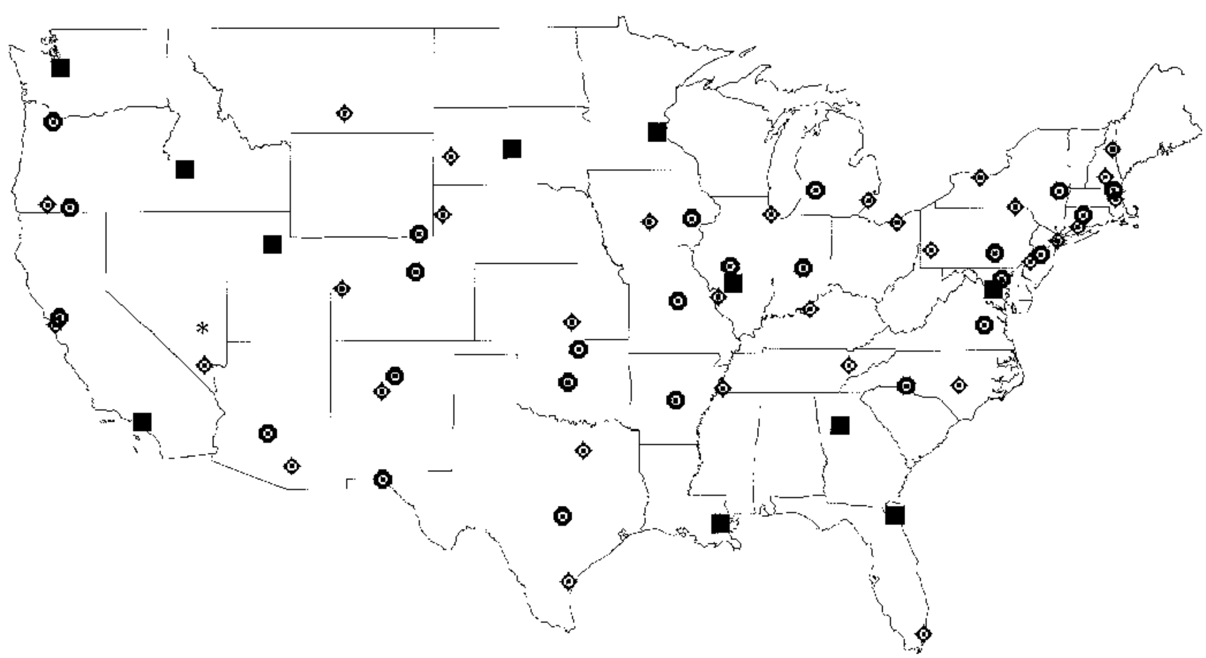


Figure 3.4. Geographical coverage of the deposition network during the Plumbbob test series in 1957. The diamonds represent the gummed-film stations operated by HASL; the circles represent the sites where air and precipitation were collected and analyzed for their activity content by PHS; the squares represent the cities where both HASL and PHS had monitoring stations; the approximate center of the Nevada Test Site is marked with a star.



ples, and (e) the preparation of preliminary reports from which public information might be made available by State and Territorial departments of health (PHS 1957). The results of the Nationwide Radiation Surveillance Network were used in this report to supplement the daily estimates of ^{131}I deposition derived from the HASL gummed-film network.

(b) The National Air Sampling Network, established in 1953, consisted of 17 stations in 1953 and about 200 in 1957. Twenty-four hour samples of suspended particulate matter were collected on filters on a predetermined sampling schedule. Unfortunately, the only results that could be found (PHS 1958) were presented in a statistical manner without indication of the sampling dates. This form of presentation precluded the use of the results for the purpose of reconstructing the fallout patterns after each test.

Beginning in December, 1949, the Naval Research Laboratory operated stations for the detection and collection of both natural radioactivity and radioactive atomic bomb debris (Blifford et al. 1956).There were as many as five stations in the contiguous U.S. (Washington, D.C.; Glenview, IL; San Francisco, CA; San Diego, CA; Bremerton, WA). A filter was used to collect airborne particles for each 24-h period beginning at 1600 local time. At the end of the collection interval the filter was removed from the pumping system and its activity recorded overnight or for approximately 16 hours. The results, reported on a daily basis, constitute the only time series of radioactivity measurements that could be found for the Ranger test series (January - February 1951).

The other measurement programs operated or sponsored by governmental agencies (RHD 1960) were not used because their results were either not found or not suitable for the purposes of this study, usually because the sampling times were too long.

3.2.6. Precipitation Data

Precipitation, hereafter used interchangeably with the words rain or rainfall, efficiently scavenges particles suspended in the atmosphere and can result in much greater deposition than that due to dry processes such as sedimentation, impaction, and diffusion. However, although a substantial fraction of the amount of radioactive materials present in the air may be scavenged by rainfall at particular locations, the fraction of the whole radioactive cloud so removed during one day is small.

Nuclear weapons were detonated when dry weather was predicted so that the deposition of radioactive materials onto the ground in the vicinity of the NTS would be as low as possible. However, because dry conditions were seldom maintained over the entire U.S. for several days after each shot, rainfall represents the primary means by which ^{131}I was deposited east of the Rocky Mountains. Fortunately, there was (and is) a very comprehensive national network of precipitation monitoring stations operated by cooperative observers for the U.S. Weather Bureau, now the National Oceanic and Atmospheric Administration (NOAA). For many years, this network, with rare exceptions, provided at least one measurement location in each of the counties of the contiguous United States. *Figure 3.5* illustrates the location of such stations, together with county boundaries, for one state.

The rainfall amounts represent 24-h accumulations ending usually at 9:00 a.m. local time or within an hour or two of that time. For the purposes of this report, a single precipitation value for each day (the arithmetic average of all readings in the county) was assigned to the entire county. The date to which the precipitation value was assigned was the day that collection of precipitation was begun. Counties without data were rare; such counties were assigned amounts of rainfall based on measurements from locations in the closest adjacent counties. For the purpose of this report, the amounts of rain were categorized on a logarithmic scale by index value as shown in *Table 3.2*.

3.3. DESCRIPTION OF THE METHODS USED TO ESTIMATE DAILY DEPOSITIONS OF ^{131}I PER UNIT AREA OF GROUND

Two approaches were used to estimate daily depositions of ^{131}I per unit area of ground (also called daily deposition densities of ^{131}I):

(a) The historical monitoring data approach: for the tests and counties for which environmental radiation measurements were available that could be used to derive estimates of ^{131}I depositions per unit area of ground, these measurements served as a basis for the assessment of ^{131}I depositions per unit area of ground in the counties and for the days in which the samples or the measurements were taken. For other counties and days in which no environmental radiation measurement was available that could be used to derive estimates of ^{131}I depositions per unit area of ground, the estimates of daily depositions of ^{131}I per unit area of ground were inferred from the closest counties in which daily depositions of ^{131}I per unit area of ground were derived from environmental radiation measurements for the same day, using mathematical techniques that took into account the daily precipitation values.

(b) The meteorological transport approach: for the Ranger series of tests (January-February 1951) and during the underground testing era, useful environmental radiation measurements were not available, either for the entire country or for a large part of it. For those tests, calculations of the deposition of ^{131}I were based upon a meteorological transport model for those counties where precipitation occurred.

Figure 3.5. Network of stations collecting precipitation in New York State. The numbers represent rainfall on April 27, 1953 in hundredths of inches. The solid lines are the county boundaries. The circles show the location of the gummed-film stations.

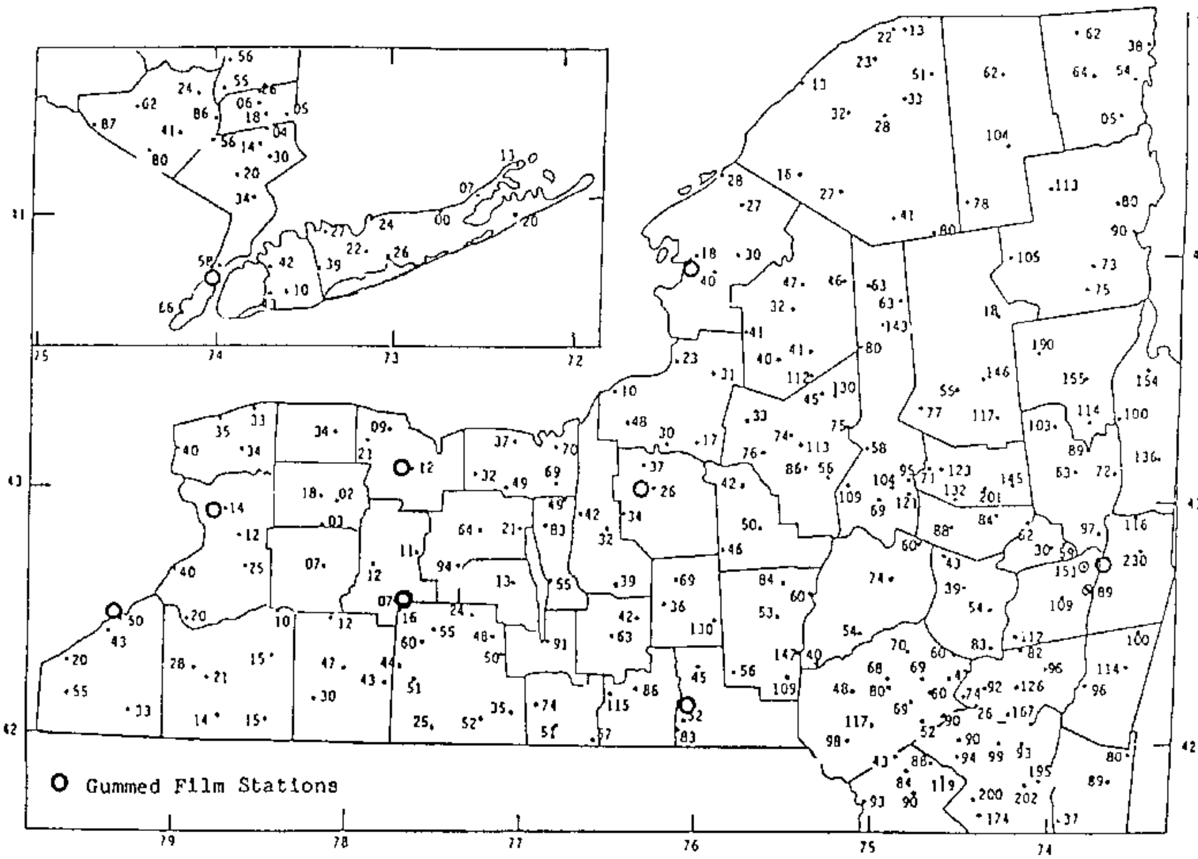


Table 3.2. Relationship between the 24-h precipitation amount and the precipitation index.

Precipitation index number	24-h precipitation amount	
	(inches)	(millimeters)
1	none	none
2	trace	trace
3	0.01-0.03	0.25-0.76
4	0.03-0.10	0.76-2.5
5	0.10-0.30	2.5-7.6
6	0.30-1.00	7.6-25
7	1.00-3.00	25-76
8	3.00-5.00	76-127
9	5.00 or over	127 or over

3.3.1. Historical Monitoring Data Approach

The historical monitoring data approach consists of: (a) processing the historical data available to derive estimates of deposition of ^{131}I per unit area of ground, and (b) using mathematical techniques to interpolate between observed sampling locations using auxiliary information. The main advantage of this method is that it does not require the knowledge of:

(a) the amount of ^{131}I released into the atmosphere,

(b) the mechanisms of transport and diffusion of ^{131}I in the atmosphere, or

(c) parameters for predicting deposition of ^{131}I on the ground.

3.3.1.1. Determination of ^{131}I deposition in counties with monitoring data

3.3.1.1.1. Close-in deposition

The depositions of ^{131}I per unit area of ground after each test were derived for 134 counties near the NTS from the County Data Base and the Town Data Base, which provide estimates for the time of arrival, TOA, of the radioactive cloud and for the exposure rate normalized at 12 hours after detonation, H + 12, for specific localities and areas.

As shown in *Table 2.6* and *Figure 2.4,* the activity of ^{131}I that is found in the radioactive cloud or on the ground after a nuclear test results not only from the production of ^{131}I itself but also from the decay of its precursor radionuclides (^{131m}Te, ^{131}Te, and, to a lesser extent, ^{131}Sb). The activity of ^{131}I calculated 12 hours after a nuclear test does not, therefore, represent the "total" activity of ^{131}I that will be found 1 or 2 days later and which is the quantity of interest of this study. In order to take into account the contribution that these precursors eventually will make to the activity of ^{131}I, the activity of ^{131}I at H + 12 is calculated as if all precursors had already decayed into ^{131}I. The activity obtained, called "total" activity of ^{131}I at H + 12, and denoted as A_{12}, is calculated as:

$$A_{12} = \frac{3{,}600 \times 0.027 \times \ln 2 \times N_{12}}{T_4} \qquad (3.1)$$

where:

N_{12} is the total number of atoms present per square meter of ground of ^{131}Sb, ^{131m}Te, ^{131}Te, and ^{131}I,

T_4 is the radioactive half-life of ^{131}I (hours),

3,600 is the number of seconds per hour, and

0.027 nCi per disintegration s^{-1} is a conversion coefficient.

The value of N_{12} is:

$$N_{12} = \frac{A_1 T_1 + A_2 T_2 + A_3 T_3 + A_4 T_4}{0.027 \times 3{,}600 \times \ln 2} \qquad (3.2)$$

where:

T_1, T_2, and T_3 are the radioactive half-lives of ^{131}Sb, ^{131m}Te, and ^{131}Te, respectively, expressed in hours, and

A_1, A_2, A_3, A_4 are the depositions at H + 12 of ^{131}Sb, ^{131m}Te, ^{131}Te, and ^{131}I obtained using the tabulated quotients, published by Hicks (1981a), of the deposition of ^{131}I per unit area of ground at H + 12 and of the exposure rate at H + 12.

If N_{12} in *equation 3.1* is replaced by its value, one obtains:

$$A_{12} = \frac{A_1 T_1 + A_2 T_2 + A_3 T_3 + A_4 T_4}{T_4} \qquad (3.3)$$

The variation with time of the "total" activity of ^{131}I deposited per unit area of ground is only due to the radioactive decay of ^{131}I. Therefore, the "total" activity of ^{131}I deposited per unit area of ground at the time of arrival, TOA in hours, of the radioactive cloud is estimated as:

$$A_{TOA} = A_{12} \times e^{\frac{-\ln 2}{T_4} \times (TOA - 12)} \qquad (3.4)$$

3.3.1.1.1.1. Estimation of deposition densities of ^{131}I in the Town Data Base area

The values of A_{TOA} derived from the Town Data Base are for 173 inhabited places in five counties (Clark, Esmeralda, Lincoln, and Nye in Nevada, and Washington in Utah). As an example: *Table 3.3* presents the estimates of "total" ^{131}I deposition densities at TOA following the Simon test, detonated April 25, 1953. Results for each of the 173 inhabited locations were derived from the Town Data Base. Results for the other 71 tests for which Town Data Base data are available are provided in the Annexes.

It is to be noted that the estimates of ^{131}I deposition densities (per unit area of ground) that are listed in *Table 3.3* are, in most cases, derived from several measurements of exposure rates and that the values selected are the medians of readings taken within 2.5 km of the inhabited location considered. (The median [or median value] of a distribution is such that, if a number of measurements are taken, half would be greater than the median and half would be less than that value).

In this report, the distribution of the estimates of deposition density is assumed to be log-normal. A log-normal distribution is in *Figure 3.6:* it is characterized by its median value and by its geometric standard deviation, GSD, which describes the dispersion of the values around the median. The arithmetic mean of a log-normal distribution is always greater than the median whereas the mode of the distribution is lower than the median. The relative spread between the mode, the median, and the mean increases with the GSD. The log-normal distribution presented in *Figure 3.6* has a GSD of 2. *Figure 3.7* shows,

Table 3.3. Estimates of median ^{131}I depositions per unit area of ground (nCi m^{-2}) at the Town Data Base sites following the test Simon detonated 4/25/1953.

Site code	State	County	Sub-county (Fig. 3.8)	^{131}I depostion density (A_{TOA}, nCi m^{-2}) Median	GSD	Deposition weight, w (Eq. 3.3 and 3.4)
1	NV	LINCOLN	1	9300	1.4	0.035
2	NV	LINCOLN	1	3900	1.4	0.035
3	NV	LINCOLN	1	16000	1.4	0.0035
4	NV	LINCOLN	1	2900	1.4	0.035
5	NV	LINCOLN	1	2500	1.4	0.035
6	NV	LINCOLN	1	2000	1.4	0.035
7	NV	LINCOLN	1	1800	1.4	0.035
8	NV	LINCOLN	1	1100	1.4	0.035
9	NV	LINCOLN	1	900	1.4	0.035
10	NV	LINCOLN	1	820	1.4	0.035
11	NV	LINCOLN	1	770	1.4	0.035
12	NV	LINCOLN	1	610	1.4	0.035
13	NV	LINCOLN	1	600	1.4	0.035
14	NV	LINCOLN	1	810	1.4	0.035
15	NV	LINCOLN	1	810	1.4	0.035
16	NV	LINCOLN	1	400	1.4	0.035
17	NV	LINCOLN	1	380	1.4	0.035
18	NV	LINCOLN	1	770	1.4	0.035
19	NV	LINCOLN	1	240	1.4	0.035
20	NV	LINCOLN	1	0	1.0	0.035
21	NV	LINCOLN	1	0	1.0	0.035
22	NV	LINCOLN	1	0	1.0	0.035
23	NV	LINCOLN	1	240	1.4	0.035
24	NV	LINCOLN	1	0	1.0	0.035
25	NV	LINCOLN	1	0	1.0	0.035
26	NV	LINCOLN	1	0	1.0	0.0035
27	NV	LINCOLN	1	0	1.0	0.035
28	NV	LINCOLN	1	0	1.0	0.0035
29	NV	LINCOLN	1	0	1.0	0.035
30	NV	LINCOLN	1	0	1.0	0.0035
31	NV	LINCOLN	1	0	1.0	0.035
32	NV	LINCOLN	1	0	1.0	0.035
33	NV	LINCOLN	1	0	1.0	0.0035
34	NV	LINCOLN	1	0	1.0	0.0035
35	NV	LINCOLN	1	0	1.0	0.0035
36	NV	LINCOLN	2	280	1.4	0.15
37	NV	LINCOLN	2	0	1.0	0.015
38	NV	LINCOLN	2	55	1.4	0.015
39	NV	LINCOLN	2	110	1.4	0.15
40	NV	LINCOLN	2	0	1.0	0.15
41	NV	LINCOLN	2	0	1.0	0.15
42	NV	LINCOLN	2	0	1.0	0.15
43	NV	LINCOLN	2	0	1.0	0.15
44	NV	LINCOLN	2	0	1.0	0.015
45	NV	LINCOLN	2	0	1.0	0.015
46	NV	LINCOLN	2	0	1.0	0.015

Table 3.3. cont'd

Site code	State	County	Sub-county (Fig. 3.8)	^{131}I depostion density (A_{TOA}, nCi m^{-2}) Median	GSD	Deposition weight, w (Eq. 3.3 and 3.4)
47	NV	LINCOLN	2	0	1.0	0.015
48	NV	NYE	1	0	1.0	0.14
49	NV	NYE	1	0	1.0	0.14
50	NV	NYE	1	0	1.0	0.14
51	NV	NYE	1	0	1.0	0.14
52	NV	NYE	1	0	1.0	0.014
53	NV	NYE	1	0	1.0	0.014
54	NV	NYE	1	0	1.0	0.14
55	NV	NYE	1	0	1.0	0.14
56	NV	NYE	1	0	1.0	0.14
57	NV	NYE	2	0	1.0	0.0046
58	NV	NYE	2	0	1.0	0.0046
59	NV	NYE	2	0	1.0	0.0046
60	NV	NYE	2	0	1.0	0.0046
61	NV	NYE	2	0	1.0	0.046
62	NV	NYE	2	0	1.0	0.0046
63	NV	NYE	2	0	1.0	0.046
64	NV	NYE	2	0	1.0	0.0046
65	NV	NYE	2	0	1.0	0.046
66	NV	NYE	2	0	1.0	0.046
67	NV	NYE	2	0	1.0	0.046
68	NV	NYE	2	0	1.0	0.046
69	NV	NYE	2	0	1.0	0.046
70	NV	NYE	2	0	1.0	0.046
71	NV	NYE	2	0	1.0	0.046
72	NV	NYE	2	0	1.0	0.046
73	NV	NYE	2	0	1.0	0.046
74	NV	NYE	2	0	1.0	0.046
75	NV	NYE	2	0	1.0	0.046
76	NV	NYE	2	0	1.0	0.046
77	NV	NYE	2	0	1.0	0.046
78	NV	NYE	2	0	1.0	0.046
79	NV	NYE	2	0	1.0	0.0046
80	NV	NYE	2	0	1.0	0.046
81	NV	NYE	2	0	1.0	0.0046
82	NV	NYE	2	0	1.0	0.046
83	NV	NYE	2	0	1.0	0.046
84	NV	NYE	2	0	1.0	0.046
85	NV	NYE	2	0	1.0	0.046
86	NV	NYE	3	0	1.0	0.24
87	NV	NYE	3	0	1.0	0.024
88	NV	NYE	3	0	1.0	0.024
89	NV	NYE	3	0	1.0	0.024
90	NV	NYE	3	0	1.0	0.024
91	NV	NYE	3	84	1.4	0.24
92	NV	NYE	3	83	1.4	0.024
93	NV	NYE	3	0	1.0	0.24
94	NV	NYE	3	0	1.0	0.024

Table 3.3. cont'd

Site code	State	County	Sub-county (Fig. 3.8)	^{131}I depostion density (A_{TOA}, nCi m^{-2}) Median	GSD	Deposition weight, w (Eq. 3.3 and 3.4)
95	NV	NYE	3	0	1.0	0.024
96	NV	NYE	3	0	1.0	0.024
97	NV	NYE	3	0	1.0	0.024
98	NV	NYE	3	0	1.0	0.024
99	NV	NYE	3	0	1.0	0.024
100	NV	CLARK	1	0	1.0	0.077
101	NV	CLARK	1	0	1.0	0.077
102	NV	CLARK	1	0	1.0	0.077
103	NV	CLARK	1	0	1.0	0.077
104	NV	CLARK	1	70	1.4	0.077
105	NV	CLARK	1	70	1.4	0.077
106	NV	CLARK	1	0	1.0	0.077
107	NV	CLARK	1	0	1.0	0.077
108	NV	CLARK	1	1200	1.6	0.077
109	NV	CLARK	1	150000	1.4	0.077
110	NV	CLARK	1	80000	1.4	0.077
111	NV	CLARK	1	26000	1.6	0.077
112	NV	CLARK	1	15000	1.4	0.077
113	NV	CLARK	2	0	1.0	0.010
114	NV	CLARK	2	0	1.0	0.10
115	NV	CLARK	2	0	1.0	0.010
116	NV	CLARK	2	0	1.0	0.10
117	NV	CLARK	2	0	1.0	0.10
118	NV	CLARK	2	0	1.0	0.10
119	NV	CLARK	2	0	1.0	0.10
120	NV	CLARK	2	0	1.0	0.10
121	NV	CLARK	2	0	1.0	0.010
122	NV	CLARK	2	0	1.0	0.10
123	NV	CLARK	2	0	1.0	0.010
124	NV	CLARK	2	0	1.0	0.10
125	NV	CLARK	2	0	1.0	0.010
126	NV	CLARK	2	0	1.0	0.010
127	NV	CLARK	2	0	1.0	0.10
128	NV	CLARK	2	0	1.0	0.010
129	NV	CLARK	2	0	1.0	0.010
130	NV	CLARK	3	0	1.0	0.33
131	NV	CLARK	3	0	1.0	0.33
132	NV	CLARK	3	0	1.0	0.33
133	NV	ESMERALDA	1	0	1.0	0.71
134	NV	ESMERALDA	1	0	1.0	0.071
135	NV	ESMERALDA	1	0	1.0	0.071
136	NV	ESMERALDA	1	0	1.0	0.071
137	NV	ESMERALDA	1	0	1.0	0.071
138	NV	ESMERALDA	2	0	1.0	0.25
139	NV	ESMERALDA	2	84	1.0	0.25
140	NV	ESMERALDA	2	83	1.0	0.25
141	NV	ESMERALDA	2	0	1.0	0.25

Table 3.3. cont'd

Site code	State	County	Sub-county (Fig. 3.8)	^{131}I depostion density (A_{TOA},nCi m^{-2}) Median	GSD	Deposition weight, w (Eq. 3.3 and 3.4)
142	UT	WASHINGTON	1	810	1.4	0.24
143	UT	WASHINGTON	1	810	1.4	0.24
144	UT	WASHINGTON	1	810	1.4	0.24
145	UT	WASHINGTON	1	0	1.0	0.24
146	UT	WASHINGTON	1	810	1.4	0.024
147	UT	WASHINGTON	2	1100	1.4	0.018
148	UT	WASHINGTON	2	0	1.0	0.18
149	UT	WASHINGTON	2	1100	1.4	0.018
150	UT	WASHINGTON	2	720	1.4	0.18
151	UT	WASHINGTON	2	810	1.4	0.18
152	UT	WASHINGTON	2	810	1.4	0.18
153	UT	WASHINGTON	2	810	1.4	0.18
154	UT	WASHINGTON	2	810	1.4	0.018
155	UT	WASHINGTON	2	810	1.4	0.018
156	UT	WASHINGTON	2	810	1.4	0.018
157	UT	WASHINGTON	2	810	1.4	0.018
158	UT	WASHINGTON	3	0	1.0	0.062
159	UT	WASHINGTON	3	810	1.4	0.062
160	UT	WASHINGTON	3	810	1.4	0.062
161	UT	WASHINGTON	3	0	1.0	0.062
162	UT	WASHINGTON	3	0	1.0	0.062
163	UT	WASHINGTON	3	0	1.0	0.062
164	UT	WASHINGTON	3	0	1.0	0.062
165	UT	WASHINGTON	3	0	1.0	0.062
166	UT	WASHINGTON	3	0	1.0	0.062
167	UT	WASHINGTON	3	0	1.0	0.062
168	UT	WASHINGTON	3	0	1.0	0.062
169	UT	WASHINGTON	3	0	1.0	0.062
170	UT	WASHINGTON	3	0	1.0	0.062
171	UT	WASHINGTON	3	0	1.0	0.062
172	UT	WASHINGTON	3	0	1.0	0.062
173	UT	WASHINGTON	3	0	1.0	0.062

for a constant median of 1, how the mean of a log-normal distribution increases with the GSD. Also shown in *Figure 3.7* are curves labelled "Median x 1 GSD" and "Median / 1 GSD"; the probability of a value lying between the median and either "Median x 1 GSD" or "Median / 1 GSD" is 0.34.

