Appendix G

External Dose Estimates from Global Fallout

External Radiation Exposure to the Population of the Continental U.S. from High Yield Weapons Tests Conducted by the U.S., U.K. and U.S.S.R. between 1952 and 1963

Harold L. Beck

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Abstract

This report provides estimates of the external radiation exposure and whole body effective dose received by residents of the continental U.S. during the period 1953-2000 from nuclear weapons tests. Doses were calculated for tests carried out in the Pacific by the U.S. and U.K. and by the U.S.S.R. at various sites in the former Soviet Union during the years 1952-62. Estimates are given on a county by county basis for each month from 1953-1972.

The average population dose from the fallout from all of these tests was about 0.7 mSv, about equivalent to 2-3 years of external radiation exposure from natural background. In contrast to the fallout from tests at the Nevada Test site, the variation in exposure across the country from "global" fallout was relatively small, reflecting primarily variations in annual rainfall. Precipitation was the main mechanism for the deposition of fallout from these mostly high-yield thermonuclear tests that injected most of their debris into the stratosphere. Thus residents of counties in the eastern and Midwestern U.S. that received above average rainfall were impacted more than residents of the more arid Southwestern states. Since the states downwind from the NTS that were impacted most by the NTS fallout are in general more arid than the eastern U.S., the areas most impacted by NTS fallout were in general least impacted by "global" fallout.

In contrast to fallout from the NTS where most of the exposure was due to the short-lived radionuclides (primarily I-Te-132 and Ba-La-140), Zr-Nb-95 was the major contributor to external dose from "global" fallout during the years of testing. The total dose through 2000 was dominated by the long-lived Cs-137. Cs-137 present in soil continues to result in a small radiation exposure to the public even at the present time. As was the case for NTS fallout, the most exposed individuals were outdoor workers, the least exposed, persons who spent most of their time indoors in heavily constructed buildings.

The deposition of all radionuclides that contribute significantly to external exposure, as well as a few that contributed significantly (Sr-89, Sr-90) to internal radiation exposure via the ingestion pathway, were calculated on a county by county and test by test basis. The general pattern of deposition is discussed. In general the population-weighted total deposition of long-lived radionuclides such as Sr-90 and Cs-137 was about a factor of about 10-15 greater than that from NTS fallout. However, the population-weighted deposition of short-lived isotopes such as I-131 was generally much less than from NTS fallout.

Introduction

In response to a request by Congress to the CDC and NCI to investigate the impact on the U.S. population from weapons tests, the NCI contracted with the author of this report to:

1. Prepare crude estimates of the doses *from external irradiation* received by the American people as a result of the above-ground tests carried out in the 1950s and early 1960s *by the U.S. in the Pacific and by the USSR in Kazakhstan and on Arctic Islands*. These dose estimates would be:
    - based on a review of the readily available open literature and information. It is not expected that sophisticated computer models should be developed or used for this purpose nor that a formal uncertainty analysis be carried out;
    - averaged over states or groups of states of the continental U.S., with indications on how the high-risk populations would be identified. However, if feasible, primary dose estimates should be made on a county-by-county basis, and averaged only for presentation purposes;
    - calculated separately for the most important radionuclides produced in these nuclear weapons tests with respect to external irradiation of the U.S. population. Those would include, but would not be limited to Cs-137, Zr-Nb-95, Mn-54, Sb-125, and Ba-La-140;
    - provided in terms of average whole-body dose for gamma irradiation. The dose to the skin for beta irradiation should also be indicated, however, since this dose is expected to be small compared to the gamma dose, it is not expected that detailed beta dose calculations will be made for each geographical area and month/year of fallout; calculated by year of fallout and summed over all tests, with a comparison to the results previously obtained for the NTS tests. If feasible, calculations should be carried out by month of fallout.

2. Provide an electronic database with the deposition densities and estimated doses of the important fallout radionuclides, by month of fallout and geographical area (county, state or group of states). From the point of view of external irradiation, the important radionuclides include those listed above. In addition, the deposition densities of Sr-90, Sr-89, I-131, Fe-55, and Pu-239 should be estimated, as they are important from the point of view of internal irradiation.

3. Indicate whether it would be feasible to improve the dose and deposition density estimates provided in this assessment. If so, discuss briefly how it could be done and estimate the level of effort, in terms of man-months, that would be needed.

This report along with an associated electronic database is presented in fulfillment of the above scope of work.

In a previous report (Beck, 1999), this author estimated the external exposure of the population of the continental U.S. from Nevada Weapons Tests. The mostly low-yield (<100 kT) weapons tests conducted at the NTS injected almost all of their debris into the

troposphere where it was deposited mostly within the continental U.S.A. (Beck, 1999). In contrast, the mostly high-yield (thermonuclear tests with yields greater than 1 MT accounted for over 90% of the fission products produced) tests carried out by the U.S., UK and USSR in the Pacific and at various sites in the USSR injected most of their debris into the stratosphere (UNSCEAR, 1982,1993). The total fission yield of these tests was about 150 MT (see Table 1) compared to about 1 MT for NTS tests. However, because of the long residence times for the transfer of air between the stratosphere and troposphere (on the order of 1 year), the fallout from these high yield tests was relatively depleted of short-lived radionuclides. Thus the total deposition in the continental U.S.A. of short-lived radionuclides such as I-131 was considerably lower than that from NTS tests.

The debris from these high-yield tests was dispersed throughout the atmosphere resulting in “global” fallout as opposed to the local and regional fallout from the NTS tests. This resulted in even the deposition of long-lived radionuclides such as Cs-137 and Sr-90 in the continental U.S. being only about 10-15 times that from NTS fallout. The deposition from this “global” fallout was also much more evenly distributed across the U.S. than the fallout from NTS tests. Thus even the deposition density for I-131 may have been comparable to the deposition of I-131 from NTS tests at some sites in the eastern U.S. with high average annual precipitation. Unfortunately, however, in this preliminary study, it was not feasible to estimate the deposition of I-131 from “global” fallout in any particular county with a reasonable degree of confidence.

While much of the fallout from NTS tests, particularly in areas close to the NTS, was dry deposition, most of the debris from this “global” fallout was deposited by precipitation scavenging of debris which had reentered the troposphere from the stratosphere or was originally injected into the high troposphere. Thus the deposition of fallout at any site tended to reflect whether or not, and how frequently, rain occurred at that site, particularly during the months of peak atmospheric fission product concentrations. While separate estimates were made for each NTS test, the estimates in the present report cannot easily be attributed to any particular test due to the frequency of the tests and the difference in the mechanism of fallout deposition. During the periods of testing, tests were often held on a daily basis and sometimes multiple tests occurred on the same day at separate sites. Fig.1 shows the estimated FY on a monthly basis and illustrates that the debris was released over a few relatively intense intervals of testing, primarily in 1954, 1956, 1958 and 1961-62. Since most of the debris from these tests was injected into the stratosphere, the activity in stratospheric air at any time generally represented a complex mixture of contributions from a large number of tests. Since most if not all of the subsequent fallout was from this stratospheric reservoir, it is impossible to attribute the deposition at any particular time to a particular test. However, one can assume that the relative contribution of USSR tests to the total U.S. fallout is roughly proportional to the relative fission yield of Soviet versus U.S. and UK tests. About 84 MT of the total estimated fission yield of 150 MT is estimated to be from tests carried out in the USSR (see Table 1).