The GSD values associated with the distributions of the deposition of ^{131}I per unit area of ground at each Town Data Base site for the test Simon are taken from Thompson (1990) and listed in *Table 3.3*.

Many of the ^{131}I depositions per unit area of ground presented in *Table 3.3* are listed as zeros. In fact, those values may be true zeros, where there was no deposition of radioactive materials from the test Simon, or they may be lower than a threshold value of the deposition, inferred from the detection limit of the exposure-rate meter, which was taken to be equal to three times background at the time of measurement (0.06 mR h^{-1} for most tests, 0.15 mR h^{-1} for the test Harry). Since the exposure rate from fallout deposition varies sharply during the first hour after detonation, the threshold value of the deposition therefore depends on the time elapsed after detonation at the point of measurement, and this elapsed time is likely to have varied substantially from location to location and from test to test. The threshold value of the deposition also depends on the conversion coefficient from the exposure rate at H+12 to the "total" ^{131}I deposition, which also varied from test to test. The smallest non-zero ^{131}I depositions per unit area of ground

Figure 3.6. Probability density function of a positive random variable log-normally distributed with a median of 1 and a geometric standard deviation (GSD) of 2.

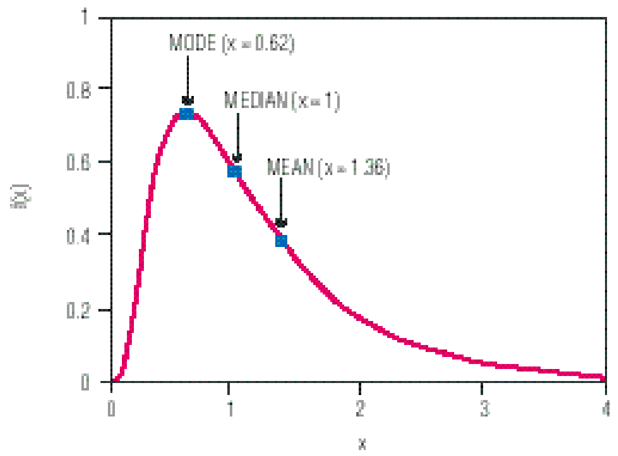
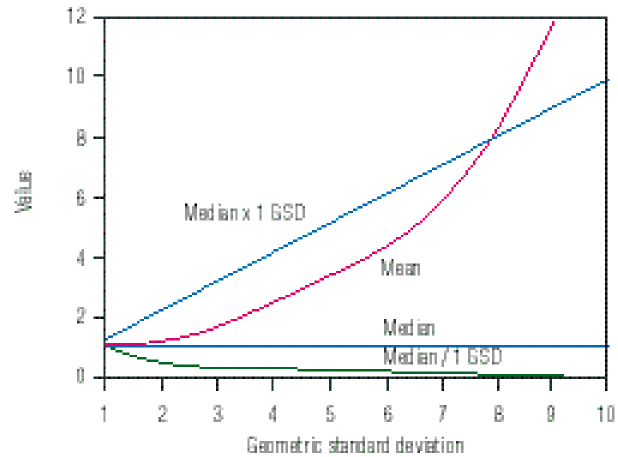


Figure 3.7. Variation of the mean of a log-normal distribution with a median of 1 as a function of the geometric standard deviation (GSD).



that were derived from the Town Data Base varied from test to test: for example, the smallest non-zero ^{131}I depositions obtained for the test Schooner detonated on 8 December 1968 was estimated as 1.8 nCi m^{-2}, while the smallest non-zero ^{131}I deposition obtained for the test Harry detonated on 19 May 1953 was estimated as 360 nCi m^{-2}. For the purpose of this report, it was assumed that there was no ^{131}I deposition in the locations where the exposure rates were below the detection limit.

Because of the substantial variations, within the same county, in the deposition of ^{131}I resulting from some of the tests (see, for example, the range of ^{131}I deposition densities in Lincoln and in Clark counties in *Table 3.3*), it would not be appropriate to select a single deposition value as representative of the ^{131}I deposition per unit area of ground in entire counties of the area covered by the Town Data Base. For that reason, each of those five counties was subdivided into two to three areas, hereafter called "sub-counties", and estimates of ^{131}I deposition were made for each sub-county. The total number of sub-counties in the area covered by the Town Data Base is 13. The variability of ^{131}I deposition estimates in each sub-county was not as large as in entire counties, but still substantial for some tests (see, for example, the range of ^{131}I depositions in sub-county LINCOLN 1 in *Table 3.3*). In determining the estimates of ^{131}I depositions in sub-counties, the fact that the resulting thyroid doses depends to a large extent on the ^{131}I concentrations in milk, and therefore on the ^{131}I contamination of pasture, was taken into account. As explained below, this was done by assigning greater weights to the deposition densities measured at locations near dairy farms than to those measured elsewhere.

The characteristics of each sub-county (location, area, population) are provided in **Appendix 2.** Within these sub-counties, the exposure rates determined in other areas were given a much higher weight than the exposure rates measured near dairy farms or farms with family cows. The location of dairy farms and of farms with family cows was taken from a survey conducted by the Public Health Service in the early 1960s (PHS 1964). The data on locations of farms and numbers of cows are shown in *Figure 3.8.* Deposition estimates for locations in the vicinity of dairy farms or farms with family cows were given a weight, w_{high}, 10 times greater than the weights, w_{low}, given for locations distant from dairy farms or from farms with family cows. In a sub-county, sc, with N_{high} Town Data Base sites with high deposition weights and N_{low} sites with low deposition weights, the relationship:

$$N_{low} \times w_{low} + N_{high} \times w_{high} = 1 \quad (3.1)$$

holds because the sum of all weighting factors must be one. Since $w_{high} = 10 \times w_{low}$, *equation 3.1* can be written as:

$$w_{low} (N_{low} + 10 \times N_{high}) = 1 \quad (3.2)$$

and the values of the weights can be computed from the following equations:

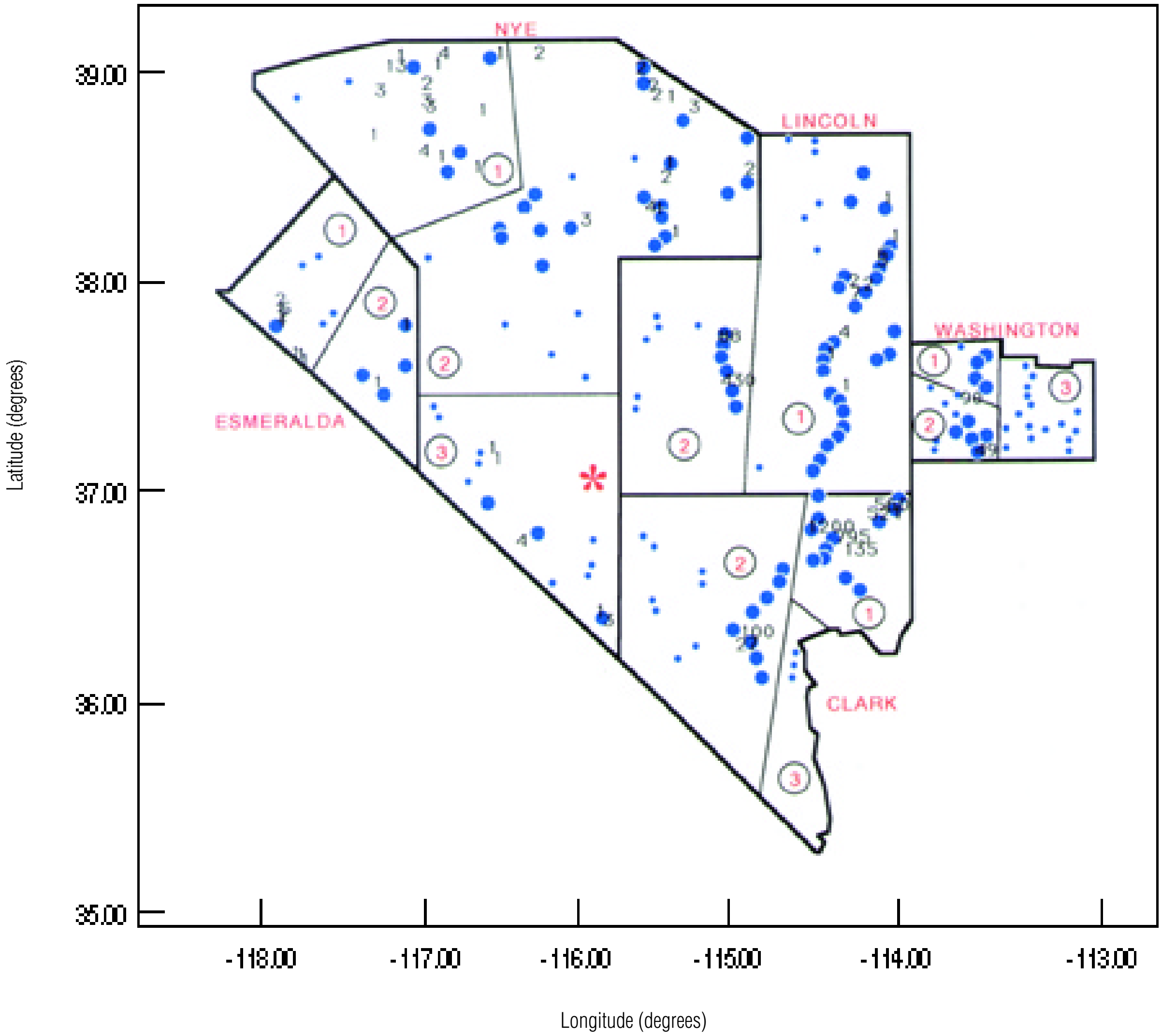
$$w_{low} = 1 / (N_{low} + 10 \times N_{high}) \quad (3.3)$$

and:

$$w_{high} = 10 / (N_{low} + 10 \times N_{high}) \quad (3.4)$$

The arithmetic means of the deposition weights for all Town Data Base sites are presented in *Table 3.3*. For the purposes of the uncertainty analysis, it is assumed that the deposition weights are log-normally distributed with a GSD of 1.5.

Figure 3.8. Location of the sites where exposure rates were measured in the Town Data Base area (small circles and large circles) and location of the dairy farms and farms with family cows (numbers indicating the number of cows in those farms). In a given sub-county, the Town Data Base sites that are represented with large circles, located near farms with cows, were given a weight 10 times greater than the Town Data Base sites represented with small circles in the estimation of the median ^{131}I deposition per unit area of ground.



The ^{131}I deposition per unit area of ground, averaged over the sub-county, $A_{TOA}(sc)$, is derived from:

$$A_{TOA}(sc) = \sum_{n=1}^{N} A_{TOA}(n) \times w(n) \qquad (3.5)$$

where:

- n refers to a Town Data Base site in sub-county, sc,
- N is the total number of sites in the sub-county, and
- w(n) is the deposition weight for Town Data Base site, n. The numerical value of w(n) is either the value of w_{low} or that of w_{high} for the sub-county considered *(Table 3.3).*

Since both $A_{TOA}(n)$ and w(n) are assumed to be log-normally distributed, the median value of $A_{TOA}(sc)$ can either be derived numerically from *equation 3.5,* by means of a Monte Carlo procedure, or analytically, using a mathematical procedure with a number of underlying assumptions. Because of the subjective and somewhat arbitrary manner in which the uncertainties on both $A_{TOA}(n)$ and w(n) have been assigned, a relatively simple analytical procedure was deemed to be sufficient for the purposes of the uncertainty analysis in this report. The basis for the simpler procedure and the associated assumptions are described below.

The analytical procedure, called the multiplicative log-normal method, is based on the following theorem (Aitchison and Brown 1969; Crow and Shimizu 1988): [2]

If:

- $X_1, X_2, ..., X_N$ are multivariate log-normal random variables,
- μ_n and σ_n^2 are the mean and variance of $Y_n = \ln X_n$,
- $r_{nn'}$ is the correlation between Y_n and $Y_{n'}$, with $n \neq n'$,

then:

- the product $X = X_1 \times X_2 \times ...X_N$ is log-normally distributed, and
- the function Y = ln X is normally distributed with:
- a mean: $\mu = \mu_1 + \mu_2 + ... \mu_N$ (3.6)

and

- a variance:

$$\sigma^2 = \sum_{n=1}^{N} \sigma^2_n + \sum_{n=1}^{N} \sum_{n'=1}^{N} r_{nn'}\, \sigma_n \sigma_{n'} \qquad (3.7)$$

If there is no correlation between any of the variables, the variance of Y is simply:

$$\sigma^2 = \sigma_1^2 + \sigma_2^2 + ...\sigma_N^2 \qquad (3.8)$$

It follows from the properties of log-normal distributions that:

- the median of X, denoted as <X>, is equal to: e^{μ}
- the geometric standard deviation of X, denoted as GSD(X), is equal to: e^{σ}
- the arithmetic mean of X, denoted as m(X), is:

$$m(X) = e^{\mu + \sigma^2/2} = \langle X \rangle \times e^{\sigma^2/2} \qquad (3.9)$$

- the variance of X, denoted as $s^2(X)$, is:

$$s^2(X) = m^2(X) \times (e^{\sigma^2} - 1) \qquad (3.10)$$

In the case of summation of variables, as in *equation 3.5,* it is also assumed that the distribution of a sum of log-normally distributed variables is log-normal. This is strictly not true (Crow and Shimizu 1988) but it has been shown that, in the case of independent log-normal variables, the sum of those variables can be approximated reasonably well by a log-normal distribution (Barakat 1976; Fenton 1960; Mitchell 1968). Therefore, if:

- $X_1, X_2, ..., X_N$ are multivariate log-normal random variables,
- m_n and s_n^2 are the mean and variance of X_n,
- $r_{nn'}$ is the correlation between X_n and $X_{n'}$, with $n \neq n'$,

then:

- $X = X_1 + X_2 + ...X_N$ is assumed to be log-normally distributed, with:
- a mean: $m(X) = m_1 + m_2 + ...m_N$ (3.11)

and

- a variance:

$$s^2(X) = \sum_{n=1}^{N} s^2_n + \sum_{n=1}^{N} \sum_{n'=1}^{N} r_{nn'}\, s_n s_{n'} \qquad (3.12)$$

If there is no correlation between any of the variables, the variance of X is simply:

$$s^2(X) = s_1^2 + s_2^2 + ...s_N^2 \qquad (3.13)$$

It follows from the properties of log-normal distributions that:

- the mean of Y = ln(X), denoted as μ, is:

$$\mu = \ln \left[\frac{m(X)}{\left(1 + \frac{s^2(X)}{m^2(X)}\right)^{0.5}} \right] \qquad (3.14)$$

[2] The assistance of Lynn Anspaugh (University of Utah), Richard Gilbert (Pacific Northwest National Laboratory), Owen Hoffman (SENES Oak Ridge Inc.), and Paul Voillequé (MJP Risk Assessment Inc.) in the development and the implementation of the multiplicative log-normal method in this report is gratefully acknowledged.

- the standard deviation of Y, denoted as σ, is:

$$\sigma = \left[\ln \left(1 + \frac{s_2(X)}{m_2(X)} \right) \right]^{0.5} \qquad (3.15)$$

- the median of X, denoted as <X>, is equal to e^{μ}
- the geometric standard deviation of X, denoted as GSD(X), is equal to e^{σ}.

In summary, two critical assumptions are involved in using the multiplicative log-normal method:

(1) the random variables must be assumed to be log-normally distributed, and

(2) the distribution of a sum of log-normally distributed random variables must be assumed to be log-normal.

The symbols used throughout this report for the parameters of a log-normally distributed variable, X, and of its logarithm, Y, are:

- the median of X is symbolized by <X>
- the geometric standard deviation of X is symbolized by GSD(X)
- the arithmetic mean of X is symbolized by m(X)
- the variance of X is symbolized by s^2(X)
- the median and arithmetic mean of Y = ln X is symbolized by μ(X) or the shortened version, μ
- the standard deviation of Y = ln X is symbolized by σ(X) or the shortened version, σ

It is useful to note that *equations 3.9* and *3.10* can be written as:

$$m(X) = \langle X \rangle \times e^{0.5\,\sigma^2(X)} \qquad (3.16)$$

$$s^2(X) = m^2(X) \times (e^{\sigma^2(X)} - 1) \qquad (3.17)$$

The values for μ (X),<X>, σ (X), and GSD (X) are computed using the following relationships:

$$\mu(X) = \ln \left[\frac{m(X)}{\left(1 + \frac{s^2(X)}{m^2(X)}\right)^{0.5}} \right] \qquad (3.18)$$

$$\langle X \rangle = e^{\mu(X)} = \frac{m(X)}{\left(1 + \frac{s^2(X)}{m^2(X)}\right)^{0.5}} \qquad (3.19)$$

$$\sigma(X) = \left[\ln \left(1 + \frac{s^2(X)}{m^2(X)} \right) \right]^{0.5} \qquad (3.20)$$

$$GSD(X) = e^{\sigma(X)} = e^{\left[\ln \left(1 + \frac{s^2(X)}{m^2(X)} \right) \right]^{0.5}} \qquad (3.21)$$

The multiplicative log-normal method has been applied to the variables in *equation 3.5* in order to derive the medians and geometric standard deviations of A_{TOA}(sc). It is assumed that there is no correlation between the variables in *equation 3.5.*

In the first step, the product of A_{TOA}(n) and w(n), denoted as WA_{TOA}(n), called the weighted ^{131}I deposition density for Town Data Base site n, is computed:

$$WA_{TOA}(n) = A_{TOA}(n) \times w(n) \qquad (3.22)$$

The median of WA_{TOA}(n) is then calculated using:

$$\langle WA_{TOA}(n) \rangle = \langle A_{TOA}(n) \rangle \times \langle w(n) \rangle \qquad (3.23)$$

The values listed in *Table 3.3* are the median of A_{TOA}(n) and the mean of w(n). The median of w(n), as used in *equation 3.23,* is derived from the mean using *equation 3.16:*

$$\langle w(n) \rangle = m(w(n)) \times e^{-0.5\,\sigma^2(X)} \qquad (3.24)$$

The geometric standard deviation of WA_{TOA}(n) is calculated using:

$$GSD(WA_{TOA}(n)) = e^{\sigma(WA_{TOA}(n))} \qquad (3.25)$$

in which the value of σ ($WA_{TOA}(n)$) is derived from the variance, computed as in *equation 3.8:*

$$\sigma^2 (WA_{TOA}(n)) = \sigma^2 (A_{TOA}(n)) + \sigma^2 (w(n)) \qquad (3.26)$$

In *equation 3.26,* the value of $\sigma^2(A_{TOA}(n))$ is obtained from the value of $GSD(A_{TOA}(n))$ listed in *Table 3.3,* using:

$$\sigma^2 (A_{TOA}(n)) = [\ln (GSD (A_{TOA}(n))]^2 \qquad (3.27)$$

while the value of $\sigma^2(w(n))$ is obtained from the assumption that GSD(w(n)) is equal to 1.5 :

$$\sigma^2 (w(n)) = [\ln (GSD (w (n)))] = [\ln (1.5)]^2 \qquad (3.28)$$

In a second step, the median and geometric standard deviation of the sum of the weighted ^{131}I deposition densities from each of the N Town Data Base sites in the sub-county considered are determined. From *equations 3.5 and 3.22:*

$$A_{TOA} (sc) = \sum_{n=1}^{N} WA_{TOA} (n) \qquad (3.29)$$

The mean of $A_{TOA}(sc)$ is obtained using:

$$m (A_{TOA} (sc)) = \sum_{n=1}^{N} m(WA_{TOA} (n)) \qquad (3.30)$$

where the values of $m(WA_{TOA}(n))$ are calculated from the relationship given in *equation 3.16.*

The variance of $A_{TOA}(sc)$ is obtained using:

$$s^2 (A_{TOA} (sc)) = \sum_{n=1}^{N} s^2 (WA_{TOA} (n)) \qquad (3.31)$$

where the values of $s^2(WA_{TOA}(n))$ are calculated from the relationship given in *equation 3.17.*

The median of $A_{TOA}(sc)$ is obtained from:

$$< A_{TOA} (sc)> = e^{\mu (A_{TOA} (sc))} \qquad (3.32)$$

where the value of μ ($WA_{TOA}(sc)$) is calculated from the relationship given in *equation 3.18.*

The geometric standard deviation of $A_{TOA}(sc)$ is obtained from:

$$GSD (A_{TOA} (sc)) = e^{\sigma (A_{TOA} (sc))} \qquad (3.33)$$

where the value of σ ($WA_{TOA}(sc)$) is calculated from the relationship given in *equation 3.20.*

The median of the A_{TOA} values obtained in each sub-county in this way was taken to represent the median deposition density of ^{131}I on the ground in that sub-county. The complete results (estimates of $<A_{TOA}(sc)>$ and of $GSD(A_{TOA}(sc))$ for each sub-county in the Town Data Base area and for each test are presented in the **Annexes.**

3.3.1.1.1.2. Estimation of deposition densities of ^{131}I in the County Data Base area

The County Data Base provides estimates for the time of arrival of the radioactive cloud and for the exposure rate normalized at 12 hours after detonation (H + 12) for 55 nuclear tests and for areas in 129 counties in Arizona, California, Colorado, Idaho, Nevada, New Mexico, Oregon, Utah, and Wyoming (Beck and Anspaugh 1991). Values of $<A_{TOA}>$ were derived from the County Data Base and from the tabulated quotients, published by Hicks (1981a) for all the tests considered, of the deposition of ^{131}I per unit area of ground at H + 12 and of the exposure rate at H + 12. The calculational procedure involves *equations 3.1* to *3.4*. The variable A_{TOA} is assumed to be log-normally distributed. The largest uncertainty in the determination of A_{TOA} is believed to be due to the estimation of the median exposure rate at H + 12 in the area considered. The geometric standard deviation attached to the distribution of A_{TOA} is assumed to be equal to the geometric standard deviation assigned by Beck and Anspaugh (1991) to the exposure rate at H + 12.

The County Data Base provides data for 120 undivided counties and for nine counties (located in Arizona, California, Nevada, and Utah) subdivided into 22 county segments because of the substantial variations in the exposure rates at H + 12 resulting from some of the tests. In this report, two of those county segments (the division of Kingman in Mohave county in Arizona and the county segment including Bishop, Independence and Lone Pine divisions in Inyo county in California) were further subdivided into two parts in order to account for large differences in the origin of fresh cows' milk supplied in those areas. The total number of geographic divisions (counties or sub-counties) in the area covered by the County Data Base is 144 (see **Appendix 2**).

The median of the ATOA values obtained in each county or sub-county was taken to represent the median deposition density of ^{131}I on the ground in that county or sub-county. As an example, *Table 3.4* presents the results obtained for the shot Simon, detonated April 25, 1953. Complete results for the 55 tests for which County Data Base information is available are presented in the Annexes.

Here again, as was the case for the depositions derived from the Town Data Base, a large number of the ^{131}I depositions per unit area of ground presented in *Table 3.4* are listed as zeros. In fact, those values may be true zeros, where there was no deposition of radioactive materials from the test Simon, or they may be lower than a threshold value of the deposition, as inferred from the detection limit of the instruments or methods that served to determine the exposure rate at H+12 in each par-

Table 3.4. Estimates of median ^{131}I depositions per unit area of ground (nCi m^{-2}) at the County Data Base area following shot Simon detonated 4/25/1953.

Test name	Date (y/mo/d)	State	County	^{131}I deposition density (A_{TOA}, nCi m^{-2}) Median	GSD
SIMON	530425	AZ	APACHE	4800	1.7
SIMON	530425	AZ	COCHISE	0	1.0
SIMON	530425	AZ	GILA	0	1.0
SIMON	530425	AZ	GRAHAM	0	1.0
SIMON	530425	AZ	GREENLEE	0	1.0
SIMON	530425	AZ	MARICOPA	0	1.0
SIMON	530425	AZ	NAVAJO	3200	1.7
SIMON	530425	AZ	PIMA	0	1.0
SIMON	530425	AZ	PINAL	0	1.0
SIMON	530425	AZ	SANTA CRUZ	0	1.0
SIMON	530425	AZ	YAVAPAI	0	1.0
SIMON	530425	AZ	YUMA	0	1.0
SIMON	530425	AZ	MOHAVE1*	1400	1.7
SIMON	530425	AZ	MOHAVE2*	1200	1.7
SIMON	530425	AZ	MOHAVE3*	1200	1.9
SIMON	530425	AZ	MOHAVE4*	1200	1.9
SIMON	530425	AZ	COCONINO1*	1400	1.7
SIMON	530425	AZ	COCONINO2*	8100	1.7
SIMON	530425	AZ	COCONINO3*	1600	1.5
SIMON	530425	CA	LOS ANGELES	8	1.7
SIMON	530425	CA	MONO	8	1.7
SIMON	530425	CA	SAN BERNADINO	8	1.7
SIMON	530425	CA	INYO1*	8	1.7
SIMON	530425	CA	INYO2*	8	1.7
SIMON	530425	CA	INYO3*	200	1.9
SIMON	530425	CO	DELTA	740	1.7
SIMON	530425	CO	DOLORES	1500	1.7
SIMON	530425	CO	GARFIELD	500	1.7
SIMON	530425	CO	LA PLATA	1100	1.7
SIMON	530425	CO	MESA	960	1.5
SIMON	530425	CO	MOFFAT	150	1.7
SIMON	530425	CO	MONTEZUMA	1100	1.7
SIMON	530425	CO	MONTROSE	740	1.7
SIMON	530425	CO	OURAY	740	1.7
SIMON	530425	CO	RIO BLANCO	510	1.7
SIMON	530425	CO	SAN JUAN	740	1.7
SIMON	530425	CO	SAN MIGUEL	740	1.7
SIMON	530425	ID	ADA	22	1.7
SIMON	530425	ID	BANNOCK	22	1.7
SIMON	530425	ID	BEAR LAKE	31	1.7
SIMON	530425	ID	BINGHAM	22	1.7
SIMON	530425	ID	BONNEVILLE	15	1.7
SIMON	530425	ID	CANYON	15	1.7
SIMON	530425	ID	CARIBOU	23	1.7
SIMON	530425	ID	CASSIA	30	1.7

* Sub-county identified by the number at the end of the county name.

Table 3.4. cont'd

Test name	Date (y/mo/d)	State	County	^{131}I deposition density (A_{TOA}, nCi m^{-2})	
				Median	GSD
SIMON	530425	ID	ELMORE	22	1.7
SIMON	530425	ID	FRANKLIN	30	1.7
SIMON	530425	ID	GOODING	22	1.7
SIMON	530425	ID	JEROME	22	1.7
SIMON	530425	ID	LINCOLN	22	1.7
SIMON	530425	ID	MINIDOKA	22	1.7
SIMON	530425	ID	ONEIDA	30	1.7
SIMON	530425	ID	OWYHEE	15	1.7
SIMON	530425	ID	POWER	30	1.7
SIMON	530425	ID	TWIN FALLS	22	1.7
SIMON	530425	NV	CHURCHILL	13	1.7
SIMON	530425	NV	DOUGLAS	6	1.7
SIMON	530425	NV	ELKO	13	1.7
SIMON	530425	NV	EUREKA	14	1.7
SIMON	530425	NV	HUMBOLDT	13	1.7
SIMON	530425	NV	LYON	6	1.7
SIMON	530425	NV	MINERAL	6	1.7
SIMON	530425	NV	PERSHING	13	1.7
SIMON	530425	NV	STOREY	6	1.7
SIMON	530425	NV	WASHOE	13	1.7
SIMON	530425	NV	WHITE PINE1*	41	1.7
SIMON	530425	NV	WHITE PINE2*	41	1.7
SIMON	530425	NV	WHITE PINE3*	41	1.7
SIMON	530425	NV	CARSON CITY	13	1.7
SIMON	530425	NV	LANDER1*	14	1.7
SIMON	530425	NV	LANDER2*	14	1.7
SIMON	530425	NM	BERNALILLO	1400	1.5
SIMON	530425	NM	CATRON	380	1.7
SIMON	530425	NM	CHAVES	3700	1.5
SIMON	530425	NM	COLFAX	270	1.5
SIMON	530425	NM	CURRY	2200	1.7
SIMON	530425	NM	DE BACA	2200	1.7
SIMON	530425	NM	DONA ANA	0	1.0
SIMON	530425	NM	EDDY	740	1.7
SIMON	530425	NM	GRANT	0	1.0
SIMON	530425	NM	GUADALUPE	2200	1.7
SIMON	530425	NM	HARDING	740	1.7
SIMON	530425	NM	HIDALGO	0	1.0
SIMON	530425	NM	LEA	740	1.7
SIMON	530425	NM	LINCOLN	3000	1.7
SIMON	530425	NM	LOS ALAMOS	1500	1.7
SIMON	530425	NM	LUNA	0	1.0
SIMON	530425	NM	MCKINLEY	3900	1.7
SIMON	530425	NM	MORA	740	1.7
SIMON	530425	NM	OTERO	0	1.0
SIMON	530425	NM	QUAY	1800	1.7

Table 3.4. cont'd

Test name	Date (y/mo/d)	State	County	^{131}I deposition density (A_{TOA}, nCi m^{-2})	
				Median	GSD
SIMON	530425	NM	RIO ARRIBA	1500	1.7
SIMON	530425	NM	ROOSEVELT	2200	1.7
SIMON	530425	NM	SANDOVAL	3000	1.7
SIMON	530425	NM	SAN JUAN	1500	1.7
SIMON	530425	NM	SAN MIGUEL	1500	1.7
SIMON	530425	NM	SANTA FE	3000	1.7
SIMON	530425	NM	SIERRA	0	1.0
SIMON	530425	NM	SOCORRO	370	1.7
SIMON	530425	NM	TAOS	740	1.7
SIMON	530425	NM	TORRANCE	2200	1.7
SIMON	530425	NM	UNION	440	1.7
SIMON	530425	NM	VALENCIA	2300	1.7
SIMON	530425	OR	HARNEY	13	1.7
SIMON	530425	OR	MALHEUR	13	1.7
SIMON	530425	UT	BEAVER	880	1.5
SIMON	530425	UT	CACHE	30	1.7
SIMON	530425	UT	CARBON	150	1.7
SIMON	530425	UT	DAGGETT	74	1.7
SIMON	530425	UT	DAVIS	74	1.7
SIMON	530425	UT	DUCHESNE	150	1.7
SIMON	530425	UT	EMERY	380	1.7
SIMON	530425	UT	GARFIELD	390	1.7
SIMON	530425	UT	GRAND	590	1.7
SIMON	530425	UT	JUAB	150	1.7
SIMON	530425	UT	MILLARD	470	1.7
SIMON	530425	UT	MORGAN	74	1.7
SIMON	530425	UT	PIUTE	390	1.7
SIMON	530425	UT	RICH	52	1.7
SIMON	530425	UT	SALT LAKE	100	1.7
SIMON	530425	UT	SAN JUAN	1100	1.7
SIMON	530425	UT	SANPETE	220	1.7
SIMON	530425	UT	SEVIER	390	1.7
SIMON	530425	UT	SUMMIT	74	1.7
SIMON	530425	UT	UINTAH	150	1.7
SIMON	530425	UT	UTAH	110	1.7
SIMON	530425	UT	WASATCH	110	1.7
SIMON	530425	UT	WAYNE	380	1.7
SIMON	530425	UT	WEBER	52	1.7
SIMON	530425	UT	IRON1*	810	1.5
SIMON	530425	UT	IRON2*	400	1.7
SIMON	530425	UT	IRON3*	400	1.7
SIMON	530425	UT	KANE1*	800	1.7
SIMON	530425	UT	KANE2*	800	1.7
SIMON	530425	UT	TOOELE1*	22	1.7
SIMON	530425	UT	TOOELE2*	110	1.7

Table 3.4. cont'd

Test name	Date (y/mo/d)	State	County	^{131}I deposition density (A_{TOA}, nCi m^{-2})	
				Median	GSD
SIMON	530425	UT	BOX ELDER1*	22	1.7
SIMON	530425	UT	BOX ELDER2*	37	1.7
SIMON	530425	WY	CARBON	150	1.7
SIMON	530425	WY	FREMONT	150	1.7
SIMON	530425	WY	LINCOLN	37	1.7
SIMON	530425	WY	SULETTE	37	1.7
SIMON	530425	WY	SWEETWATER	75	1.5
SIMON	530425	WY	UINTA	75	1.7

ticular county or sub-county. This detection limit is likely to have varied from location to location and from test to test. The threshold value of the deposition also depends on the conversion coefficient from the exposure rate at H+12 to the "total" ^{131}I deposition, which also varied from test to test. The smallest non-zero ^{131}I deposition per unit area of ground that was derived from the County Data Base varied from test to test: for example, the smallest non-zero ^{131}I deposition obtained for the test Schooner detonated on 8 December 1968 was estimated to be 0.3 nCi m^{-2}, while the smallest non-zero ^{131}I deposition obtained for the test Tesla detonated on 1 March 1955 was estimated to be 28 nCi m^{-2}. For the purpose of this report, it was assumed that there was no ^{131}I deposition in the counties and sub-counties for which exposure rates at H+12 were not reported in the County Data Base.

3.3.1.1.2. National monitoring of deposition measurements
The gummed-film network data, when available, are used to derive ^{131}I deposition densities throughout the United States for all the nuclear tests that resulted in significant fallout. The original fallout data have been re-evaluated by Beck (1984), and coworkers, Beck et al. (1990).

Beck (1984) reviewed the methods of analysis and interpretation of gummed-film data reported by Harley et al. (1960) and modified the original analysis of the fallout data in order to derive deposition estimates for ^{137}Cs. The corrections applied to the original fallout data to derive the ^{131}I deposition estimates are based on Beck's (1984) work with ^{137}Cs and are summarized as follows:

1. The collection efficiency of the gummed film was reassessed. Gummed film is an inefficient collector of fallout relative to that actually deposited on the earth's surface. The efficiency of collection was probably affected, among other factors, by humidity, dust loading, washoff by rain, wind, and particle size of the fallout (Rosinski 1957, Rosinski et al. 1959). Estimates of collection efficiency for dry deposition, which were originally thought to be about 60%, are now believed to have been only about 20% for the measured beta activity. This is based on comparisons of estimates of ^{137}Cs deposition derived from exposure rates measured at gummed-film sites near the Nevada Test Site (where dry processes were the predominant mode of deposition) with estimates of ^{137}Cs deposition made from the gummed film. There is also good agreement between the ^{137}Cs estimates based on the corrected efficiency of collection of gummed film and recent ^{137}Cs activity results from soil samples taken at different locations in the western states (see Beck and Krey 1982). The collection efficiency for wet deposition has been estimated from three sets of experimental data: (a) comparison of measurements of the fallout in precipitation carried out by the Public Health Service in the 1950s and of the corresponding gummed-film results obtained at the same time and location; (b) measurements of naturally-occurring radioactive particles deposited by precipitation in 1986 on sticky material that exhibits properties similar to those of the gummed film used in the 1950s; (c) measurements of ^{131}I originating from the Chernobyl accident and deposited by precipitation on the same sticky material. Although the results from each of the 3 sets of data contain large variabilities, the combination of the results clearly indicates that the collection efficiency of gummed film depends on the daily precipitation amount: about 30% for light rain and less than 10% for heavy showers (Beck et al. 1990). These values also are in agreement with measurements carried out under controlled conditions (Hoffman et al. 1989). *Table 3.5* presents the estimated gummed-film collection efficiencies for each precipitation index value used in this report.

Table 3.5. Variation of the estimated collection efficiency of fallout by gummed film as a function of daily rainfall. (Beck et al. 1990).

Precipitation index	Daily rainfall (mm)	Estimated collection efficiency of fallout by gummed film, %
1	0	20
2	< 0.25	30
3	0.25-0.76	30
4	0.76-2.5	25
5	2.5-7.6	15
6	7.6-25	10
7	25-76	6.7
8	76-127	6.7
9	> 127	6.7

2. The efficiencies of radioactivity counting equipment varied from test series to test series according to the counting procedure and the radioactivity standard used. The data are corrected for the appropriate counter efficiency to convert count rate to the proper value of beta activity.

3. As a result of sample preparation at temperatures ranging from 500 to 550 degrees Celsius, it has been assumed that the total beta activity measured on the original samples did not include any of the volatile radionuclides, such as ^{131}I. Although originally no corrections were made for these losses, the total beta activity results have since been corrected for the loss of the volatile radionuclides using the data reported by Hicks (1981a).

4. The total beta activity at the time of sampling was inferred from the total beta activity at the time of counting. To this end, use was made of the calculated decay rates of the total beta activity and of each of the significant radionuclides, including ^{131}I, that were published by Hicks (1981a) for a number of fixed times after detonation, and for each test that resulted in off-site fallout. These results show that the original $t^{-1.2}$ decay rate that previously was used occasionally resulted in occasional substantial errors in reported beta activities. The proper decay rate for each test was used in the evaluation.

5. The ratio of the ^{131}I activity to the total beta activity at the time of sampling is calculated from Hicks' tables (1981a). The product of this ratio and of the total beta activity permit the calculation of the ^{131}I deposition per unit area of ground; the results are expressed in nanocuries per square meter (nCi m^{-2}) at the time of deposition.

6. When data other than gummed-film data were used, further calculations were necessary to estimate the ^{131}I deposition at that location. Details on how these calculations are performed can be found in Beck (1984). For example, when high-volume air sampler data were used, it was assumed that the quotient of the deposition rate and of the air concentration at ground-level (a quantity usually called deposition velocity) was equal to 5 cm s^{-1} (Beck 1984).

Beck (1984) estimated a measurement uncertainty of 40% to all daily estimates of ^{137}Cs deposition from gummed-film data and a measurement uncertainty of 80% when other than gummed-film data were used. In this report, the daily estimates of ^{131}I deposition obtained by means of the analysis described above are taken as the median deposition densities of ^{131}I in the counties in which the gummed-film collectors were located, with associated geometric standard deviations of 1.5. These daily estimates of ^{131}I deposition were rounded to the nearest integer, with the implication that values less than 0.5 nCi m^{-2} are treated as zeros.

One of the difficulties in the re-analyses of monitoring data is that original data may have been either mislabelled or not assigned to the appropriate nuclear weapons test. In an effort to alleviate this potential difficulty, locations of gummed-film monitoring that showed that fallout occurred were systematically compared with the path of fallout cloud as projected by a meteorological model (see **Appendix 1**). When discrepancies between the data and the projected path occurred, professional judgment was applied to each case to decide whether or not to utilize the gummed-film data.

The resulting data set includes daily depositions of ^{131}I at up to 95 locations in the U.S. during most of the atmospheric testing period. Those ^{131}I depositions are associated with information on the precipitation amounts occurring during the same 24-h periods. *Table 3.6* lists, as an example, results obtained for the shot Simon for the first 7 days following detonation. The complete results for all tests for which gummed-film data were analyzed are provided in the Annexes.

3.3.1.2. Determination of ^{131}I deposition in counties without monitoring data

The estimation of ^{131}I deposition in more than 3,000 counties based upon data available from 95 or fewer locations presents a considerable problem in spatial interpolation. A solution was sought that would make the best use of all of the available information known to affect the deposition at a site. For example, the amount of fallout at a particular site is known to be highly dependent on whether or not precipitation occurred during the passage of the cloud, and on the intensity of any such precipitation. This is a systematic relationship in that, given that the cloud is present, it is believed that the deposition generally increases with the intensity of the rain. It also is clear that the amount of fallout in counties that are near one another will be more closely related than those that are farther apart. When the deposition measured in a particular county was high, it is more likely that the deposition in a neighboring county also would be high rather than low. As one moves farther from the original county, however, the strength of this relationship diminishes. This kind of relationship is far less certain than that involving the rainfall. In essence, the data are statistically correlated, and the strength of this correlation depends on the distance between the sites.

3.3.1.2.1. Selection of the interpolation technique

Several methods for spatial interpolation of ^{131}I deposition were investigated. Early analyses using a variety of interpolation techniques showed that kriging results were far more flexible than those obtained with other procedures such as spline curve fitting. Kriging originally was developed to estimate gold reserves in the mining industry, but in recent years it has been used increasingly for the analysis of environmental contamination (e.g., Zirschky 1985), including acid rain (Eynon and Switzer 1983). The technique also was used by ORERP to estimate some of the Town Data Base exposures (Thompson and Hutchinson 1988).

The kriging technique was selected because it has the advantage of being able to accommodate both systematic relationships among the data, such as the amount of rainfall, and statistical correlations among the data, such as the relative proximity of the different gummed-film sites. Kriging also is known to be an exact interpolator, in that the results will always yield the exact value of the original data at a measurement site, whereas some other methods, such as least squares, in general return a somewhat different value depending on the fit to the original data. The particular approach to kriging used in this study is described by Ripley (1981) and Oden (1984), and the reader is referred to those publications for the mathematical details. The computer code used to perform the analyses was provided by Oden (1987) and modified at EML in order to conform to the particular requirements of this study.

3.3.1.2.2. Application of the kriging technique

The data upon which the kriging analysis is based are the ^{131}I depositions inferred from total beta activity at the gummed-film locations in operation on a given day following a nuclear test (Beck et al. 1990). Generally, on the first day or two, detectable deposition was confined to a few stations within several hundred miles (or kilometers) of the Test Site. In order to insure a reasonable level of credibility in the calculated depositions, the kriging analysis was carried out only for those tests that resulted in a sufficient number (usually 20) of positive gummed-film results. When the close-in deposition pattern following a test incorporated only a few locations, the patterns for two consecutive days occasionally would be combined in order to provide an adequate data base for the kriging program. As the fallout cloud traveled (usually) eastward across the U.S., the deposition pattern widened; however, many of the stations still did not indicate any detectable fallout since the radioactive cloud rarely covered the entire country. To avoid unnecessary interpolations of many zero results between the gummed-film stations located outside the deposition pattern, a gummed-film station was not included in the analysis unless there was a measured deposition of one or more of its four closest neighboring stations. Results from Canadian stations located near the U.S. border were considered in this decision process. This procedure was found to provide satisfactory limits for enclosing the boundary of the deposition pattern while focusing the analysis on the important locations with measurable fallout. Any county outside the deposition pattern was assigned a value of zero deposition for that day. On some days, two or more distinct areas of deposition could be defined, e.g., an area of dry deposition in the west distant from an area of wet deposition in the east. In such instances, the two areas were analyzed separately because the rainfall dependences and the strength of the proximity correlations would generally be different in the two areas, and the combination of the two areas would distort these relationships.

The kriging analysis was carried out for each day and for each distinct area of deposition by first converting the data to a logarithmic scale. This was done because the data tend to span a wide range, often several orders of magnitude, with many low values and a few much higher ones. As with most environmental monitoring data, a log transformation brings the data closer to a normal (bell-shaped) distribution. Analyses performed without using this transformation resulted in physically unrealistic fallout patterns compared to those obtained with logarithmic transformed data. The transformed data at each site were fit to the reported precipitation index value for that site on that day; this removed the systematic influence of rainfall. Other system-

Table 3.6. Estimates of ^{131}I daily deposition derived from gummed-film results (DG; unit: nCi m^{-2}) and associated precipitation indices (Pi) for the test Simon detonated 4/25/1953.

Site	State	Month and day													
		4/25		4/26		4/27		4/28		4/29		4/30		5/01	
		DG[a]	Pi[b]	DG	Pi	DG	Pi	DG	Pi	DG	Pi	DG	Pi	DG	Pi
Abilene	TX	0	1	34	1	1	1	13	5	6	1	3	1	1	1
Albany	NY	0	1	11,000	7	120	6	52	2	NA	1	90	7	12	1
Albuquerque	NM	0	1	930	1	240	1	56	4	35	1	19	1	2	1
Alpena	MI	0	1	0	1	0	1	0	1	0	1	12	6	8	6
Amarillo	TX	0	1	340	1	210	1	2	1	8	2	12	1	3	1
Atlanta	GA	0	1	0	1	0	1	0	1	24	7	9	8	0	1
Baltimore	MD	0	1	0	1	0	1	12	3	16	1	18	5	1	1
Billings	MT	0	1	0	1	3	2	90	5	0	1	0	1	0	1
Binghamton	NY	0	1	24	6	0	1	0	1	0	1	8	6	2	5
Boise	ID	0	1	0	1	0	1	0	1	0	1	0	1	0	1
Boston	MA	0	1	0	1	7	4	1	1	3	1	12	6	2	6
Buffalo	NY	0	1	1	5	0	1	1	2	0	1	7	5	8	6
Butte	MT	0	1	0	1	1	1	3	5	0	1	0	1	0	1
Caribou	ME	0	1	0	1	360	6	11	2	20	2	0	1	10	1
Casper	WY	0	1	11	1	200	1	92	4	3	5	0	1	1	5
Charleston	SC	0	1	0	1	0	1	0	1	4	1	0	1	0	1
Cheyenne	WY	0	1	59	1	60	1	30	3	1	1	1	1	0	1
Chicago	IL	NA[c]	1	NA	1	NA	1	NA	1	NA	1	NA	1	NA	1
Colo Springs	CO	0	1	1	1	120	1	110	5	2	2	5	3	1	4
Concordia	KS	0	1	0	1	63	1	85	5	42	6	0	1	0	1
Corpus Chris	TX	NA	1	1	1	1	3	0	1	NA	1	1	1	NA	1
Dallas	TX	0	1	190	1	140	1	60	7	16	2	1	1	3	1
Dansville	NY	0	1	0	1	0	1	0	1	0	1	6	5	2	5
Del Rio	TX	0	1	1	1	0	1	4	1	2	1	0	1	0	1
Denver	CO	0	1	19	1	110	1	78	5	9	1	6	5	1	1
Des Moines	IA	0	1	0	1	1	1	23	1	96	6	10	6	1	2
Detroit	MI	0	1	0	1	0	1	38	5	1	2	7	5	3	5
Dunkirk	NY	NA	1	NA	1	0	1	0	1	0	1	8	2	NA	1
East Port	ME	NA	1	NA	1	140	6	0	1	10	2	NA	1	15	5
Elko	NV	0	1	0	1	1	5	0	1	2	3	0	1	0	1

Table 3.6. cont'd

Site	State	Month and day													
		4/25		4/26		4/27		4/28		4/29		4/30		5/01	
		DG[a]	Pi[b]	DG	Pi	DG	Pi	DG	Pi	DG	Pi	DG	Pi	DG	Pi
Ely	NV	12	1	7	1	20	4	1	2	0	1	0	1	0	1
Eureka	CA	0	1	0	1	0	1	0	1	0	1	0	1	0	1
Fargo	ND	0	1	0	1	1	1	14	2	115	5	NA	1	4	6
Flagstaff	AZ	1100	1	150	1	190	6	6	3	0	1	0	1	0	1
Fort Smith	AK	0	1	0	1	150	7	27	7	10	2	1	1	1	1
Fresno	CA	0	1	0	1	2	6	0	1	0	1	0	1	0	1
Goodland	KS	NA	1	NA	1	160	1	82	5	6	6	1	3	0	1
Grand JNC	CO	0	1	870	1	84	3	7	5	6	1	3	2	0	1
Grand Rapids	MI	0	1	0	1	0	1	130	5	10	2	NA	1	6	5
Green Bay	WI	0	1	0	1	0	1	6	3	13	2	10	6	0	1
Helena	MT	0	1	0	1	0	1	2	5	0	1	0	1	0	1
Huron	SD	0	1	0	1	1	1	220	6	90	6	3	7	0	1
Jackson	MS	0	1	0	1	109	1	170	1	190	8	2	1	0	1
Jacksonville	FL	0	1	0	1	0	1	0	1	0	1	0	1	0	1
Kalispell	MT	0	1	0	1	0	1	0	1	0	1	0	1	0	1
Kansas City	MO	0	1	0	1	90	1	40	4	30	7	2	2	10	3
Knoxville	TN	NA	1	0	1	0	1	6	1	12	6	1	5	0	1
Las Vegas	NV	0	1	4	1	7	1	NA	1	0	1	0	1	1	1
Los Angeles	CA	2	2	0	1	2	6	0	1	0	1	0	1	0	1
Louisville	KY	0	1	0	1	73	5	110	1	50	5	3	3	2	1
Lynchburg	VA	0	1	0	1	0	1	36	1	8	1	8	6	0	1
Marquette	MI	0	1	0	1	0	1	0	1	5	2	32	6	1	5
Medford	OR	0	1	0	1	0	1	0	1	0	1	0	1	0	1
Memphis	TN	0	1	0	1	26	1	180	2	27	8	2	1	1	1
Miami	FL	0	1	0	1	42	1	34	1	3	1	1	1	0	1
Milford	UT	320	1	240	1	240	5	6	6	1	2	0	1	0	1
Milwaukee	WI	0	1	0	1	0	1	280	6	4	3	20	6	10	5
Minneapolis	MN	0	1	0	1	0	1	110	3	180	5	18	6	1	5
Mobile	AL	0	1	0	1	0	1	19	1	13	5	0	1	NA	1
Montgomery	AL	0	1	0	1	1	1	38	1	33	7	3	5	0	1
Nashville	TN	0	1	0	1	1	1	42	1	180	7	2	1	0	1
New Haven	CT	0	1	3	5	0	1	0	1	0	1	18	7	0	1
New Orleans	LA	0	1	0	1	150	1	130	1	39	4	6	1	2	1
New York AEC	NY	0	1	0	1	0	1	1	1	NA	1	10	6	0	1
Philadelphia	PA	0	1	0	1	0	1	0	1	1	2	8	6	2	5
Phoenix	AZ	0	1	0	1	1	2	0	1	0	1	0	1	0	1

Table 3.6. cont'd

Site	State	Month and day													
		4/25		4/26		4/27		4/28		4/29		4/30		5/01	
		DG[a]	Pi[b]	DG	Pi	DG	Pi	DG	Pi	DG	Pi	DG	Pi	DG	Pi
Pittsburgh	PA	0	1	0	1	0	1	4	3	19	1	6	3	5	2
Pocatello	ID	0	1	10	1	6	6	0	1	0	1	0	1	0	1
Port Arthur	TX	0	1	17	1	18	1	28	2	10	6	4	1	0	1
Portland	OR	0	1	0	1	0	1	0	1	0	1	0	1	0	1
Providence	RI	0	1	2	6	0	1	0	1	1	1	75	7	1	5
Pueblo	CO	0	1	0	1	120	1	21	4	8	2	3	1	0	1
Rapid City	SD	0	1	0	1	5	1	250	6	4	6	0	1	0	1
Raton	NM	0	1	10	1	100	1	10	2	17	3	9	2	5	1
Reno	NV	0	1	0	1	0	1	13	1	0	1	0	1	0	1
Rochester	NY	0	1	2	5	0	1	0	1	0	1	16	6	6	6
Rock Springs	WY	0	1	42	2	14	1	1	5	0	1	0	1	0	1
Roswell	NM	25	1	4200	1	710	1	200	3	17	1	11	1	2	1
Sacramento	CA	0	1	2	6	0	1	0	1	0	1	0	1	0	1
Salt Lake	UT	0	1	64	1	37	5	0	1	0	1	0	1	0	1
San Diego	CA	0	1	0	1	0	1	0	1	0	1	0	1	0	1
San Francisco	CA	0	1	0	1	0	1	0	1	0	1	0	1	0	1
Scottsbluff	NB	0	1	1	1	28	1	55	5	0	1	0	1	0	1
Seattle	WA	0	1	0	1	0	1	0	1	0	1	0	1	0	1
Spokane	WA	0	1	0	1	0	1	0	1	0	1	0	1	0	1
St. Louis	MO	0	1	0	1	32	1	98	3	30	3	13	5	5	1
Syracuse	NY	0	1	3	5	1	5	0	1	0	1	0	1	0	1
Texarkana	AK	0	1	0	1	26	1	66	7	7	5	3	1	1	1
Tucson	AZ	0	1	0	1	0	1	0	1	0	1	0	1	0	1
Washington	DC	0	1	0	1	0	1	13	2	26	1	14	6	1	5
Watertown	NY	0	1	0	1	0	1	0	1	3	1	12	6	2	5
Wichita	KS	0	1	0	1	285	1	55	2	33	5	2	2	5	3
Williston	ND	0	1	0	1	1	2	57	4	76	6	4	6	1	5
Winnemucca	NV	0	1	0	1	0	1	0	1	0	1	0	1	0	1
Yuma	AZ	0	1	0	1	0	1	1	1	0	1	1	1	0	1

[a] DG=daily deposition of ^{131}I per unit of area of ground (nCi per m^{-2})
[b] Pi=precipitation index
[c] NA=not available

atic relationships in the data were also explored, including any possible dependence of fallout on the latitude and longitude of the gummed-film station, and the predicted amount of radioactive material in the air column above the gummed-film station as determined from NOAA's meteorological model. In virtually every case, the precipitation index emerged as the single most important parameter in predicting systematic variations in ^{131}I deposition. The calculated air column content was rarely a good predictor of the measured daily deposition. This reflects the relative discrepancy between the calculated position of the radioactive cloud and the observed areas of deposition (especially at long distances from the NTS and several days after detonation) and the uncertain altitude and efficiency of scavenging by rain clouds relative to radioactive clouds. The reasons for this are discussed in **Appendix 1,** which describes the meteorological model.