A huge body of literature exists regarding fallout from nuclear weapons tests. However, the only widespread continuous monitoring of fallout deposition were the global networks of gummed-film samplers and later precipitation collectors (stainless-steel pots and ion exchange columns) operated by the USAEC's Health and Safety Laboratory (HASL) and the network of air sampling stations along the 80th meridian operated prior to 1963 by the Naval Research Laboratory and after 1963 by HASL (Harley, 1976; Lockhart et al., 1965). The Public Health Service monitored radioactivity in milk at a number of U.S. cities beginning in 1958 and also total beta activity in air and precipitation at a number of sites in the U.S. beginning in 1957 (Rad. Health Data, 1958-; PHS, 1958-). A large amount of other scattered sources of data are available in reports by investigators at National Labs, Universities and State and Local Agencies. The HASL, in conjunction with the USDA, also carried out extensive soil sample surveys in 1956, 1958 and 1964-66 (Alexander et al., 1961; Meyer et al., 1968; Hardy et al., 1968). These soil data provide estimates of the geographical variation in the cumulative deposition estimates of long-lived radionuclides such as Cs-137 and Sr-90. The HASL also carried out nationwide surveys of external exposure rate levels in 1962-64, using in situ gamma-ray spectrometry to identify the contribution of fallout to the total exposure rate in air (Beck et al., 1964,1966; Lowder et al., 1964). These exposure rate measurements also provide confirmation of the exposure and dose estimates in this report.

The basic starting point for the estimates in this report were the monthly Sr-90 deposition density measurements reported by the HASL for about 30 sites across the U.S. (HASL, 1958-72, USERDA, 1977}. These data were supplemented by scattered data from the literature (Collins and Hallden, 1958; Collins et al., 1961; Kuroda et al., 1965). The deposition of Sr-90 (and for some sites also Sr-89) was measured by collecting precipitation using steel pots and/or ion exchange columns. Figure 2 shows the location of HASL monitoring sites in operation in 1962. The number of monitoring sites varied from year to year with the maximum number in operation during 1962-1965. Except for one or two sites (i.e. New York City) continuous measurements were not carried out extensively prior to 1958. Thus little or no data exist for years prior to 1958. The HASL did monitor total beta deposition at about 50 sites from 1952 through 1960 using gummed film (see Beck, 1999, Beck et al., 1990). However, only the data for years of NTS testing has been reevaluated and thus these data were unavailable for use in this analysis.

Monthly deposition densities were estimated for the radionuclides listed in Table 2. The expected production rates of each radionuclide per MT fission are also listed based on estimates of the fission yield from thermonuclear tests (UNSCEAR, 1993) and reported estimates of radionuclide production relative to Sr-90 for selected Pacific tests (Hicks, 1984). Because of the delay in transfer of debris from the stratosphere to the troposphere discussed above, the relative fission yields shown in Table 1 and production ratios shown in Table 2 are not necessarily reflective of the relative deposition density of particular radionuclides or the variation in deposition with time. However, the deposition of nuclides with similar half-life can be expected to track reasonably well. Note that with the agreement of the contracting officer, detailed estimates have not been made in this preliminary report for a few of the radionuclides listed in the scope of work (e.g., Fe-55, Pu-239). Pu deposition was generally proportional to Sr-90 deposition (UNSCEAR,

1993) and as a first approximation can be estimated from the reported Sr-90 estimates. Fe-55, an activation product, is a minor contributor to ingestion dose and does not contribute to external dose. Because the production of Fe-55 from any particular test may have varied considerably, it was decided not to attempt to estimate Fe-55 deposition for this preliminary feasibility study.

The patterns of total deposition for some of the longer-lived nuclides are discussed in this report and the total deposition of various radionuclides is compared to that from the fallout from the NTS previously reported by this author (Beck, 1999). The general validity of the deposition density estimates and dose estimates are indicated by comparisons with measurements of Sr-90 in soil samples and in situ gamma-ray measurements of exposure rate that were made during the peak fallout years (1963-65).

All calculations for this report were carried out separately for each county in the Continental U.S. using a relatively crude model. Fallout in Hawaii and Alaska has not been considered in this study. Estimates were made of deposition density for each nuclide contributing significantly to the external exposure for the years 1953-72, as well as for Sr-90, which is a major contributor to internal exposure. These deposition density estimates and the resultant external exposure estimates for each nuclide are included in the electronic database that accompanies this report. A portion of this database containing the estimated deposition density on a monthly and county by county basis for Sr-90 and Cs-137 was provided to NCI earlier in partial fulfillment of this contract. The database containing these deposition density estimates will be used by the NCI to estimate internal radiation doses due to ingestion of contaminated food.

The monthly results for individual nuclides were summed to provide annual and total estimates of deposition density and doses for each county as well as population weighted estimates for the continental U.S. Besides the total free-in-air exposure rate from gamma emitters, estimates were also made of the annual whole-body effective dose. The beta-ray dose to the skin from radionuclides in the surface soil is also discussed and the radionuclides that contributed most to both gamma and beta-ray exposures were identified.

The results presented in this report are not intended to be definitive estimates of the geographical and temporal variations in “global” fallout across the U.S. They are preliminary estimates intended to demonstrate the feasibility of making such estimates given sufficient data and the resources to develop more sophisticated models than the crude models used here. The present results are believed to reasonably indicate the overall geographical and temporal variations in fallout, particularly for the years of greatest fallout (1961-65). However, the specific county estimates or estimates for years prior to 1958 and for any particular month and county at any time may be quite uncertain and should be used with discretion. This is particularly true for the short-lived radionuclides for which little or no actual data was available upon which to base estimates. Possible improvements in the methodology are discussed later in this report, as are additional data requirements. Recommendations are made on how to improve the estimates in this preliminary feasibility study and to estimate the uncertainty in the individual monthly or annual dose estimates for residents of any particular county.

The next section of this report describes in detail the methodology used to calculate exposure and deposition densities.

Table 1: Estimated Fission Yields*- MT

Year	US, UK	USSR
1952	6.0	0
1953	0	0.04
1954	31	0.1
1955	0.0	1
1956	8.6	1
1957	1.5	2.4
1958	18.5	8.5
1959	0	0
1960	0	0
1961	0	18
1962	53	19

*Total yields were reported in DOE (1994) and VNIEF (1996). Because the fission yield of individual tests are still classified, assumptions were made to estimate the values of the fission yields. For purposes of providing values for Table 1, all tests smaller than 0.1 Mt total yield were assumed to be due only to fission. For tests in the range 0.5-5 Mt, fission yields averaging about 50% have been assumed here. For tests in the range 0.1-0.5 MT, a fission yield of 67% was assumed. There were 17 tests in the range 5-25 Mt. With no other indications available, fission yields of 33% were assumed for those tests. However, the fission yields of the U.S. tests were arbitrarily adjusted to agree with the reported total fission yields for the years 1952, 1954 and 1958 (USDOE, 1999). Note: tests carried out at the NTS are not included in Table 1.

Table 2: Radionuclides for which deposition densities and external exposures were calculated

Nuclide	**Half life (parent), d**	**FY(%) (a)**	**PBq/MT**
Mn-54	313	activation product	b)
Sr-89	51	3.2 (c)	731
Sr-90,Y-90*	28.6 y	3.5	3.9
Zr-95,	64	5.1	922
Nb-95	35	0	0 (d)
Ru-103, Rh103m*	39	5.2	1540
Ru-106, Rh-106*	372	2.4	76.4
Sb-125	2.73 y	0.4	4.66 (e)
I-131	8	2.9	4200
Cs-137	30.14 y	5.6	5.9
Ba-140, La-140*	13	5.2	4730
Ce-141	33	4.6	1640
Ce-144, Pr-144*	285	4.7	191

- In equilibrium with parent

a) Fission yields from UNSCEAR, 1993.
b) approx. 15.9 PBq/MT fusion (UNSCEAR, 1993)
c) Based on reported ratio to Sr-90 for US Pacific tests (Hicks, 1984).
d) Nb-95 is a decay product of Zr-95. The deposition of Nb-95 will depend on the age of the fallout as will the amount of Nb-95 present in soil at any time.
e) Some additional Sb-125 (as well as Sb-124) was also produced by activation of Sb-123 in some of the very high yield tests carried out by the USSR in 1962 (UNSCEAR, 1993).