Statistical correlations among the deposition values at different locations were examined as a function of the relative distance between locations by using one of a number of simple mathematical functions depending on a single parameter. In this study, several such mathematical functions were fit to each data set, and the most appropriate data set for a given day and test was determined by a cross-validation procedure. This procedure consisted of removing one data point from the set and using the other data points to predict its value by kriging. The average error obtained after sucessively removing and predicting each point of the set in sequence is the cross-validation error. The mathematical function with the smallest associated cross-validation error generally was the one used. The magnitude of the improvement in the estimation of the interpolated values which results from the use of statistical correlations was determined by comparing the cross-validation error after kriging, including the effects of statistical correlations, with that obtained after only correcting for the effect of precipitation (and any other significant systematic relationships that were found). This improvement corresponded to a reduction factor in the cross-validation error of about 50% on average.

After the best fit to both systematic and statistical relationships among the data was determined, these relationships were used to calculate the deposition at the geographic center (centroid) of each county that could have received fallout. The average precipitation index for each county, as provided by NOAA, was used to predict the average wet deposition in the county. A map of the U.S. was generated for each day following each test showing the measured deposition at each gummed-film location and the interpolated values at each county cen-

Figure 3.9. Estimates of daily deposition of ^{131}I per unit area of ground for April 27, 1953 (2 days after detonation of the shot Simon). The numbers in large characters represent the ^{131}I deposition derived from the gummed-film results whereas the numbers in small characters are the interpolated results, for each county centroid, obtained by kriging.

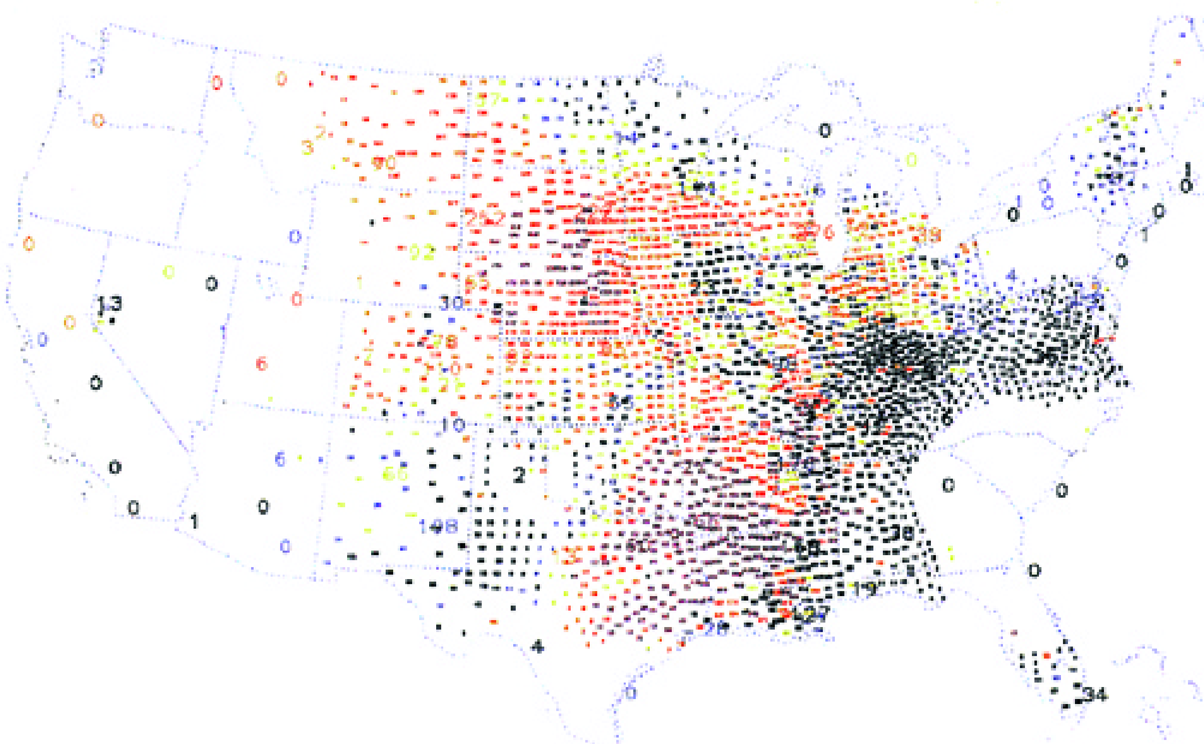


Table 3.7. Geometric standard deviations (GSDs) attached to the estimates of ^{131}I deposition, according to the values of the kriging error and of the precipitation index.

Multiplicative kriging error	GSD	
	Precipitation indices 1 to 4	Precipitation indices 5 to 9
1.0-1.5	1.5	2.0
1.5-2.0	2.0	2.5
2.0-2.5	2.5	3.0
2.5-3.0	3.0	3.5
> 3.0	3.5	4.0

troid. An example is shown in *Figure 3.9*. Each map was examined to ensure that the interpolated values were consistent with the measured deposition pattern, the rainfall pattern, and expected atmospheric transport processes.

3.3.1.2.3. Discussion of uncertainties

The success of the interpolation effort can be measured in several ways. The magnitude of the cross-validation errors indicates that the deposition at any given location could be predicted from the ^{131}I depositions derived from gummed-film data at other locations to within about a factor of three. The kriging analysis itself produces an estimate of the interpolation error at each site using the mathematical function describing the statistical correlations. This is called the kriging standard deviation. Most alternative interpolation methods provide no such estimate. While there are a considerable number of assumptions necessary to deduce an interpolation error from the kriging standard deviation, it can be used as a relative indicator of the uncertainty in the results. In general, the closer a county centroid is to actual measurement locations, the smaller the interpolation error. The highest errors occur when values are extrapolated beyond the boundaries of the fallout pattern. Fortunately, this occurred rarely and generally involved low deposition values. The kriging standard deviation indicates that the typical interpolation error is about a factor of two or three. This is in general agreement with that estimated from the cross-validation errors.

The deposition estimate for each day and each county obtained by the kriging analysis is assumed to represent the geometric mean of a log-normal distribution; the geometric standard deviation, GSD, associated with the deposition estimate was taken to be slightly higher than the kriging error in order to account for other possible sources of error such as the uncertainties attached to the estimates of ^{131}I deposition at the gummed-film sites and the precipitation index. The GSDs were assigned as indicated in *Table 3.7*.

The estimate of ^{131}I deposition derived from gummed-film data at each gummed-film site was compared to the interpolated value at the centroid of the county within which it was located in order to assess any potential biases in the interpolated depositions for individual counties. The average difference in these values was only 12%, which is very small compared to the other estimates of interpolation error. This would indicate that the interpolation errors are about as likely to result in an overestimate as in an underestimate at any particular site. The total activity of ^{131}I deposited over the U.S. for each day was calculated by multiplying the interpolated deposition value at each county centroid by the area of the county and summing all of the county depositions. When the total activity of ^{131}I deposited over the entire U.S. is summed for all days on which fallout occurred following a given test, the result can be compared to the total amount of ^{131}I estimated to have been produced by the test. For example, the total ^{131}I deposition across the U.S. from the test Simon was estimated to be 1.8 MCi by the kriging technique, or approximately 30% of the ^{131}I produced by that test. This does not include the deposition in the immediate vicinity of the NTS, for which the spatial resolution of the gummed-film stations is insufficient to provide adequate interpolated values. However, the result is consistent with other estimates, and indicates that the kriging analysis does not result in a significant systematic bias. For other tests, the range of estimated total ^{131}I deposition was 3-70% of that produced, and varies generally in a manner consistent with what is known of relationships between amounts of ^{131}I produced by a test and the fallout associated with that test (Beck et al. 1990). Estimates of the total deposition of ^{131}I is discussed in **Section 3.6.**

In summary, the challenging task of estimating realistic deposition values in over 3,000 U.S. counties from fewer than 100 data points was accomplished for 38 tests by using a combination of statistical analysis together with all available information about the physical deposition process. The method consisted in using an interpolation scheme known as kriging, the results of which were carefully monitored and inspected thoughout the process to ensure that the results were physically reasonable. The predicted values are estimated by a variety of means to be generally accurate within about a factor of three, and do not appear to contain any significant bias in either direction.

3.3.1.2.4. Use of the Area-of-Influence Precipitation-Corrected (AIPC) method

For those tests and days that resulted in a very small number of positive gummed-film results, the determination of the deposition in the counties without monitoring data required a less complex approach. In those cases, the irregular deposition patterns that were generally involved would lead to unreasonable or questionable values if the interpolation were performed by the objective kriging technique. Such cases were treated by a much simpler method than kriging: the deposition in the county of interest was taken to be the same as in the nearest county with a measured gummed-film value if the precipitation indices were the same; if the precipitation indices differed, the estimates of deposition were adjusted using precipitation weights. The values of the precipitation weights, which were derived from the scavenging coefficients used in the meteorological model described in **Appendix 1**, are presented in *Table 3.8.*

This simple technique, denoted as AIPC (acronym for Area-of-Influence, Precipitation Corrected method) was used for the days when the kriging procedure was not applied but positive ^{131}I depositions per unit area of ground had been derived from the gummed-film measurements and precipitation data were available. The AIPC technique was either used for complete tests or for days following a test that had few positive gummed film results. Generally, the tests to which this simpler procedure has been applied released less ^{131}I into the atmosphere than did the tests for which kriging was done.

For the days and tests for which the AIPC method was used, the GSD associated with the depositions obtained with the AIPC method was taken to be 1.5 for counties with gummed-film values and 4.0 for all other counties

3.3.2. Meteorological Transport Approach

The national network of gummed-film monitoring stations was operational from the autumn of 1951 until 1960. The gummed-film network was not operational for the tests of the Ranger series detonated in January and February 1951, or for the tests of the underground testing era (from 1961 to date). No deposition data that can be related to those tests conducted at the NTS are available, except in the close-in area. For these tests, another method for determining the deposition of ^{131}I across the U.S. has been employed, but it is deemed less reliable than either the kriging or the AIPC methods. This alternative method simulates the transport and diffusion of the cloud of radioactive debris across the United States based on observed wind patterns and assumes that the ^{131}I deposits only with precipitation.

The ^{131}I releases from the nine tests evaluated using the meteorological transport model were relatively small; only four of them released more than 1 MCi of ^{131}I and none more than 3.5 MCi. The smaller amounts of ^{131}I produced by the 9 tests in this category should be kept in mind when the associated large uncertainties using this approach are compared to the smaller uncertainties associated with the depositions predicted by the kriging and AIPC methods.

Three of the four larger tests (Baker, Baker-2, and Fox from the Ranger series) were air bursts which helps to justify the use of a model which only predicts deposition by precipitation

Table 3.8. Relationship between the 24-h precipitation values and the precipiation weights used in the AIPC method.

Precipitation Index	24-h precipitation amount		Precipitation weight
	(inches)	(millimeters)	
1	none	none	1
2	trace	trace	1.5
3	0.01-0.03	0.25-0.76	2
4	0.03-0.10	0.76-2.5	2
5	0.10-0.30	2.5-7.6	4
6	0.30-1.00	7.6-25	6
7	1.00-3.00	25-76	10
8	3.00-5.00	76-127	10
9	5.00 or over	127 or over	10

scavenging. The fourth test (Sedan) was a cratering event, which produced airborne dust that deposited quickly. Very little of the radioactive debris was transported much farther than a few hundred kilometers, where it was measured.

There are major uncertainties in each of the steps leading to the predictions of deposited ^{131}I by the meteorological transport model. Rather than quantifying each of these uncertainties, the overall uncertainty was described in the uncertainty of the estimate of the scavenging, or wet removal, coefficient. This coefficient is the ratio of the deposited activity to the activity in the overhead radioactive cloud, and its uncertainties are due to errors in the source term of ^{131}I, in the meteorological transport model, in the assumed dispersion of the clouds and the character of the scavenging process. The scavenging coefficient is estimated from data obtained during the predicted passage of radioactive clouds over gummed-film stations while there was precipitation and thus it contains all the uncertainties of the transport and dispersion model as well as the uncertainties in the scavenging characteristics. It also includes the smaller uncertainties of the gummed-film ^{131}I depositions at monitoring sites, referred to in **Section 3.2.2.2.** The uncertainty in the scavenging coefficient as described above can be applied directly to the uncertainty that is assigned to the deposition of ^{131}I estimated by this method.

It should be emphasized, however, despite the limitations of the meteorological transport method, the relatively small atmospheric releases of ^{131}I from these tests to which it is applied produce small estimated deposition values. The use of the meteorological model to estimate ^{131}I depositions per unit area of ground resulting from a given nuclear weapons test involves the estimation of:

(a) the activity of ^{131}I released into the atmosphere by the test considered,

(b) the initial distribution of ^{131}I in the mushroom cloud produced by the explosion,

(c) the transport and dispersion across the U.S. of the ^{131}I present in the radioactive cloud, and

(d) the deposition of ^{131}I on the ground with falling precipitation.

A detailed description of the meteorological model is provided in **Appendix 1.**

3.4. COMPARISON OF THE ESTIMATES OF DAILY ^{131}I DEPOSITIONS PER UNIT AREA OF GROUND OBTAINED WITH VARIOUS METHODS

There are, all together, 3,094 counties and sub-counties for which ^{131}I deposition densities were estimated:

(a) 5 counties in the Town Data Base, subdivided into 13 counties,

(b) 120 undivided counties and 9 counties sub-divided into 24 sub-counties in the County Data Base, and

(c) 2,937 undivided counties in the remainder of the contiguous United States.

In the area covered by the Town and County Data Bases (157 counties and sub-counties, also called "near-NTS area"), estimates of ^{131}I deposition per unit area of ground could be obtained for the tests for which both exposure rates and gummed-film data are available, using ORERP results, the kriging method, the AIPC method, and the meteorological transport model. The last three methods could also be used to estimate ^{131}I depositions per unit area of ground in the 2,937 counties representing the remainder of the contiguous United States when gummed-film data were available. In order to illustrate the advantages and disadvantages of the various methods, and also in order to show the importance of some of the assumptions used in the calculations, the deposition results obtained with the different methods are compared in the following sections, using several days of deposition following the test Simon detonated April 25, 1953 as examples.

3.4.1. Comparison of the ^{131}I Depositions Per Unit Area of Ground Obtained with Various Methods for the Counties Near the NTS

The estimates of ^{131}I deposition per unit area of ground derived by ORERP using measured exposure rates, as well as those obtained by the kriging and by the AIPC method for the counties in the near-NTS area are presented for the test Simon are presented in *Figures 3.10, 3.11, and 3.12,* respectively. *Figure 3.11* shows, in addition, the ^{131}I depositions per unit area of ground that are calculated from the gummed-film data, expressed in nanocuries per square meter. These values form the basis for the estimation of ^{131}I deposition per unit area of ground for the kriging *(Figure 3.11)* and the AIPC methods *(Figure 3.12)*. An array of supplementary data, some of which is classified, was used by ORERP to produce the results in *Figure 3.10*. The estimates of ^{131}I deposition per unit area of ground that would be obtained with the meteorological transport model have not been calculated since it did not rain in most of the counties considered during the time of deposition of radioactive materials following the test Simon. The results obtained with the meteorological transport model would have been extremely patchy because the meteorological model can only calculate the depositions associated with falling precipitation.

The overall patterns of deposition obtained with the three methods are fairly similar, with the highest values in northern Arizona, southern New Mexico, and southwestern Colorado, and with low values in California, southern Arizona, and western Nevada. There are, however, substantial differences in the deposition levels obtained in some counties: for example, a very high deposition is calculated in Clark county in southeastern Nevada with the ORERP data (*Figure 3.10*) whereas both the kriging and the AIPC methods yield lower values for that county; conversely, the deposition estimates derived from the ORERP data for counties in the southern part of New Mexico are lower than those estimated using either the kriging or the AIPC method. This is undoubtedly due to the fact that the deposition at the widely separated gummed-film sites did not represent adequately the average deposition in those counties for that particular day. The ORERP approach employed more sources of information and a finer resolution in the measurements and produced better estimates of the average deposition. It is also to be noted that the AIPC method, in the absence of rain, yields constant deposition levels over large areas (see, for example, New Mexico in *Figure 3.12*), resulting in areas of either high or low contamination, whereas the transitions of contamination levels between counties are smoother when the other two methods are used.

The overall similarity of the deposition patterns obtained with the three methods is also verified in *Figures 3.13* and *3.14,* where the ratios of the depositions obtained in the same counties with, on the one hand, the kriging or the AIPC method, and, on the other hand, the ORERP data, are plotted as histograms. *Figure 3.13,* which compares the estimates of ^{131}I deposition per unit area of ground obtained with the kriging method to those derived from the ORERP data, shows that, on the average, the kriging method resulted in deposition estimates that were lower than those derived from the ORERP data. The dispersion of the ratios, however, is relatively small, with most of the values in agreement within a factor of 4.

Figure 3.14, which compares the estimates of ^{131}I deposition per unit area of ground obtained with the AIPC method to those derived from the ORERP data, shows, on the contrary, a wider dispersion of the ratios but a larger number of counties in which the AIPC method led to higher deposition estimates than those derived from the ORERP data.

Even though the comparison of the estimates of ^{131}I deposition per unit area of ground obtained with the three methods for the counties in the near-NTS area are limited to a single test, it seems that the overall agreement is relatively good. It is clear that the depositions obtained from the ORERP data are to be preferred to those obtained with the other two methods as the ORERP data are culled from a large array of measurement results, some of which are not available to the general public. Since the spatial variation of the fallout deposition was quite substantial in the area near the NTS, the finer grid of measurement results used by ORERP leads to a better representation of the fallout pattern.

Figure 3.10. Estimates of ^{131}I deposition per unit area from the exposure rates at H + 12 reported by ORERP for the test Simon detonated April 25, 1953 and for the near-NTSarea.

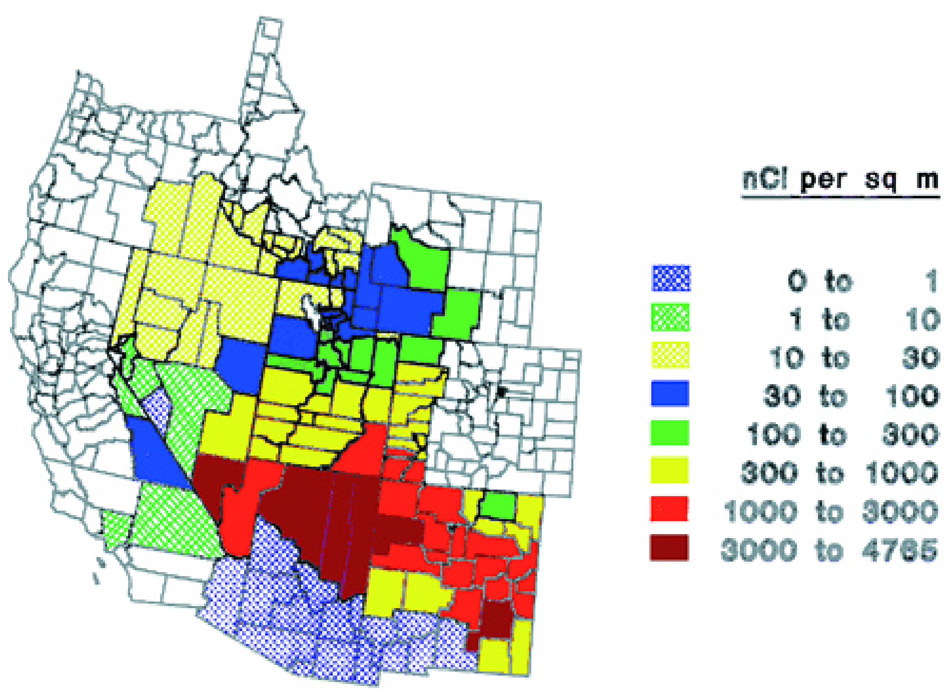


Figure 3.11. Estimates of ^{131}I deposition per unit area of ground derived from the test Simon detonated on April 25, 1953 and for the near-NTS area. The numbers represent the ^{131}I depositions derived from gummed-film measurements at the gummed-film sites.

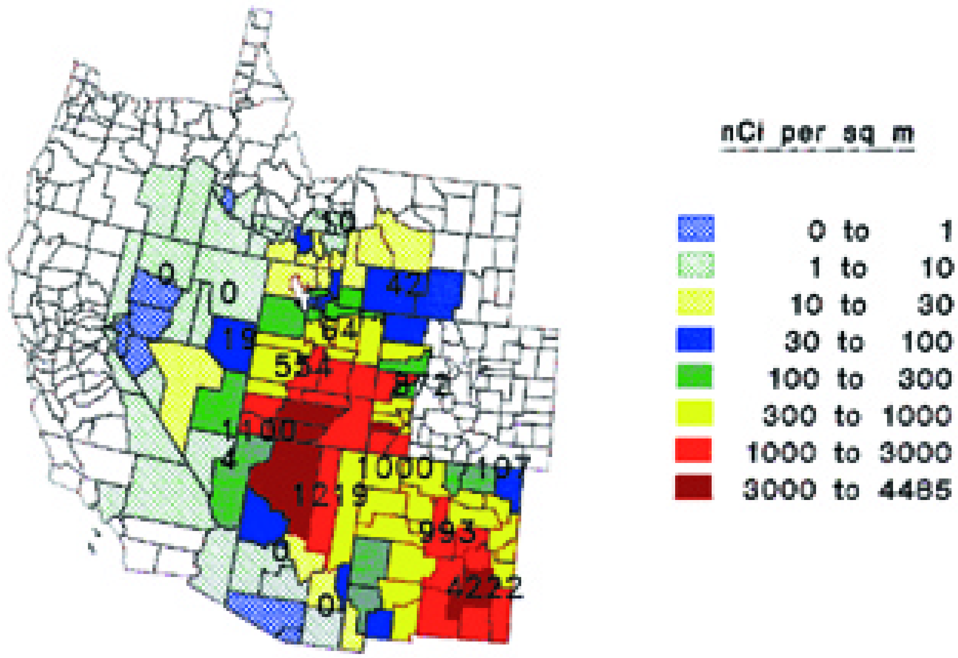


Figure 3.12. Estimates of ^{131}I deposition per unit area of ground derived from the gummed-film measurements by the AIPC method for the test Simon detonated on April 25, 1953 and for the near-NTS area.