Methodology

General

The basic model used to estimate the deposition of various fallout radionuclides from the "global" fallout produced by the generally high yield tests described in the introduction was as follows.

a) The average precipitation for each month for each county of the continental U.S. was estimated from U.S. Weather Service records.

b) Based on available deposition data and soil analysis results, a crude model was developed to describe the geographical variation in Sr-90 deposition density per unit precipitation as a function of latitude and longitude. This geographical variation was assumed to be independent of time.

c) The deposition density of Sr-90 per unit precipitation (specific activity) in the NE U.S. for each month from 1952 through 1971 was estimated from available monitoring data. The deposition for other areas of the U.S. was then estimated from the model described in b) and the measured monthly precipitation.

d) The ratio of the deposition of each nuclide listed in Table 2 to the deposition of Sr-90 for each month for the period 1953-1972 was estimated using actual data if data were available. If no data were available for a particular period for a particular radionuclide, an atmospheric model was used to estimate the ratio of the deposition density of that nuclide that of a nuclide of similar half-life for which data was available. For the purposes of this preliminary feasibility study, the deposition-density ratios of one nuclide to another were assumed to be independent of location.

e) The monthly deposition density of each radionuclide was then calculated by multiplying its estimated ratio to Sr-90 for that month by the estimated Sr-90 deposition density for that month to obtain an estimate of the nuclide deposition density.

f) The cumulative amount of each radionuclide present in the soil in each county was calculated from the estimated monthly depositions and nuclide half-life,

correcting for decay during the month of deposition and decay from one month to another as well as ingrowth of daughter activity (e.g., Nb-95 from Zr-95).

g) The exposure rate in air and dose to a typically-exposed adult produced by each radionuclide present in the soil was calculated from its cumulative deposition density using conversion factors from (Beck, 1980). The dose contributions from each radionuclide were summed to estimate the total monthly dose, the annual dose from external radiation and the total dose for an individual resident in the same county throughout the period 1953-2000. Population doses (per capita doses) were also calculated by weighting the individual county estimates by the county population during the time of testing.

h) An electronic data base with the estimated deposition densities of Sr-90 by month and county, the estimated isotopic ratios by month, the estimated external doses to a typically exposed individual for each county, month and radionuclide was prepared.

In the following paragraphs, each of the steps above is described in more detail.

Precipitation estimates

Monthly precipitation has been measured at over 8000 U.S. Weather Service cooperative monitoring sites and data is available for most sites beginning in about 1900. This data is available on the world wide web (http://www.ncdc.noaa.gov/ol/climate/online/coop-precip.html). Not all sites were in operation at all times and even for sites in operation continuously, data was often missing for some or all months during a given year. Since there are about 3,000 counties in the continental U.S., the average number of monitoring sites per county was about 3. However, some counties had a large number of sites (10 or more) while precipitation was not measured at all in other counties.

For this preliminary feasibility study a single estimate of monthly precipitation was obtained for each county for each month from 1953-1972 by averaging the available reported monthly data for each site in operation during that month. If no data were available for a county for any particular month the value for the nearest county was used (the nearest county was defined as the smallest distance between county centroids).

The crude estimates of monthly precipitation thus obtained are subject to a certain level of bias. First, for many counties, particularly large counties with large variation in topography, there were large variations in monthly precipitation from one monitoring site to another as shown in Table 3. Thus the average for that county may not be representative of the precipitation in the areas where most of the population reside (e.g., Seattle or Salt Lake City). Furthermore, the average precipitation may be much less than the maximum in the county. As will be discussed later, the exposure to individuals living in these higher precipitation regions may be considerably higher than the average exposure estimated for the county. Also, the substitution of missing values with values for the nearest county may not be the most appropriate for areas of the country with

rapidly varying topology. Suggestions for improving the estimates of precipitation are discussed later in this report.

The estimates of average precipitation for each county used for the calculations in this report are contained in the electronic database accompanying this report.

Table 3: Variation of monthly precipitation within selected counties during Dec., 1962

Clallam County, WA		King County, WA		Salt Lake County, UT	
Site	(cm)	Site	(cm)	Site	(cm)
Clallam Bay	32	Cedar Lake	25	Alta	4.0
Elwha	22	Grotto	34	City Creek	1.1
Forks	48	Landburg	19	Cottonwd. W.	0.8
Lake Suther.	23	Mod Mt. Dam	17	Gorfield	0.15
Neah Bay	45	Palmer	34	Midvale	0.4
Port Angelos	9	Scenic	27	Mt. Dell Dam	1.4
Suppho	34	Seattle	10	Salt Lake	0.23
Sequim	4	SeTac AP	13	SLC AP	0.71
Tatoosh Is.	33	Snaqual. Falls	15	Silver Lake	3.2
		Snaqual. Pass	34	Univ. Utah	0.8

Variation in specific activity of Sr-90 with latitude and longitude

Previous studies have demonstrated that the deposition of Sr-90 or Cs-137 from “global” fallout was generally proportional to the amount of precipitation over any particular localized area (Krey and Beck, 1981; Beck and Krey, 1983; Collins and Hallden, 1958; Martell, 1959; Alexander et al., 1961; Hardy et al.,1962, 1968). However, the slope of the regression (Bq per cm of rain) was known to vary significantly with both latitude and longitude across the continental U.S. Fig 3 from Alexander et al., (1964) shows the variation of cumulative Sr-90 deposition with latitude at sites with the same average annual precipitation in the central U.S. as determined from soil sampling at various times as shown. There is a clear variation with latitude with a maximum in the 35-40 degree latitude band. The deposition at low latitudes is less than the maximum by about a factor of two. Furthermore, based on the different sampling times, the variation with latitude did not appear to vary significantly over time.

A similar variation with longitude is illustrated by Fig 4. Here the cumulative activity per cm of rain for cumulative Sr-90 measured in soil samples at sites in the latitude band 35-45 degrees is shown. Data from the cumulative deposition of Sr-90 from 1958-65 as measured in deposition in the HASL pot and column sites are also plotted. These data indicate a clear trend of a relatively constant specific activity in the eastern U.S. and then a steep increase as one approaches the mountainous area of western Colorado, Utah and Wyoming. The specific activity reaches a peak of about a factor of two at approximately the longitude of Salt Lake City but drops precipitously to less than northeastern U.S.

levels as one reaches the West Coast. The result of this increase in specific activity is that sites such as Salt Lake City, where the average annual rainfall is about ½ that of New York City, received about the same total Sr-90 deposition as New York City. The exact reason for apparent steep gradient with longitude is not known but may be due to a combination of factors including the relatively high latitudes and increased thunderstorm activity during the months of peak stratosphere to troposphere air transfer (Hardy et al., 1968).

As described below, the results shown in Figures 3 and 4 were used to create a crude time-independent model of the variation of Sr-90 specific activity as a function of latitude and longitude that was used to estimate Sr-90 deposition density for each county of the continental U.S.

Specific activity of Sr-90 at NE U.S. sites

As discussed earlier, monitoring of fallout deposition was carried out at only a limited number of sites in the U.S., mostly in the late 1950's and 1960's. Many of these monitoring sites were in the northeastern U.S. (Fig 2). Thus it was decided to use the average of the measured data for sites in the latitude band 38-45 degrees and longitude band 70-85 degrees as the benchmark for estimating the specific activity in other regions of the continental U.S. This choice was made for several reasons. First, as shown in Fig 4, the variation in specific activity in this longitude band was relatively constant. Second, for years beginning in 1958 and for several months in 1956, data were available for at least 2-3 or more sites that could be used to obtain a reasonable estimate of the mean for the region. Finally, for periods prior to 1956, data are available only for NYC.

The benchmark specific activity values thus obtained are shown in Fig 5 for the years through 1965. It should be noted that there were often large variations in measured monthly values at sites relatively near to each other (e.g., New York City and Westwood, NJ) as well as occasional large differences in duplicate samples taken at the same site. This suggests that significant measurement errors were possible in either the Sr-90 measurement or the local precipitation measurement that was reported by the HASL. Thus in calculating the average specific activity for any particular month, the author's judgment was used to discard apparent anomalous measurements in order to obtain a set of specific activity measurements that were consistent with the time of year and previous and subsequent months data. The data from other sites in the U.S., along with Figures 3 and 4, was also used to identify clearly anomalous data. Note that the monthly variations in specific activity do not track the fission yields shown in Fig 1. This reflects the fact that most of the fallout in the U.S. was from debris injected into the stratosphere resulting in a relatively long delay between its creation and subsequent deposition. Note also the annual spring peaks in deposition that reflect the greater transfer of debris from the stratosphere to the troposphere during the late winter and early spring (Bennett, 1978; UNSCEAR, 1982).

Prior to 1954, there were no reported measurements of Sr-90 from which to make specific activity measurements. However, soil sample data were available for a few sites in the eastern U.S. These provided a crude estimate of the total deposition of Sr-90 from

"global" fallout up to 1954. Almost all of this deposition was assumed to have occurred in 1953, primarily as a result of the high-yield U.S. tests carried out in the Pacific in late 1952. The monthly variation in specific activity during the year was assumed to be the same as that measured in NYC during 1954.

For each month from 1953 through 1972, an estimate of the baseline specific activity of Sr-90 in precipitation was thus obtained for use in estimating the specific activity in other regions of the country as described in the next section. These specific activity estimates are contained in the electronic database supplied with this report. The section later in this report on possible improvements to the crude estimates in this report discusses improvements that might be made in these estimates.

Deposition density of Sr-90 in the continental U.S.A.

In order to estimate the deposition density of Sr-90 in each county of the continental U.S.A. a monthly basis a number of assumptions have been made.

First, it was assumed that the deposition in any particular county was proportional to the precipitation that occurred in that county during that month. Since the specific activity has been shown to vary significantly with latitude and longitude, it was thus necessary to develop a model describing this variation. Because of the sparse available data, it was not feasible to develop a detailed continuously varying model of the variation with latitude and longitude for this preliminary feasibility study. Thus a relatively crude model consistent with the data shown on Fig 3 and 4 was adopted. The Continental U.S. was divided into 25 latitude-longitude quadrangles and the average specific activity for each quadrangle relative to the default specific activity discussed in the previous section was estimated from the data shown in Figs 3 and 4. These default specific activities are given in Table 4. For this study, it is assumed that the variation was independent of time. This may not be strictly true, as discussed later in the section on possible methodology improvements, particularly for months of testing when some of the fallout may have been from debris injected into the troposphere instead of the stratosphere.

Table 4 :Sr/cm:default ratios (relative to NE U.S. baseline values)

Lat \ lon:(degrees):	60-90	90-100	100-110	110-120	>120
25-30	0.45	0.45	0.6	0.5	0.5
30-35	0.6	0.65	1.2	1.0	0.7
35-40	0.8	0.9	1.5	2.0	0.8
45-45	1.0	1.1	1.6	1.9	0.6
45-50	0.8	0.85	0.9	1.0	0.5

Because the variation with longitude and latitude is not uniform, counties near the boundary of quadrangles where the default specific activity estimates differ significantly will have larger uncertainties in Sr-90 deposition estimates than counties in sections of the U.S. where the gradations from quad to quad are smaller. Clearly, as discussed later, a more sophisticated model might be developed, particularly if additional data can be

located to better define the actual variations with latitude and longitude and with time. However, it is likely that the variations in precipitation within a county discussed earlier are a larger contributor to the total uncertainty in deposition in these areas than the crude estimates of geographical variation in specific activity.

Finally, the present model does not account for dry fallout. For most areas of the U.S. dry fallout was probably less than 10% of the total deposition. However, for any particular month where the precipitation was very low the dry deposition may have been more significant. The impact of not accounting for dry deposition is most significant for the more arid regions of the U.S. Thus, as discussed in the section on possible improvements, the estimates for fallout for those areas are likely underestimated in this report. It should be noted, however, that even, accounting for more dry fallout in such counties, the total fallout in these counties would still have been relatively low compared to counties with even average amounts of precipitation.

The deposition density of Sr-90 was thus estimated for each county for each month from 1953-1972 by multiplying the average precipitation for that county for that month by the benchmark specific activity and the assumed relative specific activity for that particular latitude-longitude band. The resultant deposition density estimates for each county and month are provided in the electronic database accompanying this report.[1]

Although the model used to estimate the Sr-90 deposition is fairly crude, a comparison with the available data for a number of sites where sufficient data is available indicates that the agreement is fairly good. This is true even on a monthly basis when one considers the measurement errors and variations in monthly precipitation within a given county. Figures 6a-6f compare the model estimates of Sr-90 deposition for six different cities in various parts of the U.S. with the actual measured Sr-90 in rain. Although there are sometimes large differences for a particular month, the overall agreement is quite good. Keep in mind that the model results are based on the average precipitation for the entire county while the measurement results are for a single location.

For this preliminary study, any NTS Sr-90 deposition density in precipitation at the northeastern benchmark sites was not subtracted. As shown in Beck (1999), the deposition density of Sr-90 in the N.E. U.S.A. was fairly low compared to areas closer to the NTS and to “global” fallout. Thus the resultant slight bias in the estimates of “global” fallout for months of NTS testing based on using uncorrected benchmark data did not have any significant impact on the annual or total estimates of “global” fallout.

In addition to the comparisons shown in Figs. 6a-6f, the annual depositions for the years 1958-65 predicted by the model were compared to those at the measured sites for about 30 measurement sites with a significant amount of measured data. On average, the agreement in annual Sr-90 deposition was better than ∀10% although for some sites,

[1] Note that even for counties where an actual measurement exists at one or more sites for a particular month, the model estimates appear in the database. A subsequent analysis might decide to substitute measured values if available.

there were differences in the calculated and measured total deposition density estimates of as much as ∀50% for some years.

An additional test of the validity of the model estimates can be obtained by comparing the calculated cumulative Sr-90 deposition density for a given county with the results of soil samples taken at a site in that county. Comparisons with soil samples from 1964-66 are shown in Table 5. As seen, the model estimates of cumulative Sr-90 deposition agree reasonably well with the soil data. The largest differences occur in counties in mountainous regions of the country. The average precipitation for these counties may not be representative of the rainfall at the measurement site. In addition, the soil samples include both "global" and NTS fallout while the model estimates exclude most of the NTS fallout. Thus one would expect the soil data to be somewhat higher than the model estimates for areas immediately downwind of the NTS. There are also large differences for counties in very arid locales where the model's neglect of dry fallout resulted in a significant underestimate in Sr-90 deposition density. Additional soil data are available beginning in 1953 and further comparisons, subtracting the contributions from NTS fallout, might be useful for refining the deposition model.