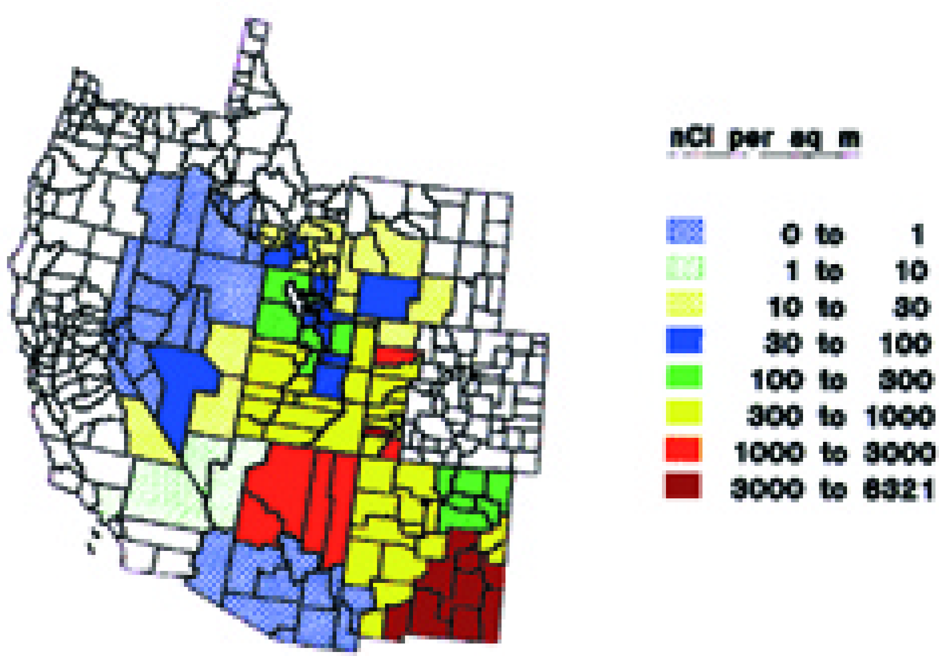


Figure 3.13. Distribution of the ratios of the estimates of ^{131}I deposition per unit area of ground derived from the gummed-film measurements by the kriging method to those derived from the exposure rates at H + 12 reported by ORERP for the test Simon detonated on April 25, 1953 and for the near-NTS area.

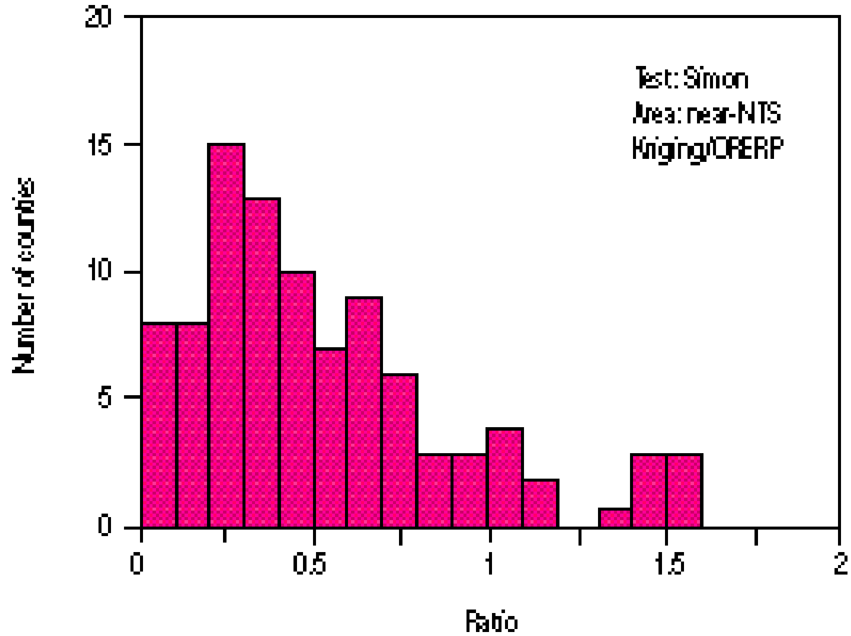
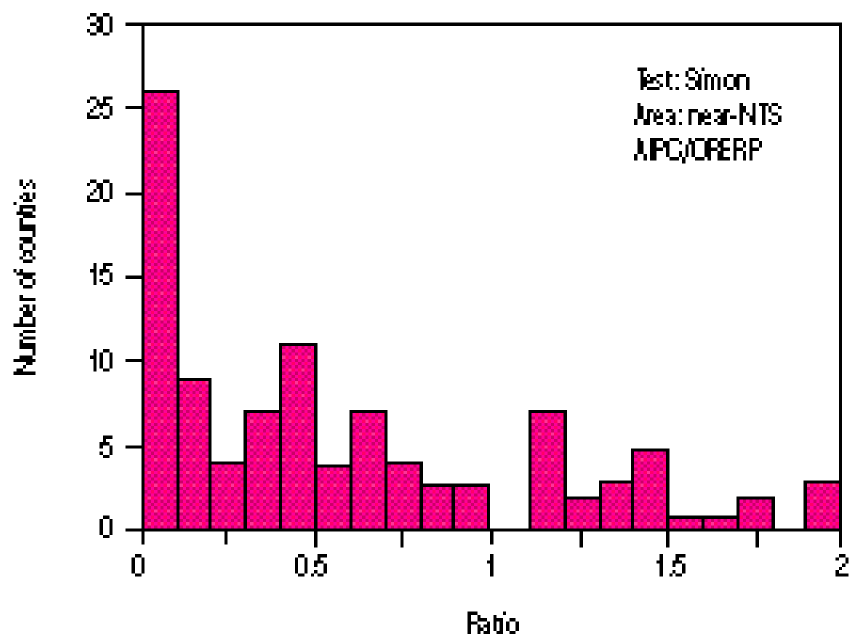


Figure 3.14. Distribution of the ratios of the estimates of ^{131}I deposition per unit area of ground derived from the gummed-film measurements by the AIPC method to those derived from the exposure rates at H + 12 reported by ORERP for the test Simon detonated on April 25, 1953 and for the near-NTS area.



3.4.2. Comparison of the ^{131}I Depositions Per Unit Area of Ground Obtained with Various Methods for the Counties in the Remainder of the Contiguous United States

The sets of deposition estimates that have been obtained with the meteorological model and with the kriging and AIPC methods for the 2,937 counties that are in the remainder of the contiguous United States have been compared for April 28 and 29, 1953, that is, 3 and 4 days after the detonation of the test Simon, at a time when deposition almost had ceased in the near-NTS area but was observed in the eastern part of the country. A third comparison was made for July 8, 1957, three days after detonation of the test Hood. The date was selected because rainfall was widespread and it provided an expanded test of the meteorological transport model.

3.4.2.1. Comparison of the ^{131}I depositions per unit area of ground obtained with various methods for the counties in the remainder of the contiguous United States for April 28, 1953 following test Simon

The estimates of ^{131}I deposition per unit area of ground that were calculated with the kriging method, with the AIPC method, and with the meteorological transport model are presented in *Figures 3.15, 3.16, and 3.17,* respectively. *Figures 3.15 and 3.16,* which are based on the same set of gummed-film measurements, are very similar, and both are notably different from *Figure 3.17. Figures 3.15 and 3.16* show the same deposition pattern, with relatively high values in Louisiana, Arkansas, Missouri, Indiana, and South Dakota, and a widespread deposition area extending from Montana to Alabama. In comparison, the deposition pattern obtained with the meteorological transport model is more limited because the predicted location over the entire radioactive cloud, calculated from the airmass trajectories and shown in *Figure 3.18,* is located over the eastern half of the country. Also, there were large areas in the eastern part of the country where it did not rain on April 28, 1953. The meteorological transport model predicts no deposition at those locations.

The overall similarity of the deposition patterns obtained with the kriging and with the AIPC methods is verified in *Figure 3.19,* where the ratios of the depositions estimated in the same counties with the AIPC and with the kriging methods are plotted as a histogram. On the average, the kriging and the AIPC methods resulted in deposition estimates that were within a factor of 2, with about 16% of the counties with no deposition according to the AIPC method and with some deposition according to the kriging method.

Figure 3.20, which compares the estimates of ^{131}I deposition per unit area of ground obtained with the meteorological model and with the kriging method shows, in contrast, that the deposition estimates obtained with the kriging method were in general higher than those calculated with the meteorological model, and that the meteorological model did not predict any deposition in almost 2,000 counties for which estimates of deposition are available with the kriging method.

Figure 3.15. Estimates of ^{131}I deposition per unit area of ground derived from the gummed-film measurements by the kriging method on April 28, 1953 resulting from the test Simon detonated on April 25, 1953 for all counties of the contiguous United States.

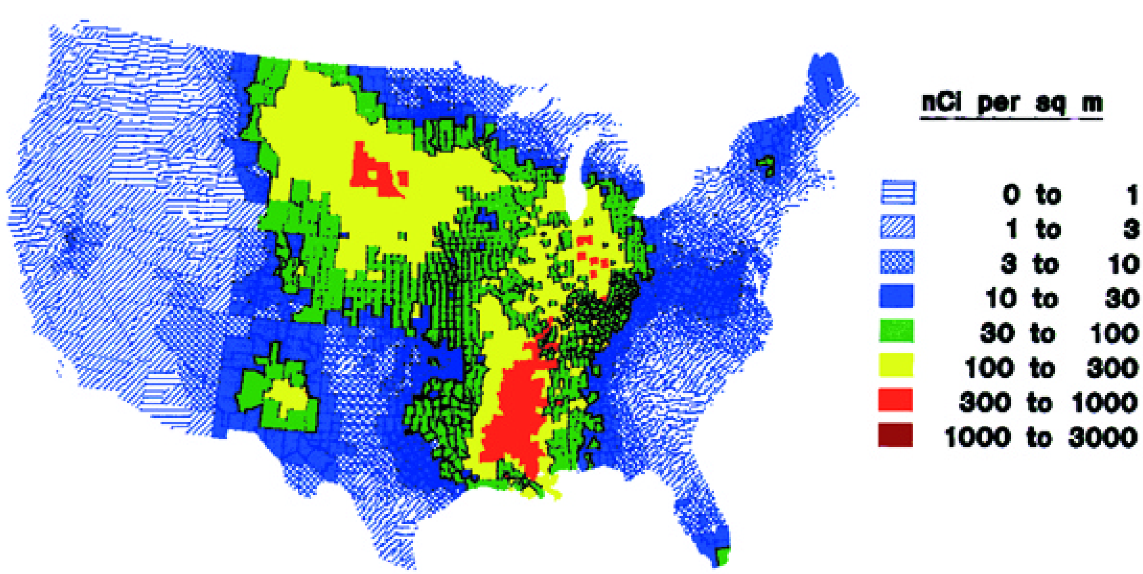


Figure 3.16. Estimates of ^{131}I deposition per unit area of ground derived by the AIPC method on April 28, 1953 resulting from the test Simon detonated on April 25, 1953 for all counties of the contiguous United States.

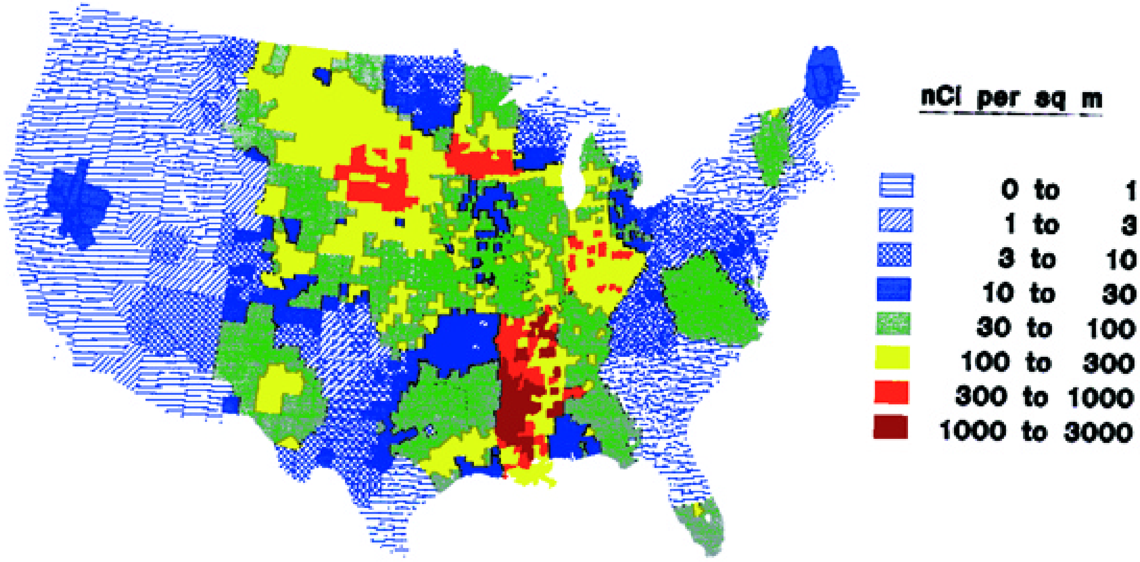


Figure 3.17. Estimates of ^{131}I deposition per unit area of ground obtained using the meteorological transport model on April 28, 1953 following the test Simon detonated on April 25, 1953 for all counties of the contiguous United States in which precipitation was recorded.

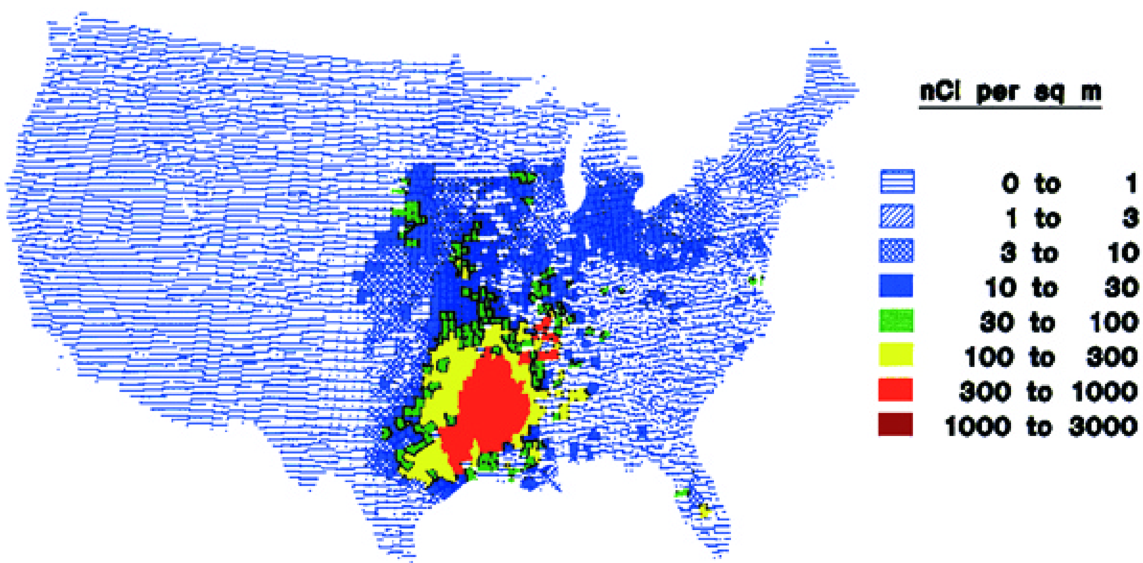


Figure 3.18. Estimates of 131I contained in the radioactive cloud per unit area of ground obtained using the meteorological transport model on April 28, 1953 following the test Simon detonated on April 25, 1953 for all counties of the contiguous United States.

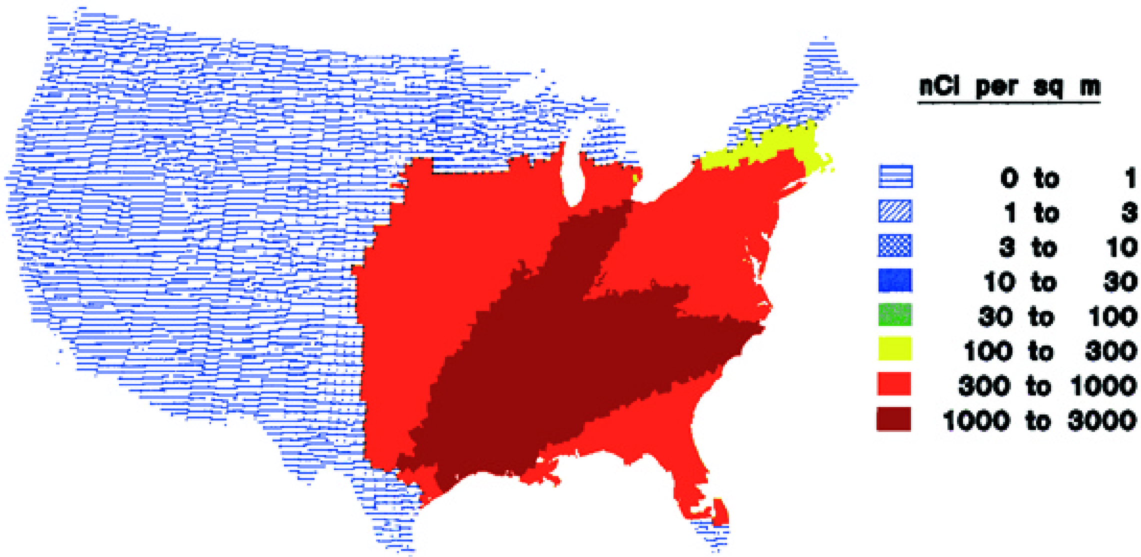


Figure 3.19. Distribution of the ratios of the estimates of 131I deposition per unit area of ground derived from the AIPC method to those derived from the gummed-film measurements by the kriging method for April 28, 1953 resulting from the test Simon detonated on April 25, 1953 for all counties of the United States with estimated non-zero deposition by the kriging method.

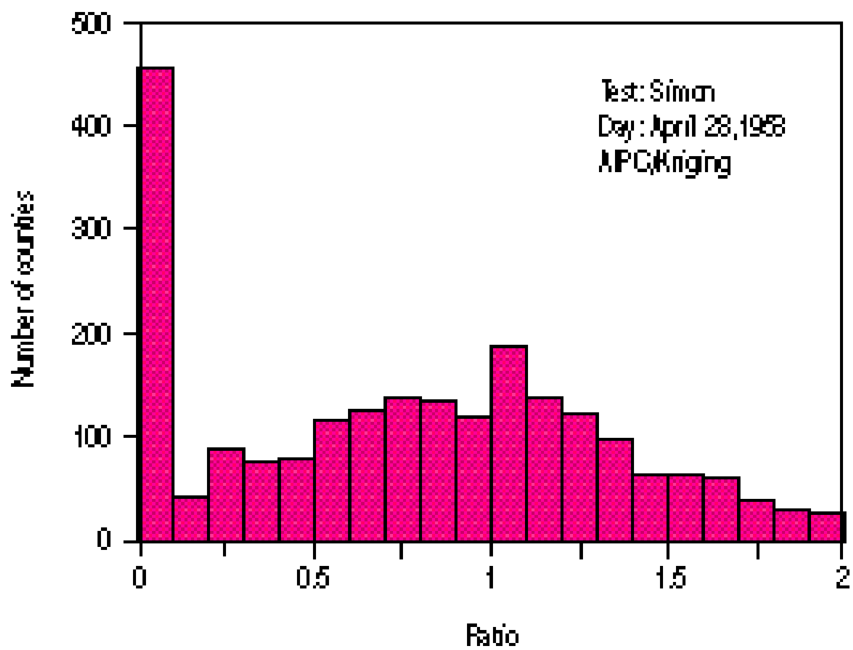
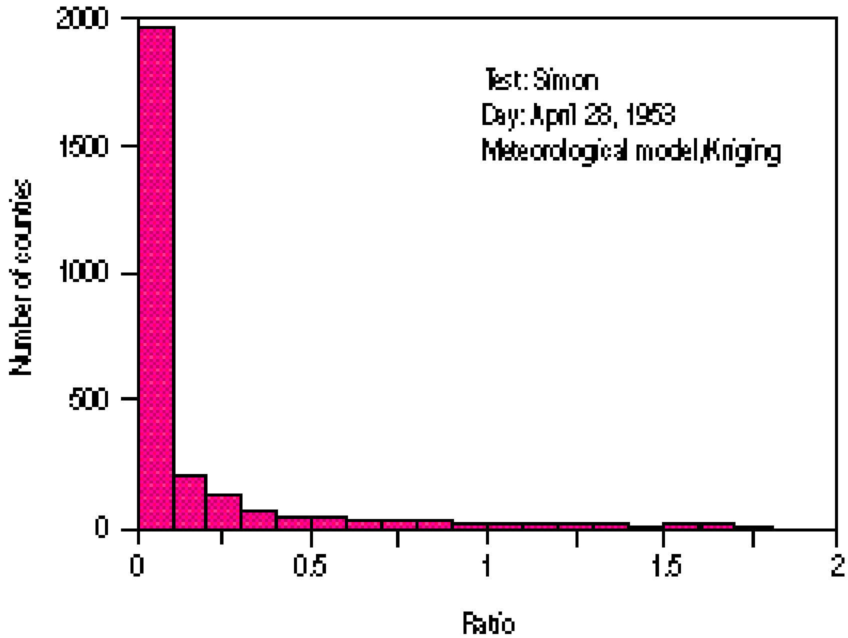


Figure 3.20. Distribution of the ratios of the estimates of ^{131}I deposition per unit area of ground derived from the meteorological model to those derived from the gummed-film measurements by the kriging method for April 28, 1953 resulting from the test Simon detonated on April 25, 1953for all counties of the United States with estimated non-zero deposition by the kriging method.



3.4.2.2. Comparison of the ^{131}I depositions per unit area of ground obtained with various methods for the counties in the remainder of the contiguous United States for April 29, 1953 following test Simon

The general conclusions from comparison of the depositions calculated for April 28, 1953 are also valid for April 29th, 1953. The estimates of ^{131}I deposition per unit area of ground that were calculated for that day with the kriging method, with the AIPC method, and with the meteorological model are presented in *Figures 3.21, 3.22, and 3.23,* respectively. *Figures 3.21 and 3.22,* which are based on the same set of gummed-film measurements, are very similar, and both are notably different from *Figure 3.23. Figures 3.21 and 3.22* show deposition patterns that are similar in size to those of the day before, the absolute deposition levels being, however, substantially lower. In comparison, the deposition area predicted by the meteorological transport model is now limited to an even smaller part of the country (see also *Figure 3.24*).

The overall similarity of the deposition patterns obtained with the kriging and with the AIPC methods is verified in *Figure 3.25,* where the ratios of the depositions obtained in the same counties with the AIPC and with the kriging methods are plotted as an histogram. On the average, the kriging and the AIPC methods resulted in deposition estimates that were within a factor of 2, with about 14% of the counties with no deposition according to the AIPC method and with some deposition according to the kriging method.

Figure 3.26, which compares the estimates of ^{131}I deposition per unit area of ground obtained with the meteorological model and with the kriging method shows, again, that the meteorological model did not predict any deposition in almost 2,000 counties for which estimates of deposition are available with the kriging method. However, in the remaining few counties for which positive deposition values were calculated with both the kriging method and with the meteorological model, there is a relatively good agreement between the two sets of deposition estimates for that day. Most ratios were within the range 0.5-2.

3.4.2.3. Comparison of the ^{131}I depositions per unit area of ground obtained with various methods for the counties in the remainder of the contiguous United States for July 8, 1957 following test Hood.

To further check the general patterns seen from comparisons of ^{131}I deposition estimates following test Simon, the three methods of estimating ^{131}I deposition were also compared for the test Hood, detonated on July 5, 1957. The day selected for comparison was July 8, 1957, because precipitation records indicated that rainfall was widespread on that day. This provided the meteorological model with the possibility of estimating ^{131}I depositions in a large part of the area covered by the radioactive cloud.

The estimates of ^{131}I deposition per unit area of ground that were calculated for July 8, 1957 with the kriging method, with the AIPC method, and with the meteorological model are

Figure 3.21. Estimates of ^{131}I deposition per unit area of ground derived by the kriging method from the gummed-film measurements on April 29, 1953 resulting from the test Simon detonated on April 25, 1953 for all counties of the contiguous United States.