The comparisons discussed above suggest that the model estimates of total Sr-90 deposition density for any given year and over a longer period are probably quite reasonable although estimates for any particular month may be quite uncertain. Possible improvements are discussed later in this report.

Table 5: Comparison of Model Sr-90 Cumulative Deposition Density Estimates with Soil Sample Measurements

Site	Soil Sample Date	Cumulative Deposition Density (Bq.m2)	
		Soil Sample	Model
Clallam County, WA	9/64	1150-4200 (6 sites)	2290
	9/65	1300-6440	2440
Puyallup, WA	9/64	2110	1850
	9/65	2180	2110
Mandan, ND	10/64	3000	1440
Bozeman, MT	9/64	2780	1630
Orono, ME	6/64	2110	2410
	7/65	2180	2480
St. Paul. MN	10/64	2740	1890
Corvalis, OR	9/64	1630	1920
	9/65	1920	2070
Burlington, VT	6/64	1960	2440
	7/65	2220	2590
Rapid City, SD	9/64	3590	3150
	9/65	3590	3480

Boise, ID	9/64	2150	1630
	9/65	2550	1810
Ithaca, NY	9/64	2040	2440
	10/65	2110	2590
Amherst, MA	6/64	2000	2660
	7/65	2330	2890
S. Wellflect, MA	6/64	2780	2920
	7/65	2890	3030
Logan, UT	9/64	1520	2590
	9/65	1810	2740
Des Moines. IO	9/64	2780	2960
	8/65	3030	3180
Kingston, RI	6/64	2780	3030
	7/65	3330	3180
Brigham City, UT	9/64	3440	2370
	9/65	3370	2550
New York City	12/64	2590	2590
Salt lake City, UT	9/64	3740	3260
	9/65	3850	3550
Heber, UT	9/64	2330	2740
	9/65	2550	2960
Rosemont, NB	9/64	2890	2370
	9/65	3110	2850
Columbus, OH	8/64	2890	2180
	8/65	2960	2370
Derby, CO	9/64	2180	1700
	9/65	2290	1920
Healdsburg, CA	9/64	1920	2070
	9/65	1920	2220
Cedar City, UT	9/64	1260	1330
	9/65	1410	1550
Norfolk, VA	2/64	2110	2220
	2/65	2740	2290
	2/66	2810	2370
Tulsa, OK	10/64	1850	2330
Florence, SC	2/65	2890	2220
	3/66	2810	2220
Los Angeles, CA	9/64	810	1000
	9/65	850	1110
Atlanta, GA	2/64	2000	2510
	3/65	2740	2590
	3/66	2110	2660
El Centro, CA	9/64	570	110
	9/65	670	110

Newton, MS	3/65	1890	2260
Tifton, GA	3/65	2000	2290
Jacksonville, FL	2/65	2260	2370
	3/66	2150	2520
New Orleans, LA	3/65	2260	2520
	3/66	1890	2630
Ft. Lauderdale, FL	2/65	1850	2070
	3/66	2370	2070

Soil data from Meyer et al., 1968.

Ratios of deposition to Sr-90, Sr-89

The previous sections discussed the estimates of Sr-90 deposition density. Only two radionuclides were monitored fairly continuously for global fallout, Sr-90 and for fewer sites and times, Sr-89. The reason for this was that Sr-90 at that time was considered to be the most significant health hazard from "global" fallout due to its incorporation in bone via ingestion of contaminated foodstuffs and its long physical and biological half life. Thus other radionuclides were monitored infrequently and only at a few sites in the U.S. Because short-lived nuclides such as Zr-Nb-95 and others listed in Table 2 contributed significantly to external exposure rates, it is necessary to estimate the deposition density of these nuclides as well in order to estimate the exposure of the U.S. population to external gamma radiation.

Because of the sparseness of actual data, a critical assumption was required for this preliminary study, i.e., that the ratios of the various radionuclide deposition densities for any given month did not vary significantly across the U.S. Considering that most of the fallout deposited in the continental U.S. was from debris originally injected into the stratosphere where it had time to mix and equilibrate, this assumption is probably reasonable for the nuclides with half-lives greater than about a month. However, it may not be reasonable for nuclides with shorter half-lives for several reasons. First, some significant fraction of the fallout during months of testing, particularly for tests held at latitudes comparable to the U.S., may be from debris injected into the troposphere. The fallout would then vary across the U.S. because of decay in transit as the debris traversed the country. If debris from the stratosphere was transferred preferentially to the troposphere at specific longitudes, as indicated by Figure 4, again one might expect a variation with longitude in deposition. Debris injected into the troposphere tends to remain in a band close to the latitude of injection. However, some of the debris injected into the troposphere from U.S. tests in the Pacific at low latitudes might have diffused to higher latitudes and impacted the southern latitudes of the U.S. more than the more northerly latitudes. Unfortunately, except for Sr-89 with a half-life of 50 d, there is insufficient data upon which to base a geographical variation in deposition for these nuclides. In general, the Sr-89 to Sr-90 ratios do not indicate any significant geographical

variation. Measurements of short-lived nuclides have been reported in precipitation and in air at only a few scattered sites across the U.S. and only during years after 1957.

Scattered data on individual nuclide activities in precipitation samples are available for Pittsburgh, Westwood, NJ, Houston TX (HASL, 1958-72, USAEC, 1958), New York City (Collins et al., 1961) and Fayetteville AK (Kuroda et al., 1965). There is also some data on short-lived and long-lived radionuclides in air for Miami and Sterling, VA (Lockhart et al., 1965), Richland, WA (Perkins et al., 1965), and Argonne, IL (Gustafson et al., 1965). Data for Ce-144 are also available from England for 1955 and 1956 (Stewart et al., 1957). Although these data do indicate a possible geographical variation during some of the months of testing, the data are often inconsistent and ambiguous. Further study is required along with a search for additional data in order to develop a credible model for the variation with location for these radionuclides. Thus, the deposition density estimates for nuclides shorted than about 1 month are highly uncertain and should be used with discretion.

Because of the sparseness of available data, even for Sr-89, a global circulation model developed by Bennett (1978) was used as an aid in estimating ratios of radionuclide deposition. This model was developed to describe atmospheric dispersion and deposition of radioactive debris produced in atmospheric nuclear testing (Bennett, 1978; UNSCEAR, 1982). The atmosphere is divided into a number of equatorial and polar regions from 0 to 30 and 30 to 90 degrees latitude, respectively. The troposphere height is variable with latitude and season, but for modeling purposes it is assumed to be at an average of 9 km altitude in the polar region and 17 km in the equatorial region. The lower stratosphere is assumed to extend to 17 km or 24 km in the two regions and the upper stratosphere to 50 km in both regions. The model requires certain assumptions regarding the fraction of fission products injected into the stratosphere versus the troposphere from each test. It also requires information on the yield and height of burst and estimates of the residence time and transfer rates of air from various regions of the stratosphere to other regions, from the stratosphere to the troposphere, and from the troposphere to deposition. Apportionment of debris to various compartments in the atmosphere is based on the reported stabilization heights of cloud formation following the explosion. Empirical values derived from a number of observations are used (Bennett, 1980, UNSCEAR 1982). The model tends to predict the temporal variation of Sr-90 deposition quite well (UNSCEAR, 1982). However, the estimates of the deposition of the shorter-lived nuclides are much more uncertain due to uncertainties in the exact fission yields for any particular test and the fractions of activity injected into the stratosphere versus the troposphere. The latter estimates are much more important for the short-lived nuclides than for the longer-lived nuclides.

Although the model is not able to accurately predict the actual deposition density of a particular short-lived nuclide, it served as a useful guide to the expected ratio of depositions for nuclides of about the same half life. Thus, for example, for periods when no measurements of Zr-95 were reported anywhere in the U.S., but measurements of Sr-89 were available, the model estimates of the ratio of Zr-95 to Sr-89 as a function of time were used to estimate the Zr-95/Sr-90 deposition density ratio from the average measured

Sr-89/Sr-90 ratio. Similarly, where Ce-144 data were available, but not Ru-106 data, the model deposition-density ratios of Ru-106/Ce-144 and the measured ratios of Ce-144/Sr-90 were used to estimate the Ru-106/Sr-90 ratio. A similar procedure was used to estimate I-131 deposition density from the sparse Ba-140 measurements. Ratios of Nb-95 to Zr-95 were estimated based on the estimated age of the Zr-95 being deposited and the relative half-lives of Zr-95 and Nb-95[2]. Since the half lives of Cs-137 and Sr-90 are similar (Table 2), the ratios of deposition were assumed to be equal to the production ratio for this report.[3] For periods where no data were available for a particular radionuclide the author made rough estimates using the production ratios shown in Table 2, and the model calculations as a guide. In all cases, where actual credible data was available, the actual data was used.

Again, the author's judgement was used to evaluate available data and thus the final estimates of the isotopic ratios presented in Appendix 1 of this report are a synthesis if the available data, the model predictions, and the author's professional judgement. Recommendations for estimating the uncertainty in and improving the estimates of isotopic ratios are discussed later in this report. The estimated ratios of Zr-95 to Sr-90 deposition density versus time are shown in Figure 7. Note that the ratio approaches the ratio of production rates given in Table 2 during the fall of 1961. This is expected since the stratospheric reservoir of Sr-90 was relatively depleted due to the moratorium on atmospheric testing from 1959 through most of 1961. At other times, the large inventory of Sr-90 in the stratosphere from earlier tests reduces the ratio below the production ratio even during months of heavy testing.

Deposition densities of radionuclides contributing to external radiation exposure

The deposition density of each of the radionuclides listed in Table 2 was thus estimated for each county and month by multiplying the estimated Sr-90 deposition density for that county and month by the monthly isotopic ratio estimates in given in Appendix 1. The estimates for the more important contributors to external dose, Zr-Nb-95 and Cs-137 are probably quite reasonable since Zr-95 was measured in precipitation or air at several sites in 1958 and 1961-62 and Sr-89 was measured at a relatively large number of sites (HASL, 1958-72). Furthermore, the model Sr-89/Zr-95 ratios agree reasonably well with the measurements for periods where both were measured simultaneously, supporting the use of the model ratios at other times. Similarly, the estimates for Ce-144 and Ru-106 are also considered reasonably valid. The deposition of Cs-137 as estimated from the production ratios is in reasonable agreement with available data. Ru-103 was not generally measured but Ce-141 measurements were occasionally reported. The use of the model and available Ce-141 data to infer Ru-103 deposition is probably reasonably valid. The most uncertain estimates are for Ba-140 and I-131, both for reasons discussed above

[2] Nb-95 is not produced during fission but grows in as Zr-95 decays. The ratio of Zr-95 to Nb-95 at any time thus depends on the time since the Zr-95 was produced. Nb-95 reaches about 97 % of secular equilibrium (Nb/Zr=2.2) in about 12 months.

[3] Since the half life of Cs-137 is actually slightly greater than that of Sr-90, this ratio probably increased very slightly with time since injection of debris into the stratosphere. Thus the total Cs-137 deposition may have been very slightly underestimated.

regarding geographical variations and due to the sparseness of available data. No actual data on I-131 deposition density was available for this report and thus I-131 deposition densities were estimated from available Ba-140 data. Scattered Ba-140 measurements in precipitation are available for Pittsburgh, Westwood, NJ, Houston, Richmond, CA, and Fayetteville, Arkansas at various times and a rough ratio to Sr-89 could be inferred from these measurements that was consistent with the ratio suggested by the Bennett model.

External radiation exposure

For the author's previous report on external exposure from NTS fallout, conversion factors from Beck (1980) were used to convert cumulative deposition density[4] to exposure rate in air assuming the radioactivity was distributed in the soil with a relaxation length of about 0.1 cm for the first 20 days. From 20 d to 200 d, a relaxation length of 1 cm was used, while for times greater than 200 days, a relaxation length of 3 cm was used. This report uses a similar model, multiplying the deposition on the ground less than 1 month by the conversion factor corresponding to a relaxation length of 0.1 cm. A relaxation length of 1 cm is used for the activity remaining in the soil that was deposited within the period 1-6 months while a relaxation length of 3 cm was used to calculate the exposure rate from the activity that had been present for greater than 6 months. The corresponding deposition-density to exposure conversion factor for each of these relaxation lengths is from Beck (1980). Since the penetration into the soil would be slower in more arid regions, maintaining the 0.1-cm relaxation length for the first 30 d provides a slightly conservative estimate of the exposure for sites with greater precipitation. Table 6 illustrates the dependence of the exposure rate in air on the various relaxation lengths. Note that the exposure rate is reduced by about 1/3 as the activity penetrates to a relaxation length of 1 cm and about ½ as the activity penetrates to a relaxation length of 3 cm from 0.1 cm. This accentuates the importance of the first few weeks after deposition with respect to total external radiation exposure to an even greater degree than previous calculations based only on radionuclide decay. For a discussion of available data on nuclide penetration with depth on the soil see Beck (1999).

[4] Again the ingrowth of Nb-95 from the decay of deposited Zr-95 was accounted for in the calculation of the cumulative deposition density of Nb-95. The buildup of Nb-95 activity relative to Zr-95 at any time is given by Nb = Zr * 2.17 * (1- exp (-0.00914 * t)) where t is in d.

Table 6: Exposure rate (: R/h per mCi/km^2) versus relaxation length for selected fission products (Beck, 1980)

Nuclide	Relaxation length (cm)		
	0.1	1	3
Zr-95	1.20E-02	7.94E-03	5.63E-03
Nb-95	1.24E-02	8.20E-03	5.82E-03
Mn-54	1.34E-02	8.82E-03	6.28E-03
Ba-La-140	3.57E-02	2.44E-02	1.71E-02
Sb-125	6.91E-03	4.61E-03	3.17E-03
Ru-103	7.85E-03	5.25E-03	3.58E-03
Rh-106	3.37E-03	2.25E-03	1.56E-03
I-131	6.32E-03	4.34E-03	2.89E-03
Cs-137	9.29E-03	6.15E-03	4.32E-03
Ce-141	1.09E-03	7.25E-04	4.92E-04
Ce-Pr-144	7.04E-04	4.80E-04	3.37E-04

Whole-body effective dose

In order to calculate the whole body dose from the free-in-air exposure data, one must first convert exposure to dose in air by multiplying by a factor of 0.875 rad/R. Then, to convert to dose in tissue and account for shielding by the body, one must convert from rads in air to rem (or in S.I. units, Gy to Sv). In this report, as was the case for NTS fallout (Beck, 1999, we chose to follow the ICRP guidelines (ICRP, 1991) and estimate the effective whole body dose that weights the effects on various organs in a proscribed manner. The UNSCEAR (1993) recommends a factor of 0.75 ± 0.05 to convert from Gy to Sv for adults. This is similar to average values recommended by the ICRP and others (NCRP, 1999). This factor of course varies with the energy of the radiation and the orientation with respect to radiation incidence (NCRP, 1999, Eckerman and Ryman, 1993), However, a value of 0.75 is a reasonable average for fission products (NCRP, 1999). The net conversion from exposure in air to effective dose is thus about 0.875 * 0.75 = 0.66 for adults. Calculations using computer phantoms have indicated that the effective dose to young children is about 30% higher (NCRP, 1999).