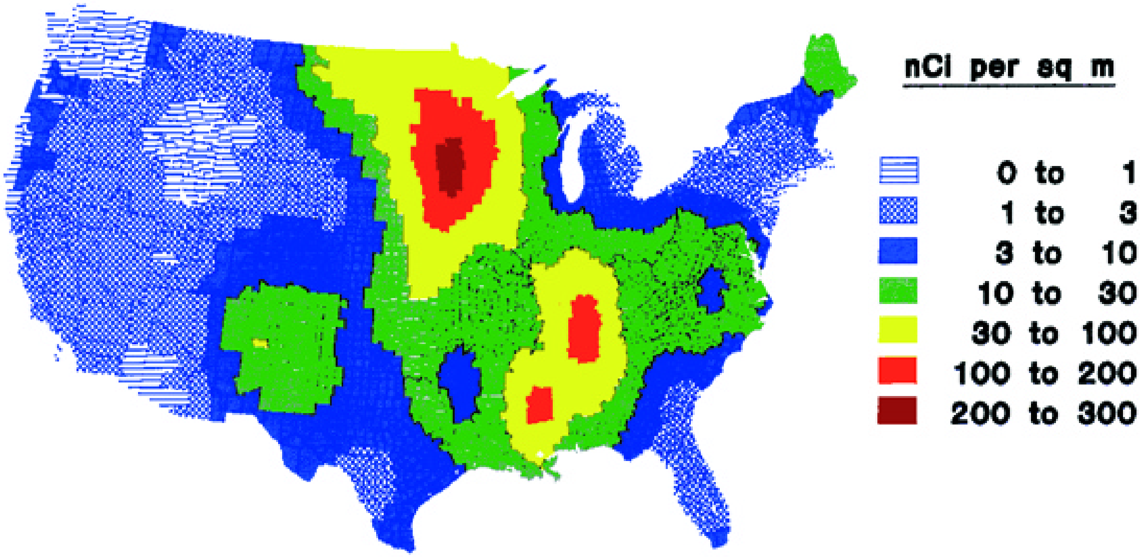


Figure 3.22. Estimates of ^{131}I deposition per unit area of ground derived by the AIPC method from the gummed-film measurements on April 29, 1953 resulting from the test Simon detonated on April 25, 1953 for all counties of the contiguous United States.

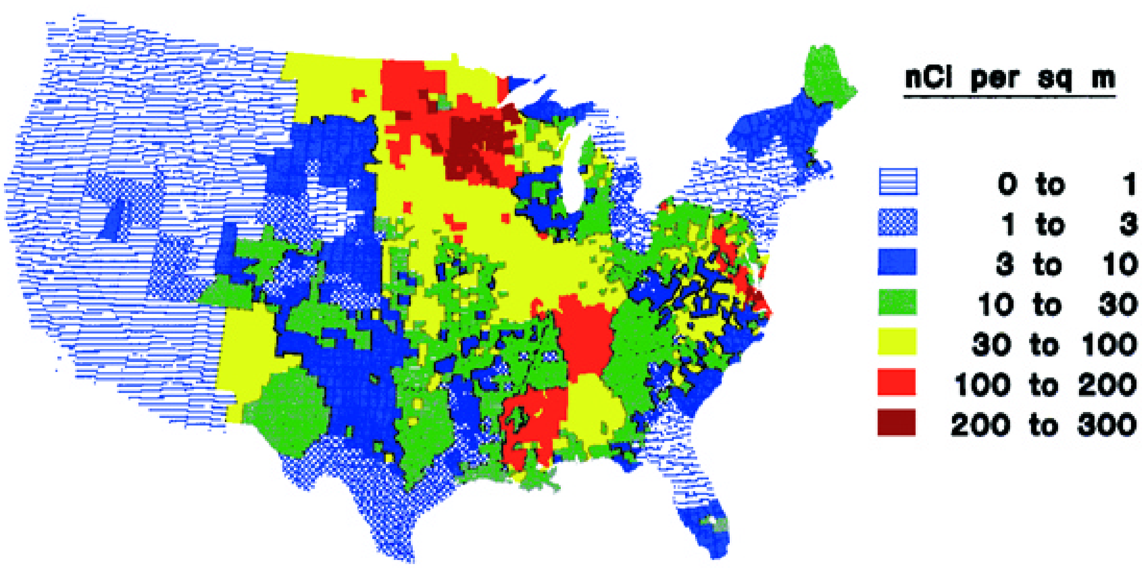


Figure 3.23. Estimates of ^{131}I deposition per unit area of ground obtained using the meteorological transport model for April 29, 1953 following the test Simon detonated on April 25, 1953 for all counties of the contiguous United States in which precipitation was recorded.

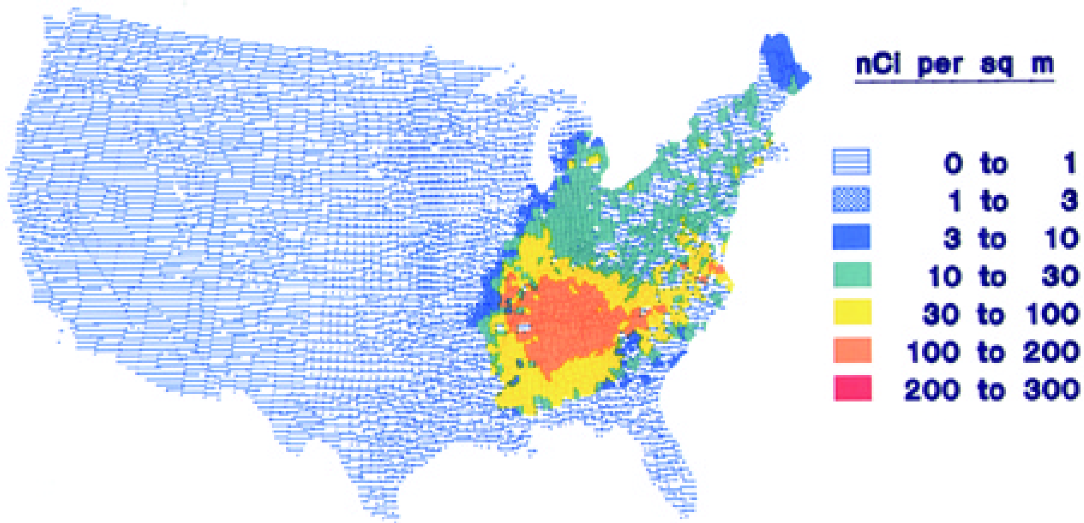


Figure 3.24. Estimates of ^{131}I activity in the radioactive cloud per unit area of ground obtained using the meteorological transport model on April 29, 1953 following the test Simon detonated on April 25, 1953 for all counties of the contiguous United States.

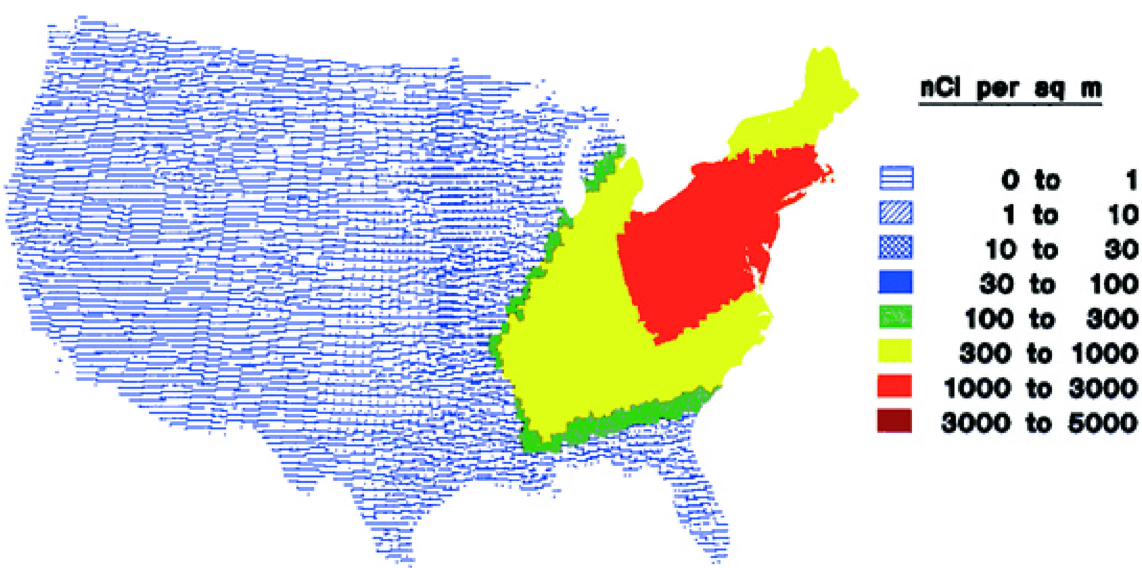


Figure 3.25. Distribution of the ratios of the estimates of ^{131}I deposition per unit area of ground derived from the gummed-film measurements by the AIPC method and by the kriging method for April 29, 1953 resulting from the test Simon detonated on April 25, 1953 for all counties of the United States with estimated non-zero deposition by the kriging method.

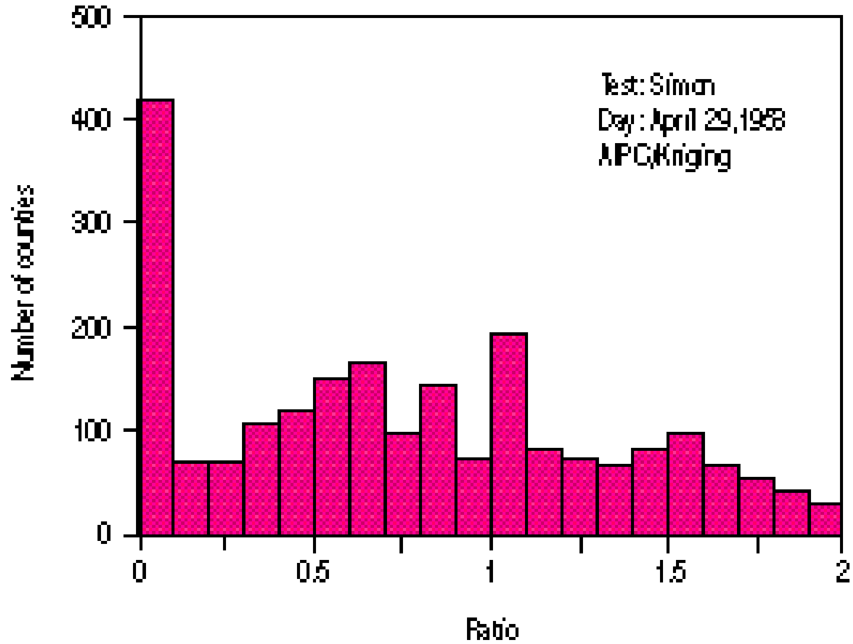


Figure 3.26. Distribution of the ratios of the estimates of ^{131}I deposition per unit area of ground derived from the meteorlogical model and from gummed-film measurements by the kriging method for April 29, 1953 resulting from the test Simon detonated on April 25, 1953 for all counties of the United States with estimated non-zero deposition by the kriging method.

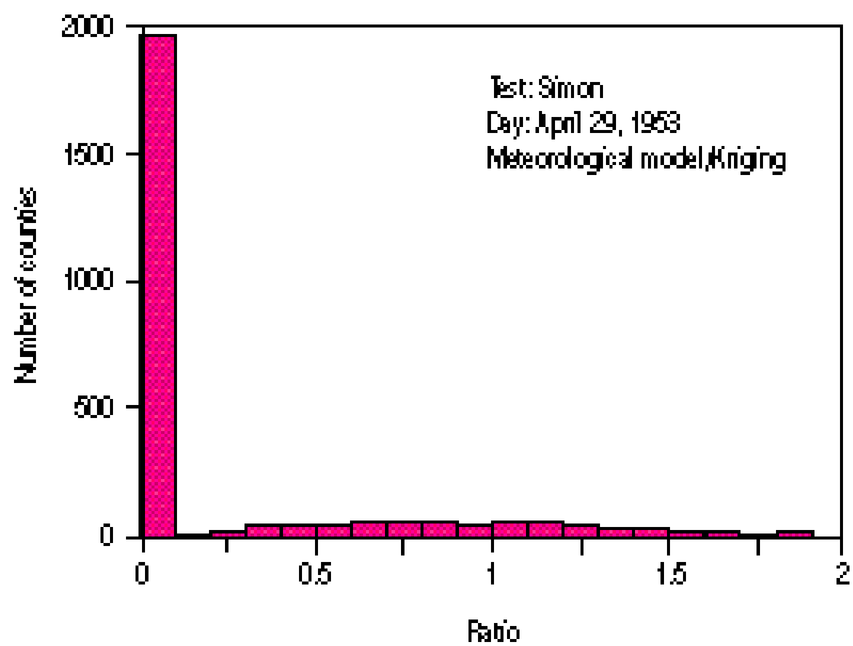


Figure 3.27. Estimates of ^{131}I deposition per unit area of ground derived by the kriging method from the gummed-film measurements for July 8, 1957 following the test Hood detonated on July 5, 1957 for all counties of the contiguous United States.

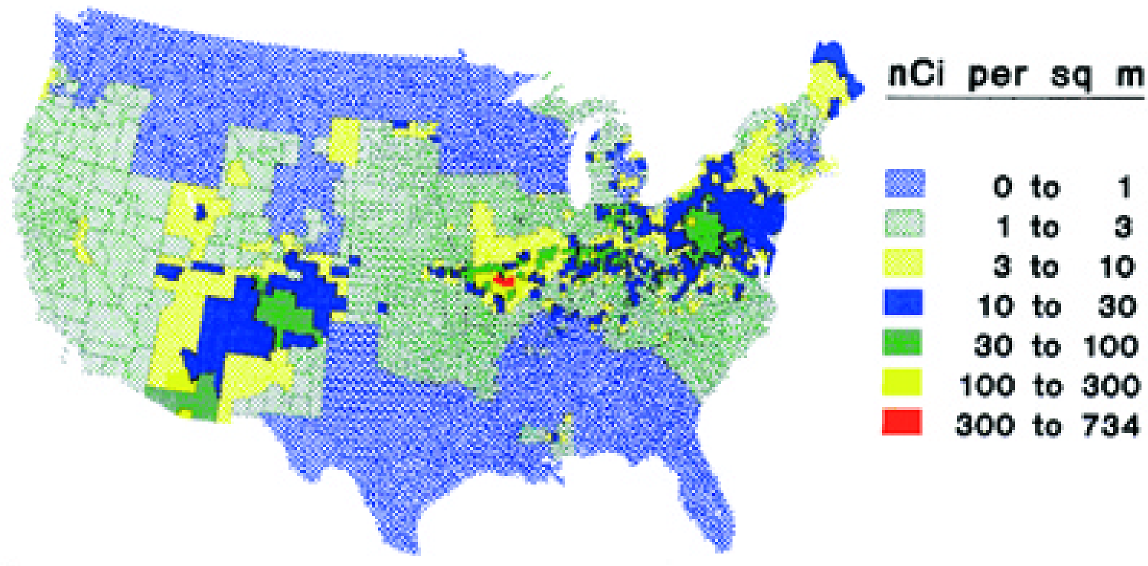


Figure 3.28. Estimates of ^{131}I deposition per unit area of ground derived by the AIPC method from the gummed-film measurements for July 8, 1957 following the test Hood detonated on July 5, 1957 for all counties of the contiguous United States.

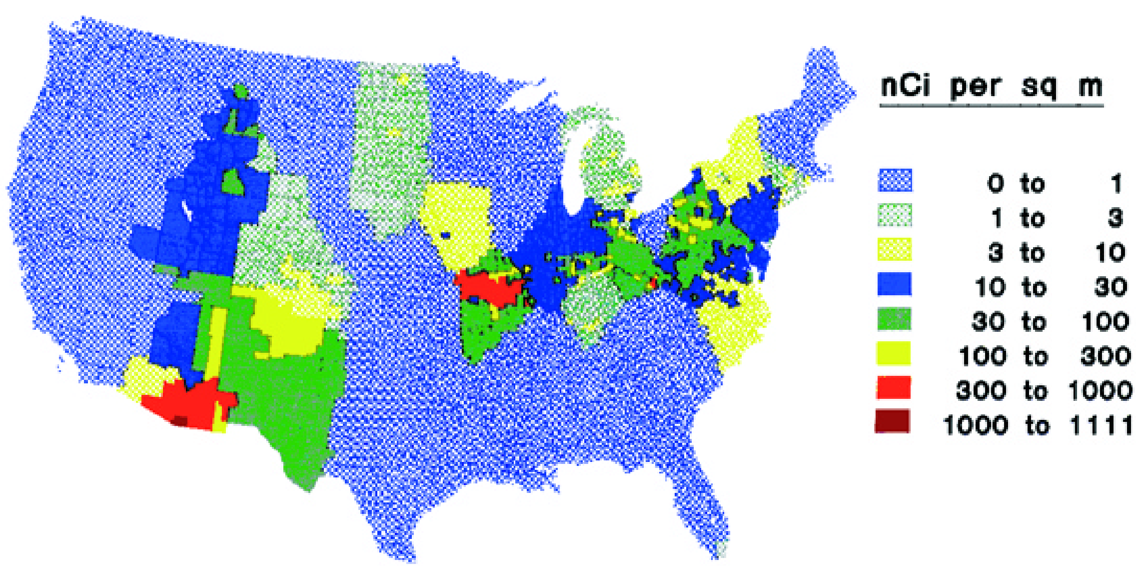
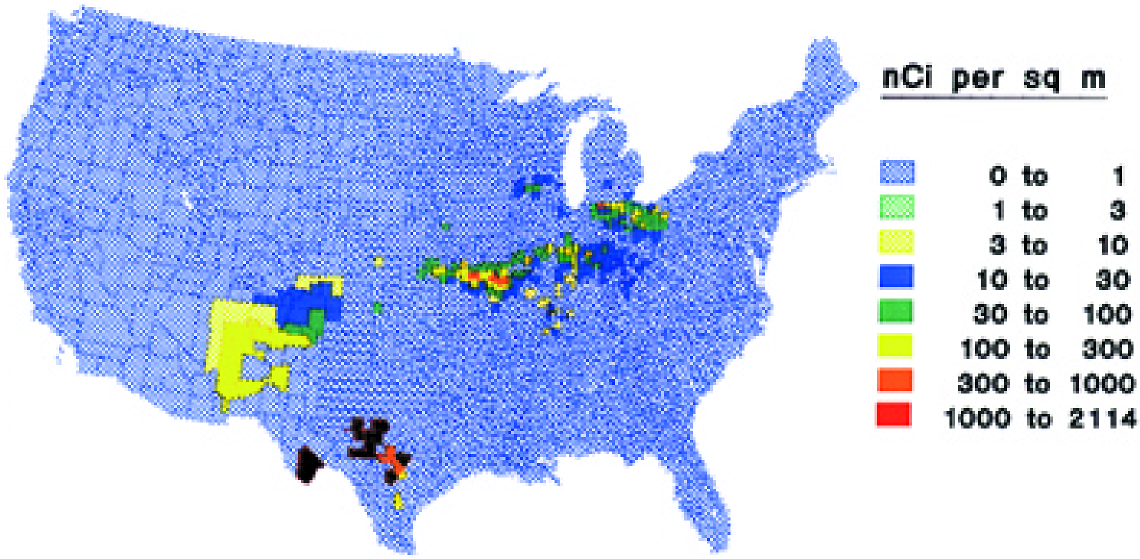


Figure 3.29. Estimates of ^{131}I deposition per unit area of ground obtained using the meteorological transport model on July 8, 1957 following the test Hood detonated on July 5, 1957 for all counties of the contiguous United States, in which precipitation was recorded.



presented in *Figures 3.27, 3.28,* and *3.29,* respectively. *Figures 3.27* and *3.28* are similar and show that both the kriging and the AIPC methods predicted depositions of ^{131}I across the country from the far west to the eastern seaboard; the deposition pattern obtained with the kriging method, however, is more extensive than the one observed with the AIPC method, notably in California, Oregon, Nebraska, Kansas, Oklahoma, and Maine, but the ^{131}I depositions obtained with the kriging method in those States are generally low. The AIPC model predicted some higher depositions in New Mexico and Texas and also over a greater area in west Texas.

In comparison, the deposited area obtained with the meteorological model is limited to a smaller part of the country as the cloud coverage predicted by that model (*Figure 3.30*) is only a diagonal band extending from New Mexico and Texas to Ohio. Some relatively high depositions were predicted for some countries in southwest Texas by the meteorological transport model.

The histogram containing the ratios of the ^{131}I depositions obtained in the same counties using the AIPC and kriging methods (*Figure 3.31*) shows a relatively good agreement between the two methods, with many ratios close to one. In about 700 counties no deposition was predicted by the AIPC method but some deposition was estimated by the kriging method. *Figure 3.32,* comparing the estimates of ^{131}I deposition obtained with the meteorological model and with the kriging method, shows, as was the case for the two other days (**Sections 3.4.2.1** and **3.4.2.2**) for which a similar comparison was made, that the agreement is not as good as between the kriging method and the AIPC method.

3.4.3. Summary

Both the meteorological transport modeling technique and the re-analysis of nationwide historical data have limitations. The calculated position of the radioactive cloud is not always in agreement with the areas of deposition derived from monitoring data, usually because of the simplifying assumptions used to calculate transport and dispersion of the cloud. In particular, measured depositions often occurred over a longer period of time than predicted by the meteorological model. In addition, although the meteorological model has the potential of predicting ^{131}I deposition by wet processes, it can only do so in a crude way for those areas where precipitation occurred during the predicted passage of the radioactive cloud. The meteorological model, however, can be applied to all tests for which there are no historical monitoring data.

The re-analysis of nationwide historical monitoring data, on the other hand, provides the best available estimates of ^{131}I deposition per unit area. However, under the best conditions, measurements were made at only about 100 locations and interpolation is needed to estimate deposition at many other places. Finally, nationwide monitoring data have not been reported, or found, for a sizable number of tests. Despite these shortcomings, the deposition estimates based on the analysis of measured environmental radiation data, when available, are thought to be less uncertain than those calculated with the meteorological transport model.

In the near-NTS area, the deposition estimates derived from the vast array of monitoring data processed by ORERP constitutes the preferred method when those monitoring data are available.

The daily depositions of ^{131}I per unit area of ground have been estimated for each of the 3,094 counties and sub-counties of the contiguous United States. In order to estimate the ^{131}I deposition in any given county or sub-county, the following procedure, in which preference is systematically given to the monitoring data, has been applied:

- For the 157 counties or subcounties near the NTS, the deposition densities derived from the exposure rate data bases were adopted without modification when they were available. In the absence of such data, the depositions per unit area were interpolated from the gummed-film results. If no monitoring data were available, the ^{131}I deposition per unit area of ground was calculated using the meteorological model.

- In the remaining 2937 counties, the monitoring data used in this assessment are those of the HASL deposition (gummed-film) network. For those counties, two situations may arise:

  1. if monitoring data for a test are available (for up to about 100 sites), the estimation of the deposition densities at the county centroids was generally obtained by interpolation between the counties with measured data by means of the kriging procedure, using the daily rainfall amounts as a prediction parameter; however, if the gummed-film results are too spotty or very low, the estimation of the deposition density was obtained by using the simple AIPC procedure;

  2. if monitoring data for a test are not available, meteorological modeling was used to estimate deposition densities in the counties where precipitation occurred during the predicted passage of the radioactive cloud. Counties where precipitation did not occur during the predicted passage of the radioactive cloud were assigned a zero deposition.

Figure 3.30. Estimates of ^{131}I contained in the radioactive cloud per unit area of ground derived by the meteorological model for July 8, 1957 resulting from the test Hood detonated on July 5, 1957 for all counties of the contiguous United States.

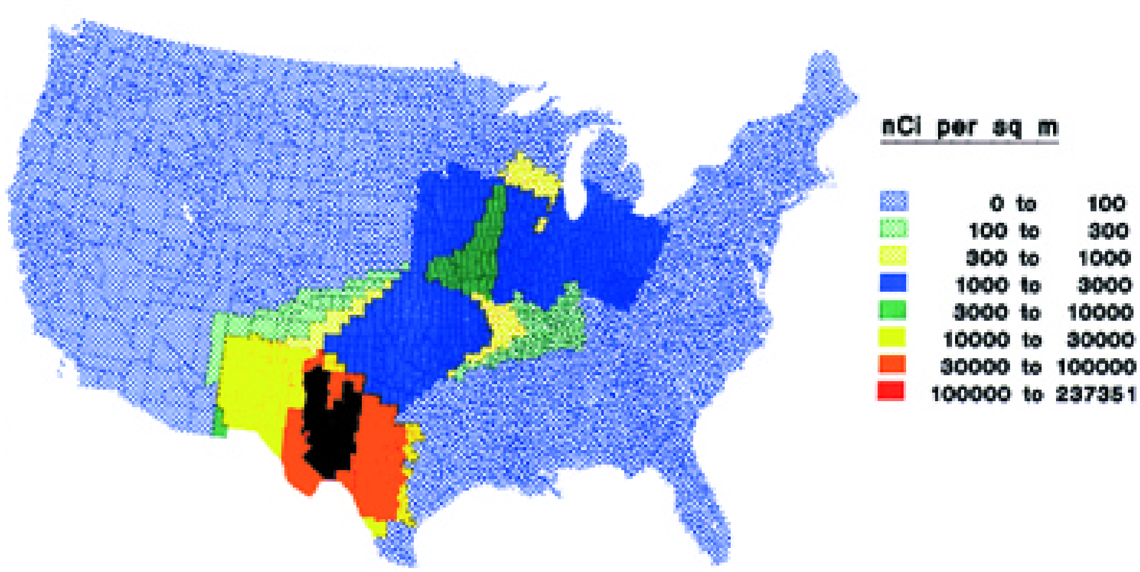


Figure 3.31. Distribution of the ratios of the estimates of ^{131}I deposition per unit area of ground derived from the gummed-film measurements by the AIPC method and by the kriging method for July 8, 1957 following the test Hood detonated on July 5, 1957 for all counties of the United States with estimated non-zero deposition by the kriging method.