Thus the dose to adults exposed outdoors is about 2/3 the outdoor exposure. However, most people spend most of their time indoors and thus their exposure is reduced greatly due to attenuation of the radiation by building materials. The amount of shielding (i.e. the shielding factor) will depend on the type of structure. In general, based on a review of the available literature, it is estimated that heavily constructed buildings made of brick or concrete will provide a shielding factor of about 0.2 ± 20% (1 s,d,) while lightly constructed buildings will provide a shielding factor of about 0.4. ±20% (NCRP, 1999). These estimates are fairly conservative and allow for a small amount of radioactivity that may be tracked into the home from contamination of shoes, etc. Assuming that on

average most persons spend about 80% of their time indoors (UNSCEAR, 1993; NCRP, 1999) with an average shielding factor of 0.3, their whole body effective dose would be 0.66 * (0.2 + 0.8 * 0.3) = 0.29 x Outdoor exposure. However, the UNSCEAR estimated that persons who work outdoor spend on average only 40% of their time indoors and the most exposed outdoor worker spends only about 30% of his/her time indoors. The NRC (1977) made a similar estimate of 40% of time spent indoors for the maximum exposed individual. Assuming only 30% indoors in a lightly shielded structure for the maximum exposed outdoor worker, the dose to the most exposed individuals would be 0.66 * (0.7 + 0.3 * 0.4) = 0.54 x Outdoor exposure or almost twice that of the average exposure. Conversely, the UNSCEAR (1993) estimated indoor workers spend only about 10% of their time outdoors while other estimates indicate some individuals spend even less time outdoors. Assuming 5% as a reasonable estimate for the least exposed individual living in a well shielded house and/or working in a well-shielded building, the minimum exposed individual would receive a dose of about 0.66 * (0.05 + 0.95 * 0.2) = 0.16 x outdoor exposure, or about ½ that of the average dose.

Thus the actual dose to any individual can range by about a factor of four depending on the amount of time spent outdoors and the type of structure the individual lives and works in. The dose to children could be about 30% higher than that for adults for the same fraction of time outdoors. In this report, all calculations of dose are based on the average exposure given above and estimates for any individual should be adjusted up or down based on the above discussion.

As discussed previously, the dose in a particularly individual in some counties may be considerably higher than estimated in this report. This is due to the use of an average precipitation for the county. Conversely, the use of the average precipitation for the county may have resulted in the estimated dose for most of the population being somewhat overestimated if most of the population resides at lower altitude, lower precipitation regions of the county. It should also be noted that the rate of penetration of radionuclides into the soil will also vary from site to site depending on the amount of rainfall and type of soil. Thus the relaxation lengths used for estimating the free-in-air exposure rates may also not correctly reflect the actual depth distribution at any particular locale and thus the dose to any particular individual.

Beta-ray skin dose

All of the exposures and doses discussed above refer to exposure to gamma radiation from the fission products deposited onto the ground. However almost all of the gamma emitting radionuclides also emit beta rays and a number of fission products emit beta rays but no gamma rays. Because of their low penetrating power, beta rays are attenuated rapidly in soil and even in air and thus contribute little to whole body radiation exposure (Eckerman and Ryman, 1993; NCRP, 1999). However, beta rays can contribute to the dose to skin, particularly in the days immediately following fallout before the activity has penetrated more deeply into the soil. Because the beta radiation is so sensitive to the actual depth distribution in the soil, only a very crude estimate can be made of the dose.

Besides the beta radiation itself, the beta rays produce a small amount of gamma radiation via bremsstrahlung (Eckerman and Ryman, 1993). This gamma radiation, although only a small fraction of the energy of the beta ray itself, can produce a small whole body exposure and add to skin dose. Furthermore, it is generally the only way a beta emitter can irradiate body organs other than the skin. The calculation of doses from beta radiation from fission products in the soil was discussed in the previous report by this author on NTS fallout exposure rates. Because of the fact that most of the short-lived beta ray emitters decayed prior to the deposition of "global" fallout, the relative impact of beta radiation compared to gamma radiation is expected to be have been even more minor than was estimated for NTS fallout.

Discussion of Results

Fallout deposition

The total deposition density of Cs-137 from "global" fallout through 1972 is shown in Figure 8. The total deposition Density of Zr-95+Nb-95 is shown in Fig. 9. The small differences in geographical variations for Cs-137 as compared to Zr-Nb-95 reflect the fact that Zr-Nb-95 was deposited only during and within a few months after testing while Cs-137, due to its long half-life and long stratospheric-residence time, was deposited essentially continuously. Thus areas with more frequent precipitation during periods of testing received relatively higher Zr-Nb-95 (as well as other short-lived radionuclides) deposition. Figs. 10 and 11 illustrate the variation with time of the annual population-weighted deposition density of Cs-137 and Zr-95, respectively. Also shown for Cs-137 is the cumulative deposition density. The latter illustrates the gradual build-up of activity in the soil that occurs for the longer-lived radionuclides. This buildup results in a gradually increasing exposure rate with time as shown later. Fig. 10 indicates that the deposition of Zr-95 in 1954 was less than that in 1958 and much less than the relative fission yields shown in Table 1. This is not exactly unexpected, however, since all of the tests conducted in 1954 were surface shots compared to only about 2/3 of the yield in 1958 being from surface shots in 1958 and ¾ in 1956 (USDOE, 1994). Surface shots would result in a much larger proportion of the debris being deposited locally and regionally as opposed to globally.

Table 7 gives the calculated total deposition (1953-1972) of each radionuclide and the population-weighted deposition density, and compares these with the estimates for NTS fallout from Beck (1999) and estimates for the Northern Hemisphere from UNSCEAR (1993).

As can be seen from Table 7, the deposition density of long-lived radionuclides from "global" fallout is about a factor of 10-15 greater than that from NTS fallout. However, the total deposition of short-lived nuclides such as I-131 was much less for "global" fallout than for NTS fallout. The "global" to NTS fallout ratios of population-weighted deposition density differ from the total deposition ratios reflecting the more uniform deposition of "global" fallout across the country. As shown in Beck (1999), the deposition of NTS fallout generally declined as the distance from NTS increased. The

higher relative proportion of "global" fallout in the more populous (and higher rainfall) eastern U.S. resulted in a relatively higher per capita exposure from "global" fallout for the same total continental U.S. deposition.