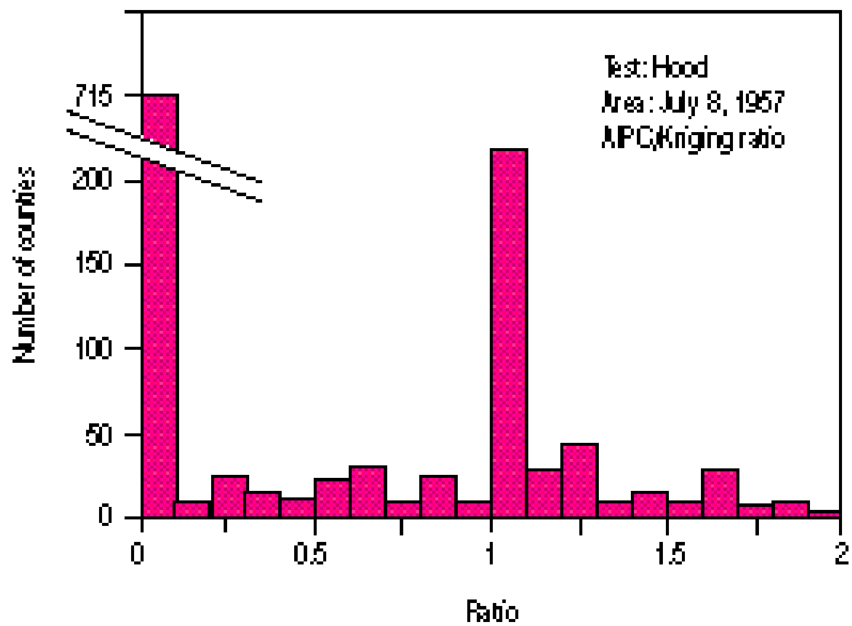
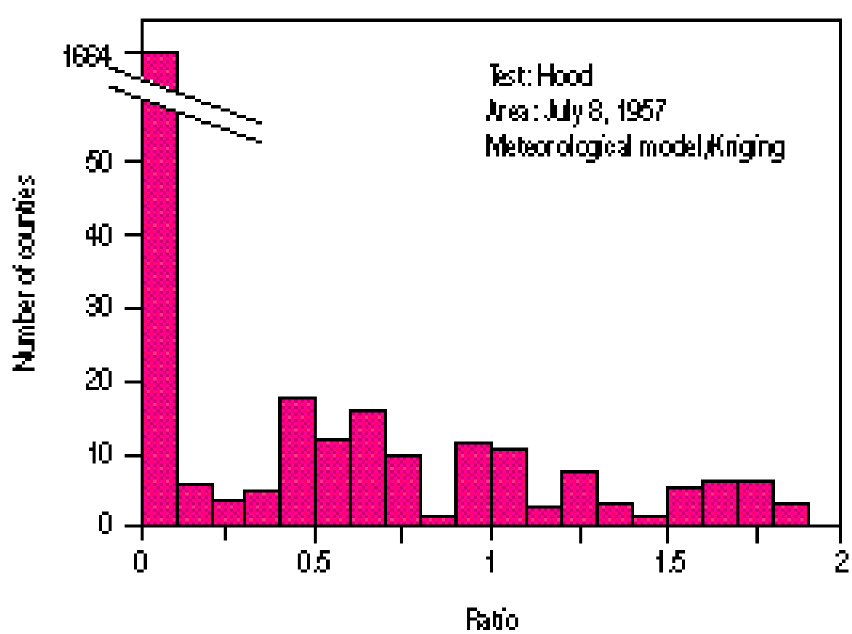


Figure 3.32. Distribution of the ratios of the estimates of ^{131}I deposition per unit area of ground derived from the meteorological transport model and from gummed-film measurements by the kriging method for July 8, 1957 following the test Hood detonated on July 5, 1957 for all counties of the United States with estimated non-zero deposition by the kriging method.



3.5. CLASSIFICATION OF THE NEVADA ATMOSPHERIC BOMB TESTS WITH RESPECT TO THE ESTIMATION OF DAILY ^{131}I DEPOSITIONS PER UNIT AREA OF GROUND

The tests carried out during the atmospheric testing era, from January 1951 through October 1958, are considered separately from those conducted in the underground testing era (1961 to 1992). Tests conducted during these two periods are discussed below.

3.5.1. Atmospheric Testing Era

The number of tests detonated at the NTS before October 31, 1958 was 119. The dates, times, types of test, and yields of these tests are given in *Table 2.1*. Those tests have been classified into 5 categories (*Table 3.9*) on the basis of the availability of monitoring data and the estimated amount of ^{131}I released to the atmosphere.

Category 1 includes the 38 tests which are shown from monitoring data to have led to significant depositions in substantial parts of the country. Most of those tests are tower shots and have yields in excess of 10 kt. The estimated total atmospheric release of ^{131}I from the 38 tests of category 1 amounts to about 100 MCi (about two thirds of the total release). Daily depositions from those tests have been determined by means of the kriging procedure for all counties except those near the NTS. For those counties, daily depositions were inferred from the exposure rates at H+12 and the times of arrival of fallout given for the 157 counties or sub-counties in the County Data Base and/or the Town Data Base provided by the ORERP (Beck and Anspaugh, 1991; Thompson and Hutchinson, 1988).

Category 2 consists of 17 tests for which the available gummed-film data show low and spotty depositions. Most of these tests are airdrop shots detonated at heights above ground in excess of 1000 feet (300 m). The estimated total atmospheric release of ^{131}I from the 17 tests of Category 2 is almost 33 MCi. Daily depositions from those tests for all counties of interest have been determined by means of the AIPC method for all counties except those near the NTS. For those counties, daily depositions were inferred from the exposure rates at H+12 and the times of arrival of fallout given in the County Data Base (Beck and Anspaugh, 1991) and/or the Town Data Base (Thompson and Hutchinson, 1988).

Category 3 includes 15 tests for which non-negligible deposition has been observed only near NTS. The total atmospheric release of ^{131}I from the 15 tests of category 3 is estimated to be about 8 MCi. Daily depositions for those tests were inferred from the exposure rates at H + 12 and the times of arrival of fallout given in the County Data Base (Beck and Anspaugh, 1991) and/or the Town Data Base (Thompson and Hutchinson, 1988).

Category 4 consists of three tests for which monitoring data are not available but which are thought to have possibly led to significant depositions of ^{131}I in the U.S. on the basis of their yield and type. Those tests, which were detonated in the Ranger series in the early part of 1951, have been analyzed using the meteorological model. The estimated total atmospheric release of ^{131}I from the three tests of category 4 amounts to about 6 MCi.

Category 5 consists of the 46 remaining tests that were shown from the measurement of β activity on gummed film to have led to negligible ^{131}I depositions or that are thought to have led to negligible depositions on the basis of their yield (less than 1 kt). The estimated total atmospheric release of ^{131}I from the 46 tests of category 5 is about 2 Mci, slightly more than 1 percent of the total release. Dose assessments have not been carried out for tests in Category 5.

3.5.2. Underground Testing Era

All of the tests performed since 1961, with the exception of Small Boy and of Little Feller I, were detonated underground. A few of these tests resulted in small off-site depositions of ^{131}I due to venting. The gummed-film program had been discontinued in 1960, however, and replaced by the PHS environmental network. The results provided by the PHS network have not been used in this assessment because the ^{131}I depositions due to NTS tests, beyond the local area, were overshadowed by the fallout resulting from much larger tests carried out by the U.S. in the Pacific or by other countries. The only environmental data that can be systematically used for the tests carried out since 1961 are those of the Town and County Data Bases close to the NTS.

The six tests of the underground test era for which dose assessments were carried out by means of the meteorological model are listed in category 6 in *Table 3.10*. They consist of four cratering tests, one low-yield tower test, and one underground test; each of those tests released into the atmosphere an activity of ^{131}I greater than 70 kCi. The total activity of ^{131}I released into the atmosphere by those six tests is about 2 MCi.

Table 3.9. Classification and characteristics of tests of the atmospheric era.

Test name	Date		Type	Atmospheric release of ^{131}I (kCi)	Burst height above ground (m)	Cloud height	
	mo/d/y	hr/min (GMT)				base (km MSL)	top (km MSL)
CATEGORY 1: INTERPOLATION OF GUMMED-FILM DATA BY KRIGING							
CHARLIE	10/30/51	1500	airdrop	2000	345	9.8	12.2
EASY	05/07/52	1215	tower	1800	90	N.A.	10.4
FOX	05/25/52	1200	tower	1600	90	N.A.	12.5
GEORGE	06/01/52	1155	tower	2200	90	N.A.	11.3
HOW	06/05/52	1155	tower	2100	90	N.A.	12.5
ANNIE	03/17/53	1320	tower	2400	90	8.5	12.5
NANCY	03/24/53	^{131}0	tower	3600	90	7.9	12.8
DIXIE	04/06/53	1530	airdrop	1700	1800	10.1	13.1
BADGER	04/18/53	1235	tower	3500	90	7.0	10.7
SIMON	04/25/53	1230	tower	6300	90	9.4	13.7
HARRY	05/19/53	1205	tower	4600	90	8.2	13.1
GRABLE	05/25/53	1530	airburst	2100	160	7.0	11.6
CLIMAX	06/04/53	1115	airdrop	8600	410	10.7	13.1
TESLA	03/01/55	1330	tower	1200	90	5.5	9.1
TURK	03/07/55	1320	tower	6400	150	11.0	13.4
HORNET	03/12/55	1320	tower	620	90	8.2	10.7
APPLE 1(1)	03/29/55	1255	tower	2000	150	6.7	9.8
+ WASP PRIME(1)	03/29/55	1800	airdrop	450	225	N.A.	9.8
POST	04/09/55	1230	tower	340	90	4.0	4.9
MET	04/15/55	1915	tower	3100	120	9.4	12.2
APPLE 2	05/05/55	1210	tower	4100	150	10.4	13.1
ZUCCHINI	05/15/55	1200	tower	4000	150	7.6	10.7
BOLTZMANN(1)	05/28/57	1155	tower	1900	150	7.0	10.1
+ FRANKLIN(1)	06/02/57	1155	tower	19	90	4.3	5.2
+ LASSEN(1)	06/05/57	1145	balloon	0.1	150	N.A.	2.1
WILSON	06/18/57	1145	balloon	1500	150	7.6	10.7
PRISCILLA	06/24/57	1330	balloon	5300	210	7.3	13.1
HOOD	07/05/57	1140	balloon	11000	460	10.7	14.6
DIABLO	07/15/57	1130	tower	2500	150	6.1	9.8
KEPLER(1)	07/24/57	1150	tower	1700	150	6.1	8.5
+ OWENS(1)	07/25/57	1330	balloon	1700	150	6.1	10.7
SHASTA	08/18/57	1200	tower	2500	150	4.9	9.8
GALILEO	09/02/57	1240	tower	1900	150	5.2	11.3
WHEELER	09/06/57	1245	balloon	27	150	4.3	5.2
+ COULOMB B(1)	09/06/57	N.A.	surface	42	N.A.	N.A.	5.5
+ LAPLACE(1)	09/08/57	1300	balloon	140	230	4.3	6.1
WHITNEY	09/23/57	1230	tower	2900	150	5.5	9.1
CHARLESTON	09/28/57	1300	balloon	1800	460	6.1	9.8
Total release (rounded)				100000			

Table 3.9. cont'd

Test name	Date		Type	Atmospheric release of ^{131}I (kCi)	Burst height above ground (m)	Cloud height	
	mo/d/y	hr/min (GMT)				base (km MSL)	top (km MSL)
CATEGORY 2: USE OF THE AIPC METHOD							
BAKER	10/28/51	1520	airdrop	600	340	7.0	8.8
DOG	11/01/51	1530	airdrop	3100	430	8.2	12.2
EASY	11/05/51	1630	airdrop	4500	400	9.4	13.7
SUGAR	11/19/51	1320	surface	170	1	3.4	4.9
ABLE	04/01/52	1700	airdrop	140	240	N.A.	4.9
BAKER	04/15/52	1730	airdrop	140	320	3.0	4.9
CHARLIE	04/22/52	1730	airdrop	4600	1050	9.4	12.8
DOG	05/01/52	1630	airdrop	2900	320	8.5	12.8
RUTH	03/31/53	1300	tower	28	90	3.4	4.3
RAY	04/11/53	1245	tower	28	30	2.4	4.0
ENCORE	05/08/53	1530	airdrop	3900	740	8.8	12.5
BEE(1)	03/22/55	1305	tower	1200	150	8.8	12.2
+ ESS(1)	03/23/55	2030	crater	140	-20	N.A.	3.7
DOPPLER	08/23/57	1240	balloon	1700	460	7.0	11.6
SMOKY	08/31/57	1230	tower	6400	210	6.1	11.6
NEWTON	09/16/57	1250	balloon	2100	460	5.8	9.8
MORGAN	10/07/57	1300	balloon	1200	460	7.9	12.2
Total release (rounded)				33000			
CATEGORY 3: USE OF LOCAL MONITORING ONLY							
UNCLE(2)	11/29/51	1700	crater	170	-5	N.A.	3.4
WASP(2)	02/18/55	2000	airdrop	160	230	4.6	6.7
MOTH(2)	02/22/55	1345	tower	320	90	4.9	7.6
STOKES(2)	08/07/57	1225	balloon	2800	460	8.2	11.3
FRANKLIN P.(2)	08/30/57	1240	balloon	690	230	6.4	9.8
FIZEAU(2)	09/14/57	1645	tower	1700	150	8.2	12.2
EDDY(2)	09/19/58	1400	balloon	12	150	2.3	3.4
HIDALGO(2)	10/05/58	1410	balloon	11	100	2.4	3.7
QUAY(2)	10/10/58	1430	balloon	11	30	2.1	3.0
LEA(2)	10/13/58	1320	balloon	240	460	3.7	5.2
VESTA(2)	10/17/58	2300	surface	4	0	N.A.	3.0
RIO ARRIBA(2)	10/18/58	1425	tower	120	22	3.4	4.1
WRANGELL(2)	10/22/58	1650	balloon	17	460	2.1	3.0
SOCORRO(2)	10/22/58	1330	balloon	1000	440	6.1	7.9
SANFORD(2)	10/26/58	1020	balloon	750	460	3.8	7.9
Total release (rounded)				8000			

Table 3.9. cont'd

Test name	Date		Type	Atmospheric release of ^{131}I (kCi)	Burst height above ground (m)	Cloud height	
	mo/d/y	hr/min (GMT)				base (km MSL)	top (km MSL)
CATEGORY 4: USE OF THE METEOROLOGICAL MODEL							
BAKER	01/28/51	1352	airdrop	1300	330	N.A.	10.7
BAKER-2	02/02/51	1349	airdrop	1300	335	N.A.	11.0
FOX	02/06/51	1347	airdrop	3200	440	N.A.	12.8
Total release (rounded)				5800			
CATEGORY 5: NOT INCLUDED IN THE ASSESSMENT							
ABLE	01/27/51	1345	airdrop	140	320	N.A.	5.2
EASY	02/01/51	1347	airdrop	160	330	N.A.	3.7
ABLE	10/22/51	1400	tower	N.D.	30	2.0	2.4
HA(2)	04/06/55	1800	airdrop	450	11000	N.A.	16.8
PROJECT 56/1	11/01/55	2210	surface	N.P.	0	N.A.	N.A.
PROJECT 56/2	11/03/55	2115	surface	N.P.	0	N.A.	N.A.
PROJECT 56/3	11/05/55	1955	surface	N.P.	0	N.A.	N.A.
PROJECT 56/4	01/18/56	2130	surface	N.P.	0	N.A.	N.A.
COULOMB-A(2)	07/01/57	N.A.	surface	N.D.	0	N.A.	N.A.
JOHN(2)	07/19/57	1400	rocket	250	6100	N.A.	13.4
PASCAL-A(2)	07/26/57	0800	shaft	10	N.A.	N.A.	N.A.
SATURN	08/10/57	N.A.	tunnel	N.D.	N.A.	N.A.	N.A.
PASCAL-B(2)	08/27/57	N.A.	shaft	N.D.	N.A.	N.A.	N.A.
RAINIER	09/19/57	1700	tunnel	N.D.	-240	N.A.	N.A.
PASCAL-C	12/06/57	2015	shaft	N.D.	N.A.	N.A.	N.A.
COULOMB-C(2)	12/09/57	2000	surface	69	N.A.	N.A.	N.A.
VENUS	02/22/58	N.A.	tunnel	N.D.	N.A.	N.A.	N.A.
URANUS	03/14/58	N.A.	tunnel	N.D.	N.A.	N.A.	N.A.
OTERO(2)	09/12/58	2000	shaft	6	-150	N.A.	N.A.
BERNANILLO	09/17/58	1930	shaft	N.D.	-140	N.A.	N.A.
LUNA	09/21/58	1900	shaft	N.D.	-150	N.A.	N.A.
MERCURY	09/23/58	N.A.	tunnel	N.D.	N.A.	N.A.	N.A.
VALENCIA	09/26/58	2000	shaft	N.D.	-150	N.A.	N.A.
MARS	09/28/58	0000	tunnel	N.D.	N.A.	N.A.	N.A.
MORA(2)	09/29/58	1405	balloon	340	460	3.0	5.5
COLFAX	10/05/58	1615	shaft	N.D.	-110	N.A.	N.A.
TAMALPAIS	10/08/58	2200	tunnel	N.D.	-100	N.A.	N.A.
NEPTUNE	10/14/58	1800	tunnel	N.D.	-30	N.A.	N.A.
HAMILTON(2)	10/15/58	1600	tower	0.2	15	1.4	1.8
LOGAN	10/16/58	0600	tunnel	N.D.	-250	N.A.	N.A.
DONA ANA(2)	10/16/58	1420	balloon	6	140	2.0	3.4
SAN JUAN	10/20/58	N.A.	shaft	N.D.	N.A.	N.A.	N.A.
RUSHMORE(2)	10/22/58	2340	balloon	17	150	N.A.	3.4
OBERON	10/22/58	N.A.	tower	N.D.	N.A.	N.A.	N.A.
CATRON(2)	10/24/58	1500	tower	4	22	1.5	2.4
JUNO	10/24/58	1601	surface	N.D.	0	N.A.	1.5
CERES	10/26/58	0400	tower	N.D.	7	N.A.	1.8
DE BACA(2)	10/26/58	1600	balloon	380	460	3.0	5.3

Table 3.9. cont'd

Test name	Date		Type	Atmospheric release of ^{131}I (kCi)	Burst height above ground (m)	Cloud height	
	mo/d/y	hr/min (GMT)				base (km MSL)	top (km MSL)
CATEGORY 5: NOT INCLUDED IN THE ASSESSMENT							
CHAVEZ(2)	10/27/58	1430	tower	0.1	16	N.A.	2.0
EVANS	10/29/58	0000	tunnel	N.D.	-260	N.A.	N.A.
HUMBOLDT(2)	10/29/58	1445	tower	1	7	1.8	2.1
MAZAMA	10/29/58	N.A.	tower	N.D.	N.A.	N.A.	N.A.
SANTA FE(2)	10/30/58	0300	balloon	220	460	4.0	5.5
TITANIA(2)	10/30/58	2034	tower	0.03	7	N.A.	1.8
BLANCA(2)	10/30/58	N.A.	tunnel	0.51	-250	N.A.	N.A.
GANYMEDE	10/30/58	N.A.	surface	N.D.	N.A.	N.A.	N.A.
Total release (rounded)				2100			

(1) these 2 or 3 shots adjacent in time were combined in the analysis because the resulting fallout in most of the country could not be unambiguously attributed to a single shot.
(2) gummed-film data are available but the derived ^{131}I depositions were judged to be negligible.
N.A. = data not available.
N.D. = no off-site detection of radioactive materials; ^{131}I release cannot be estimated but is believed to be quite small.
N.P. = no production of ^{131}I in these "safety shots" because no fission occurred.

There are 11 tests for which the activity of ^{131}I released into the atmosphere was less than 70 kCi but which gave rise to environmental activities detectable by the local monitoring network. They are included in this assessment as Category 7 (see *Table 3.10*). All together, the amount of ^{131}I activity released is about 0.1 MCi.

Table 3.10 also lists, for comparison purposes, the other 25 tests (category 8) that were reported to have released radioactive gases and particles to the atmosphere that resulted in detection off site (U.S. Department of Energy 1988), but that have not been included in the Town Data Base or in the County Data Base. All but one of these tests was underground. Dose assessments have not been carried out for those tests because the ^{131}I atmospheric releases involved were very small (total of 0.004 MCi).

In addition, more than 400 other announced nuclear tests were reported to have resulted in no detection of radioactivity off site (U.S. Department of Energy 1988). Those tests are not listed in *Table 3.10*.

3.5.3. Summary

The nuclear weapons tests that were detonated at the NTS were classified into the following eight categories:

1. Tests detonated during the atmospheric era (1951 to 1958) for which many positive deposition results are available nationwide. The kriging procedure was used throughout the country except for the 157 counties and subcounties near the NTS where the ^{131}I depositions per unit area of ground were derived from the Town and County Data Bases, when available.

2. Tests detonated during the atmospheric era (1951 to 1958) for which only a few positive deposition results are available nationwide. The AIPC procedure was used throughout the country except for the 157 counties and subcounties near the NTS where the ^{131}I depositions per unit area of ground were derived from the Town and County Data Bases, when available.

3. Tests detonated during the atmospheric era (1951 to 1958) for which positive deposition results were obtained only near the NTS. The ^{131}I depositions per unit area of ground were estimated from the Town and County Data Bases monitoring data.

Table 3.10. Classification of tests of the atmospheric era that led to off-site detection of radioactive materials (Hicks 1981b).

Test name	Date		Type	Atmospheric release of ^{131}I (kCi)
	mo/d/y	hr/min (GMT)		
CATEGORY 6: USE OF THE METEOROLOGICAL MODEL				
DANNY BOY	03/05/62	1815	crater	73
SEDAN	07/06/62	1700	crater	880
JOHNIE BOY	07/11/62	1645	crater	70
SMALL BOY	07/14/62	1830	tower	270
PALANQUIN	04/14/65	^{131}4	crater	910
BANEBERRY	12/18/70	1630	shaft	80
Total release (rounded)				2300
CATEGORY 7: USE OF LOCAL MONITORING ONLY				
ANTLER	09/15/61	1600	tunnel	0.0042
PLATTE	04/14/62	1900	tunnel	0.0114
EEL	05/19/62	1700	shaft	0.0114
DES MOINES	06/13/62	2200	tunnel	33
BANDICOOT	10/19/62	1900	shaft	9
PIKE	03/13/64	1702	shaft	0.36
SULKY	12/18/64	1935	crater	13
PIN STRIPE	04/25/66	1938	shaft	0.2
CABRIOLET	01/26/68	1600	crater	6
BUGGY	03/12/68	1704	crater	40
SCHOONER	12/08/68	1600	crater	15
Total release (rounded)				120
CATEGORY 8: NOT INCLUDED IN THE ASSESSMENT				
FEATHER	12/22/61	1730	tunnel	0.00114
PAMPAS	03/01/62	2010	shaft	0.000012
LITTLE FELLER I	07/17/62	1700	surface	3
YUBA	06/05/63	1800	tunnel	0.000022
EAGLE	12/12/63	1702	shaft	0.00228
ALVA	08/19/64	1700	shaft	0.000037
DRILL	12/05/64	2215	shaft	0.0122
PARROT	12/16/64	2100	shaft	0.0046
ALPACA	02/12/65	1610	shaft	0.000024
TEE	05/07/65	1647	shaft	0.0016
DILUTED WATERS	06/16/65	1730	shaft	0.0177
RED HOT	03/05/66	1915	tunnel	0.2
DOUBLE PLAY	06/15/66	1800	tunnel	0.12
DERRINGER	09/12/66	1630	shaft	0.00024
NASH	01/19/67	1745	shaft	0.0138
MIDI MIST	06/26/67	1700	tunnel	0.00026

Table 3.10. cont'd

Test name	Date		Type	Atmospheric release of ^{131}I (kCi)
	mo/d/y	hr/min (GMT)		
CATEGORY 8: NOT INCLUDED IN THE ASSESSMENT				
UMBER	06/29/67	1225	shaft	0.00052
DOOR MIST	08/31/67	1730	tunnel	0.008
HUPMOBILE	01/18/68	1730	shaft	0.12
POD	10/29/69	2100	shaft	0.000078
SCUTTLE	11/13/69	1515	shaft	0.000004
SNUBBER	04/21/70	1530	shaft	0.0055
MINT LEAF	05/05/70	1630	tunnel	0.08
DIAGONAL LINE	11/24/71	2015	shaft	0.00136
RIOLA	09/25/80	0826	shaft	0.00058
Total release (rounded)				4

4. Tests detonated during the atmospheric era (1951 to 1958) for which no environmental radiation data are available but which were thought to have resulted in substantial ^{131}I depositions per unit area of ground on the basis of their yield and type. The meteorological model was used throughout the country.

5. Tests detonated during the atmospheric era (1951 to 1958) for which no environmental radiation data are available and which, on the basis of their yield and type, were thought to have led to negligible ^{131}I depositions per unit area of ground. Deposition estimates are not provided for these tests.

6. Tests detonated during the underground era (1961 to date) for which positive deposition results were available near the NTS and for which the estimated activity release of ^{131}I into the atmosphere per test was greater than 70 kCi. The estimates of ^{131}I depositions per unit area of ground in the 157 counties and subcounties near the NTS were estimated from the Town and County Data Bases monitoring data. The meteorological model was used in the remainder of the country.

7. Tests detonated during the underground era (1961 to date) for which positive deposition results were available near the NTS and for which the individual estimated activity release of ^{131}I into the atmosphere was less than 70 kCi. The estimates of ^{131}I depositions per unit area of ground in the 157 counties and subcounties near the NTS were estimated from the Town and County Data Bases monitoring data. Deposition estimates are not provided for the remainder of the country.

8. Tests detonated during the underground era (1961 to date) for which no environmental radiation data are available and for which the estimated individual activity release of ^{131}I into the atmosphere was less than 70 kCi. Deposition estimates are not provided for these tests.

The distribution of the total atmospheric releases of ^{131}I as a function of the test category is presented as a histogram in *Figure 3.33*. This Figure shows that deposition estimates are calculated for all counties of the contiguous United States for the tests which represent the bulk of the ^{131}I activity released into the atmosphere (Categories 1, 2, and 4). Deposition estimates are only calculated for the 157 counties and sub-counties near the NTS for tests of category 3, which represent a small percentage of the total activity of ^{131}I that was released into the atmosphere. The tests for which no estimates of deposition are provided in this report (categories 5 and 8) represent a very small percentage of the total activity of ^{131}I that was released into the atmosphere.

Figure 3.33. Total atmospheric release of I-131 (MCi) according to test category.

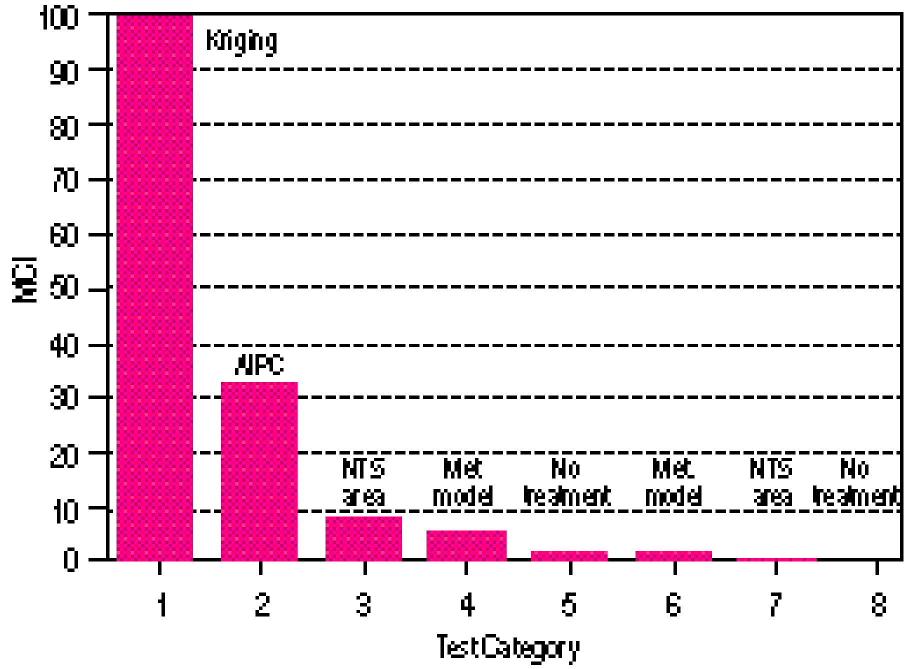
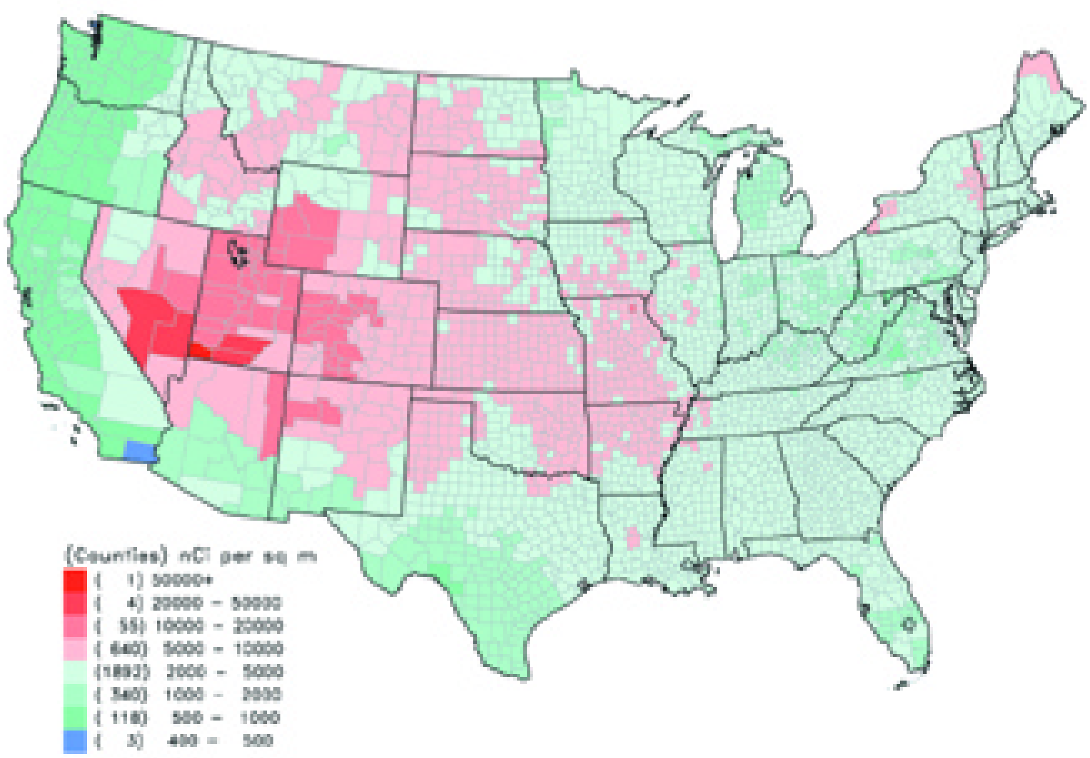


Figure 3.34. Activities of I-131 deposited per unit area of ground: All tests



3.6. ESTIMATES OF ^{131}I DEPOSITION PER UNIT AREA OF GROUND

Daily deposition densities of ^{131}I have been calculated for the 90 tests for which dose assessments have been carried out. The complete results, day by day and county by county for all shots, are presented in the Sub-annexes. This information (daily ^{131}I depositions per unit area of ground together with corresponding precipitation indices) constitutes the primary computer database from which all dose estimates were derived. The total ^{131}I depositions for each test, each test series, and each county are presented in the form of maps in the Annexes.

For illustrative purposes, *Figure 3.34* presents the distribution of the total ^{131}I depositions per unit area of ground, summed over all 90 tests, for all counties of the contiguous United States. The thyroid doses, however, are not directly proportional to the total ^{131}I depositions as intervening factors, such as interception by vegetation or presence of cows on pasture, need to be taken into account.

A summary of the estimates of ^{131}I deposited on the ground in the areas covered by the Town and County Data Bases as well as in the 48 contiguous states is presented in *Table 3.11*. In this summary, deposition estimates for some tests have been combined. This is indicated by one or more "+" in the second column. For example, "Wheeler++" in the Plumbob series includes fallout from the Wheeler, Coulomb B, and LaPlace tests (see *Table 3.9*). The test that is estimated to have led to the greatest amount of ^{131}I deposition in the U.S. is test Harry detonated on 19 May 1953. The total activity of ^{131}I that is estimated to have been deposited on the ground as a result of the tests conducted at the NTS amounts to about 25 % of the total activity of ^{131}I released into the atmosphere.

3.7. SUMMARY

- Best estimates of activities of ^{131}I deposited per unit area of ground (also called depositions or deposition densities) have been produced for 90 shots, out of a total of 115 shots that are reported to have released radioactive gases or ^{131}l to the atmosphere resulting in detection off-site. These 90 shots account for almost 99% of the total activity of ^{131}I that is estimated to have been released into the atmosphere by all shots conducted at the Nevada Test Site.

- For each of these 90 shots, median values of the activities of ^{131}I deposited per unit area of ground have been estimated for the 3,071 counties of the contiguous United States.

- Because of the heterogeneous character of the deposition field in the vicinity of the Nevada Test Site, 14 of the counties located in that area were subdivided into a total of 37 sub-counties; average values of the activities of ^{131}I deposited per unit area of ground have also been estimated for those 37 sub-counties.

- Historical environmental radiation measurements were used whenever possible to derive the best estimates of activities of ^{131}I deposited per unit area of ground. These historical environmental radiation measurements consist essentially of exposure-rate measurements near the Nevada Test Site and of measurements of the total beta activity deposited on stickysurfaces (gummed film) at 40-95 locations in the remainder of the country. Historical environmental radiation data were used for 81 of the shots that were analyzed.

- In the absence of historical environmental radiation data, a meteorological transport model was applied for 9 of the shots that were analyzed.

- The best estimates of the total activities of ^{131}I deposited per unit area of ground vary from county to county by four orders of magnitude. They are highest in the counties of Nevada and Utah that were downwind of the Nevada Test Site during the most important shots and lowest in the northwestern part of the country which was generally upwind of the Nevada Test Site. Some high depositions were obtained in the eastern part of the country where rainfall coincided with the passage of the radioactive cloud.

- The uncertainties attached to the deposition values are expressed in terms of geometric standard deviations, GSDs, around the best estimates. These GSDs, which vary according to a number of parameters (existence or non-existence of historical environmental radiation data in the county, type and quality of the data, method used to derive the deposition estimate in the absence of historical environmental radiation data, etc.), range from 1.5 to about 10 and are usually around 2 to 3.

Table 3.11. Estimates of activities of ^{131}I deposited on the ground in the areas covered by the Town and County Data Base and in the contiguous U.S.

Test I.D.	Name	Date	Type	^{131}I release (kCi)	^{131}I activities deposited (kCi)		
					TDB	CDB	U.S.
RA.1	BAKER	01/28/51	A[a]	1300	0	0	160
RA.2	BAKER-2	02/02/51	A	1300	0	0	36
RA.3	FOX	02/06/51	A	3200	0	0	1
BJ.1	BAKER	10/28/51	A	600	0	0	16
BJ.2	CHARLIE	10/30/51	A	2000	0	10	548
BJ.3	DOG	11/01/51	A	3100	0.3	0	132
BJ.4	EASY	11/05/51	A	4500	0	0	14
BJ.5	SUGAR	11/19/51	S[b]	170	29	125	242
BJ.6	UNCLE	11/29/51	C[c]	170	24	19	43
TS.1	ABLE	04/01/52	A	140	0	18	175
TS.2	BAKER	04/15/52	A	140	0	91	112
TS.3	CHARLIE	04/22/52	A	4600	0	35	228
TS.4	DOG	05/01/52	A	2900	0	20	58
TS.5	EASY	05/07/52	T[d]	1800	52	691	1269
TS.6	FOX	05/25/52	T	1600	112	431	1323
TS.7	GEORGE	06/01/52	T	2200	28	499	2843
TS.8	HOW	06/05/52	T	2100	54	451	2425
UK.1	ANNIE	03/17/53	T	2400	69	71	472
UK.2	NANCY	03/24/53	T	3600	72	590	1474
UK.3	RUTH	03/31/53	T	28	0	33	33
UK.4	DIXIE	04/06/53	A	1700	0	0	60
UK.5	RAY	04/11/53	T	28	0.02	36	70
UK.6	BADGER	04/18/53	T	3500	42	411	717
UK.7	SIMON	04/25/53	T	6300	115	1165	3233
UK.8	ENCORE	05/08/53	A	3900	0	0	171
UK.9	HARRY	05/19/53	T	4600	564	1612	3881
UK.10	GRABLE	05/25/53	A	2100	4	85	396
UK.11	CLIMAX	06/04/53	A	8600	5	98	233
TP.1	WASP	02/18/55	T	160	0	75	75
TP.2	MOTH	02/22/55	T	320	14	0	14
TP.3	TESLA	03/01/55	T	1200	28	45	164
TP.4	TURK	03/07/55	T	6400	82	314	920
TP.5	HORNET	03/12/55	T	620	14	91	287
TP.6	BEE + ESS	03/22/55	T	1300	8	41	121
TP.7	APPLE 1 +	03/29/55	T	2500	8	157	531
TP.8	POST	04/09/55	T	340	6	97	232
TP.9	MET	04/15/55	T	3100	107	279	747
TP.10	APPLE 2	05/05/55	T	4100	70	417	1787
TP.11	ZUCCHINI	05/15/55	T	4000	30	314	1132
PB.1	BOLTZMANN ++	05/28/57	T	1900	287	374	976
PB.2	WILSON	06/18/57	B[e]	1500	5	34	528
PB.3	PRISCILLA	06/24/57	B	5300	13	90	545
PB.4	HOOD	07/05/57	B	11000	2	194	821
PB.5	DIABLO	07/15/57	T	2500	141	139	1048

Table 3.11. cont'd

Test I.D.	Name	Date	Type	^{131}I Release (kCi)	^{131}I Activities deposited (kCi)		
					TDB	CDB	U.S.
PB.6	KEPLER +	07/24/57	T	3400	44	197	1020
PB.7	STOKES	08/07/57	B	2800	0	0	0
PB.8	SHASTA	08/18/57	T	2500	54	222	1073
PB.9	DOPPLER	08/23/57	B	1700	0.7	86	701
PB.10	FRANKLIN P.	08/30/57	B	690	0	0	0
PB.11	SMOKY	08/31/57	T	6400	115	660	1050
PB.12	GALILEO	09/02/57	T	1900	21	92	1014
PB.13	WHEELER ++	09/06/57	B	210	1	86	700
PB.14	FIZEAU	09/14/57	T	1700	4	25	89
PB.15	NEWTON	09/16/57	B	2100	0.4	30	258
PB.16	WHITNEY	09/23/57	T	2900	28	106	459
PB.17	CHARLESTON	09/28/57	B	1800	0	122	551
PB.18	MORGAN	10/07/57	B	1200	1	23	314
HT.1	EDDY	09/19/58	B	12	0.1	0	0.1
HT.2	HIDALGO	10/05/58	B	11	0.3	0	0.3
HT.3	QUAY	10/10/58	B	11	1	0	1
HT.4	LEA	10/13/58	B	240	1	0	1
HT.5	VESTA	10/17/58	S	4	0.007	0	0.007
HT.6	RIO ARRIBA	10/18/58	T	120	1	0	1
HT.7	SOCORRO	10/22/58	B	1000	0.2	0	0.2
HT.8	WRANGELL	10/22/58	B	17	0.02	0	0.02
HT.9	SANFORD	10/26/58	B	750	0.5	0	0.5
UE.1	ANTLER	09/15/61	U[f]	0.004	0.09	0	0.09
UE.2	DANNY BOY	03/05/62	C	73	0.1	0	76
UE.3	PLATTE	04/14/62	U	0.011	0.2	0	0.2
UE.4	EEL	05/19/62	U	0.011	0.02	0.02	0.02
UE.5	DES MOINES	06/13/62	U	33	9	0	9
UE.6	SEDAN	07/06/62	C	880	9	10	41
UE.7	JOHNIE BOY	07/11/62	C	70	2	0	89
UE.8	SMALL BOY	07/14/62	T	270	7	34	108
UE.9	BANDICOOT	10/19/62	U	9	3	0	3
UE.10	PIKE	03/13/64	U	0.4	0.06	0	0.06
UE.11	SULKY	12/18/64	U	13	0.02	0	0.02
UE.12	PALANQUIN	04/14/65	C	910	2	0	2030
UE.13	PIN STRIPE	04/25/66	U	0.2	1	8	9
UE.14	CABRIOLET	01/26/68	C	6	0.2	0	0.2
UE.15	BUGGY	03/12/68	C	40	0.05	0	0.05
UE.16	SCHOONER	12/08/68	C	15	0.4	0.7	1
UE.17	BANEBERRY	12/18/70	U	80	3	2	81
Totals (kCi)				149000	2320	10900	40100

[a] Airdrop
[b] Surface
[c] Crater
[d] Tower
[e] Balloon
[f] Underground

REFERENCES

Aitchinson, J.; Brown, J. A. C. The log-normal distribution. Cambridge University Press, London; 1969.

ANONYMOUS. Report of aerial monitoring and sampling for the Baneberry event, Dec. 18, 1970. National Environmental Research Center - Las Vegas, Environmental Protection Agency. Performed for U.S. Atomic Energy Commission;1975.

ANONYMOUS. Project Cabriolet aerial tracking and sampling, January 28, 1968. National Environmental Research Center - Las Vegas, Environmental Protection Agency. Performed for U.S. Atomic Energy Commission under AT(26-1)-539; 1976.

Barakat, R. Sums of independent log-normally distributed random variables. Journal of the Optical Society of America 66(3):211-216; 1976.

Beck, H. L.; Anspaugh, L. R. Development of the County Database: Estimates of exposure rates and times of arrival of fallout in the ORERP Phase-II Area. Comparison with cumulative deposition-density estimates based on analyses of retrospective and historical soil samples. United States Department of Energy report DOE/NV-320; 1991.

Beck, H. L.; Krey, P. W. External radiation exposure of the population of Utah from Nevada weapons tests. U.S. Department of Energy, Environmental Measurements Laboratory Report EML-401; 1982.

Beck, H. L. Estimates of fallout from Nevada weapons testing in the western United States based on gummed-film monitoring data. U.S. Department of Energy, Environmental Measurements Laboratory Report EML-433; 1984.

Beck, H. L.; Helfer, I. K.; Bouville, A.; Dreicer, M. Estimates of fallout in the continental U.S. from Nevada weapons testing based on gummed-film monitoring data. Health Phys. 59(5):565-576; 1990.

Blifford, I. H., Jr.; Friedman, H.; Lockhart, L.B., Jr.; Bass, R. A. Radioactivity of the air, Naval Research Laboratory Report NRL 4760. Washington, D.C.; 1956.

Burson, Z. G. A review of aerial radiological surveys of fallout fields 1951 through 1970. EG&G draft report; October 1984.

Crawford, T. V. Long-range travel and diffusion of the Buggy cloud. Lawrence Radiation Laboratory, University of California Report UCRL-50806; Livermore, CA; 1970.

Crow, E. L.; Shimizu, K. Log-normal distributions theory and applications. Marcel Dekker, Inc., New York; 1988.
Draxler, R. R. One year of tracer dispersion measurements over Washington, D.C. Atmos. Environ. 21(1):69-77; 1987.

Draxler, R. R. The persistence of pollutants downwind of a point source following termination of the emission. Boundary Layer Meteor. 42:43-53; 1988.

Eisenbud, M.; Harley, J. H. Radioactive fallout through September 1955. Science 124(3215):251-255; 1956.

Eisenbud, M.; Harley, J. H. Radioactive fallout in the United States. Science 121(3150):677-680; 1955.

Eisenbud, M.; Harley, J. H. Long-term fallout. Science 128(3321):399-402,1958a.

Eisenbud, M.; Harley, J. H. Summary of gummed-film results through June l957. U.S. Atomic Energy Commission Report HASL-24, 2-21; 1958b.

Eynon, B. P.; Switzer, P. The variability of acid rain. Canadian Journal of Statistics 11(1):11-24; 1983.

Fenton, L. F. The sum of log-normal probability distributions in scatter transmission systems. IRE Transactions on Communication Systems CS-8:57-67; 1960.

Gogolak, C. V.; Beck, H. L.; Hutter, A. R. Estimates of ^{131}I Deposition in U.S. counties from atmospheric weapons tests at the Nevada Test Site. paper #fam-c6, 33rd Annual Meeting of the Health Physics Society, Boston,MA, July 8, 1988, Health Phys. 54, Supplement 1; 1988.

Hague. - letter sent by Dave Wheeler - (1979)

Harley, J. H.; Hallden, N. A.; Ong, L. D. Y. Summary of gummed film results through December, 1959. Health and Safety Laboratory Report HASL-93; 1960.

Heffter, J. L. The variation of horizontal diffusion parameters with time for travel periods of one hour or longer. J. Appl. Meteor. 4(1):153-156; 1965.

Hicks, H. G. Results of calculations of external gamma radiation exposure rates from fallout and the related radionuclide compositions. Lawrence Livermore Laboratory Report UCRL-53152, Parts 1-8; Livermore, CA; 1981a.

Hicks, H. G. Radiochemical data collected on events from which radioactivity escaped beyond the borders of the Nevada Test Range Complex. Lawrence Livermore National Laboratory Report UCRL-52934; Livermore, CA; 1981b.

Hoecker, W. H.; Machta, L. Meteorological modeling of radioiodine transport and deposition within the continental United States. Health Phys. 59: 603-617; 1990.

Hoffman, F. O.; Frank, M. L.; Blaylock, B. G.; von Bernuth, R. D.;

Deming, E. J.; Graham, R.V.; Mohrbacher, D. A.; Waters, A. E. Pasture grass interception and retention of ^{131}I, 7Be, and insoluble microspheres deposited in rain. Oak Ridge National Laboratory Report ORNL-6542; Oak Ridge, TN; May 1989.

List, R. J. Radioactive fallout in North America from Operation Teapot. Joint U.S. Atomic Energy Commission/U.S. Weather Bureau Report NYO-4696 (del), February 1956; declassified with deletions, April, 1956.

List, R. J. Radioactive debris from Operations Tumbler and Snapper, Observations Beyond 200 Miles from the Test Site; Parts I and II. Joint U.S. Atomic Energy Commission/U.S. Weather Bureau Reports NYO-4505 (del), NYO-4512 (del); February 1953; declassified with deletions, April 1959.

List, R. J. The Transport of atomic debris from Operation Upshot-Knothole. Joint U.S. Atomic Energy Commission/U.S. Weather Report NYO-4602 (del); June 1954; declassified with deletions, April 1959.

Machta, L.; Hamilton, H. L. Jr.; Hubert, L. F.; List, R.J.; Nagler, K. M. Airborne measurements of atomic debris. J. Meteor. 14:165-175; 1957.

Mitchell, R. L. Permanence of the log-normal distribution. Journal of the Optical Society of America 58(9):1267-1272; 1968.

New York Operations Office. Radioactive debris from Operations Buster and Jangle, observations beyond 200 miles from the Test Site. U.S. Atomic Energy Commission Report NYO-1576 (del); January 1952; declassified with deletions, April 1959.

New York Operations Office. Radioactive debris from Operation Upshot and Knothole. U.S. Atomic Energy Commission Report NYO-4552 (del); February 1954; declassified with deletions, April 1959.

Oden, N. Kriging and its relation to least squares, Brookhaven National Laboratory Informal Report BNL 38716, Upton, NY; November 1984.

Oden, N. Personal Communication; 1987

Perkins, R. W. Physical and chemical form of ^{131}I in fallout. Health Phys. 9:1113; 1963.

Perkins, R. W.; Thomas, C. W.; Nielsen, J. M. Measurements of airborne radionuclides and determination of their physical characteristics. In: Radioactive fallout symposium series 5. National Technical Information Service; CONF-765; Springfield, VA; 1965.

PHS. (Public Health Service) A brief review of the Public Health Service Radiation Surveillance Network operated by the Public Health Service under an agreement with the Division of Biology and Medicine, Atomic Energy Commission. In: Hearings before the Special Subcommittee on Radiation of the Joint Committee on Atomic Energy. Congress of the United States, Eighty-fifth Congress, First session on The Nature of Radioactive Fallout and Its Effects on Man. May 27, 28, 29, and June 3, 1957. Part 1, pp. 459-465. United States Government Printing Office. Washington D.C.; 1957.

PHS. Air pollution measurements of the National Air Sampling Network. Analysis of suspended particulate samples collected 1953-1957. Public Health Service Publication No. 637; 1958.

PHS. Directory of milk producers and processors. Southwestern Radiological Health Laboratory Report SWRHL-9r (INTERNAL USE ONLY); 1964

Placak, O. R. Interim off-site report of the Des Moines event. Operation Nougat III. U.S. Public Health Service, Off-Site Radiological Safety Organization; 1962.

RHD. Radiological Health Data, Monthly Report. U.S. Department of Health, Education, and Welfare report PB 161371-1; April 1960.

Ripley, B. D. Spatial statistics, John Wiley & Sons, New York; 1981.

Rosinski, J. Some studies on the evaluation of gummed-film collectors used in determining radioactive fallout. Trans. Amer. Geophys. Union 38:6; 1957.

Rosinski, J.; Nagamoto, C.; Ungar, A. Adherence of solid particles to flat surfaces.
Sonderdruck aus der Kolloid-Zeitschrift l64:26-31; l959.

Segal, J.; Yu, C. H.; Arritt, R. W.; Pielke, R. A. On the impact of valley ridge thermally induced circulations on regional pollutant transport. Atmos. Environ. 22(3):471-486; 1988.

Thompson, J. K. Aerial radiological monitoring, at Nevada Test Site, of event Palanquin. Nevada Aerial Tracking System report 13-F-65. Work performed for Nevada Operations Office, U.S. Atomic Energy Commission, by EG&G Inc., Las Vegas, NV; 1966.

Thompson, C.B. Estimates of exposure rates and fallout arrival times near the Nevada Test Site. Health Phys. 59:555-563; 1990.

Thompson, C. B.; Hutchinson, S. W. The Town Data Base: estimates of fallout times and exposure rates near the Nevada Test Site (NTS). USDOE Report NVO-320; 1988.

U.S. Department of Energy. Announced United States nuclear tests, July 1945 through December 1987. Nevada Operations Office Report NVO-209 (rev. 8); 1988.

Voilleque, P. G. Iodine species in reactor effluents and in the environment. Palo Alto, CA: Electric Power Research Institute; EPRI Report NP-1269; 1979.

Voilleque, P. G. Initial retention by vegetation of ^{131}I in wet depositions of fallout. Report prepared for the National Cancer Institute; Bethesda, MD; August 1986.

Zirschky, J. Geostatistics for environmental monitoring and survey design. Environment International 11:515-512; 1985.