Table 7: Total deposition and population-weighted mean deposition density of selected radionuclides for NTS fallout and "global" fallout. Bq/m^2

Nuclide	Total Deposition (10^{15} Bq)		Population weighted Deposition density (kBq / m^2)		
	NTS	"Global	NTS	Global (this study)	"global"**
Cs-137	2.3	28	0.26	4.4	5.2
Sr-90	1.8	19	0.11	2.9	3.2
Zr-95	218	313	25	50	38
Nb-95	0	400	0	65	64
Ru-103	426	212	46	35	28
Ba-140	1390	290	144	46	23
Ce-141	500	223	54	37	21
Ce-144	40	302	4.6	47	48
Ru-106	24	157	2.6	24	24
Sr-89	333	170	36	28	20
I-131	1484	112	192	18	19
Pu-239+240	0.13	~0.4	~0.015	~0.06	0.06

** for 40-50 degree latitude band (UNSCEAR, 1993)

The deposition of course varied from year to year. The annual per capita deposition density for each nuclide for "global" fallout is shown in Table 8. Because of the delay that resulted due to the injection of debris into the stratosphere, the deposition of long-lived nuclides continued for many years after the cessation of testing.

Table 8: Annual per capita deposition density for "global" fallout. Bq/m^2

Year	Cs-137	Zr-95	Nb-95	Ru-103	Ru-106	I-131	Ba-140	Ce-141	Ce-144	Sb-125	Mn-54	Sr-89	Sr-90
1953	55	920	1549	740	475	210	614	737	671	39	40	895	37
1954	96	2424	2458	3077	873	1408	4273	2540	1095	67	58	1815	64
1955	191	296	390	129	1218	47	153	144	1261	117	58	308	127
1956	181	3738	4510	3503	935	2241	5606	3313	1367	106	132	2103	121
1957	138	3890	6978	2760	922	2120	5323	3712	1737	84	128	2139	92
1958	269	5401	6026	7442	2243	3977	10477	8337	4209	184	348	3851	180
1959	379	6685	12933	3171	2416	5	166	2870	4585	246	514	3060	252
1960	95	0	0	0	250	0	0	0	374	48	55	0	64
1961	115	4265	3257	2870	598	1463	4247	4028	1284	77	104	2279	77
1962	549	13813	14253	5307	4524	6009	15020	7327	10245	560	2125	6852	366
1963	921	8920	12477	6216	5958	62	308	3901	12954	910	2197	4526	614
1964	647	108	227	5	2660	0	0	0	5007	505	818	0	431
1965	288	0	0	0	818	0	0	0	1151	184	201	0	192
1966	109	0	0	0	220	0	0	0	314	62	52	0	73
1967	57	0	0	0	82	0	0	0	118	29	18	0	38
1968	58	0	0	0	59	0	0	0	86	26	12	0	39
1969	54	0	0	0	39	0	0	0	58	22	8	0	36
1970	67	0	0	0	34	0	0	0	51	24	6	0	45
1971	57	0	0	0	21	0	0	0	31	18	4	0	38
1972	23	0	0	0	6	0	0	0	0	7	1	0	15

Exposure and dose

The geographical distribution of total whole-body effective dose from all “global” fallout through 1972 for a typically exposed individual (80% indoors, 0.3 shielding factor) is shown in Figure 12. As can be seen, the variation across the continental U.S. is relatively small, about a factor of four for most counties, reflecting primarily variations in precipitation. The specific mean doses for each county for each month, year, and total are included in the database that accompanies this report. The interested reader can estimate his/her exposure and dose by multiplying by the appropriate indoor/outdoor and shielding factor correction factor as discussed in the previous section. The distribution of doses for 1962 is shown in Fig. 13 to illustrate the variation during a period of heavy testing when short-lived radionuclides contributed most of the exposure.

The relative impact as a function of time was investigated by calculating the population exposure for each county (the product of the average exposure for a given county multiplied by its population) and then summing over all counties. The annual population exposure versus year of exposure is given in Table 9. The per capita dose (population exposure divided by total population) is also shown. The corresponding estimates for NTS fallout from Beck (1999) are also shown for comparison.

From Table 9, one sees that the total and per capita population dose from external radiation through 2000 was about 50% higher than that from NTS fallout. The per capita dose to an average-exposed individual was 0.73 mSv. The UNSCEAR, 1993 estimate a population-weighted dose from “global” fallout in the latitude band 40-50 degrees to be about 1 mSv. Considering the variations in fallout with latitude discussed earlier in this report, the present doses estimate and the UNSCEAR estimate agree well. The highest annual per capita doses occurred in 1962 and 1963 and are comparable to the annual per capita doses from NTS fallout in 1952, 1953, 1955 and 1957. In fact the total population dose from “global” fallout through 1972 was comparable to that from the NTS for the same period.

Table 9: Population dose and per capita dose to typically-exposed individuals versus year of exposure

Year	"Global" Fallout		NTS Fallout *	
	Pop. dose (10^3person-Sv)	Per cap. dose (mSv)	Pop. dose (10^3person-Sv)	Per cap. dose (mSv)
1951			6.5	0.039
1952			15	0.093
1953	7.7	0.007	19	0.12
1954*	2.8	0.017	0.2	0.001
1955	1.0	0.006	12	0.072
1956*	4.1	0.025	0.1	0.001
1957	4.9	0.030	20	0.12
1958*	6.8	0.042	0.8	0.005
1959	7.7	0.047		-
1960	1.6	0.010		-
1961	3.3	0.020		
1962	14.5	0.089	4.7	0.029
1963	12.6	0.077		
1964	5.9	0.036		
1965	3.7	0.023		
1966	2.8	0.019		
1967	2.4	0.015		
1968	2.3	0.014		
1969	2.1	0.013		
1970	2.0	0.012		
1971	1.8	0.011		
1972	1.8	0.011		
1973-2000	34.4	0.211	0.45 (1963-2000)	
Total	119	0.73	80	0.49

*From Beck (1999). Based on 1960 population of 1.63×10^8

A large number of fission products are produced in a nuclear explosion. However, only a relatively few account for most of the external exposure. Table 10 shows the largest contributors to total integrated exposure (% of total integrated exposure from nuclide and decay products). The global fallout percentages vary only slightly with location but vary significantly from year to year as shown in Figure 14. Figure 15 shows the per capita dose that resulted from each radionuclide as a function of time. The short-lived radionuclides have been grouped. As can be seen, during periods of testing the shorter-lived isotopes contribute relatively more to the dose while for years with no testing the longer-lived radionuclides are dominant. In contrast to the doses from NTS fallout, very short-lived radionuclides such as Te-I-132 and I-131 were insignificant contributors to exposure rates while Zr-Nb-95 accounted for a large portion of the exposure. For NTS

fallout, Zr-Nb-95 was significant only at large distances from the NTS (Beck, 1999). Most of the cumulative dose from "global" fallout was due to Zr-Nb-95 and the longer-lived nuclides. Cs-137 and Zr-Nb-95 accounted for about 70% of the cumulative population exposure (see Table 9). In contrast, Cs-137 contributed only a small amount of (about 2%) of the integral dose from NTS fallout (Beck, 1999).

Table 10: Percentage of total integral exposure contributed by various fission products

Nuclide	Global Fallout (1953-2000) (%)	NTS* (%)
Te-I-132	<1	20-30
Ba-La-140	7	20-50
I-133	<<1	<1-10
Np-239	<<1	3-6
Zr-Nb-95	26	5-20
Zr-Nb-97, 97m	<<1	<1-6
I-135	<<1	<1-5
Ru-103	3	3-10
I-131	<1	3-4
Cs-137	45	1-3
Ru-106	6	<<1
Sb-125	4	<<1
Ce-Pr-144	2	<<1
Mn-54	6	0
Ce-141	<1	<1

*Depends on distance from NTS (see Beck, 1999)

Since, as discussed earlier, the estimates in this report are based on a relatively crude model(s) and there are large uncertainties, particularly, in the ratios of deposition for the short-lived radionuclides. The average monthly exposure rates calculated for various counties across the U.S. agreed quite well with actual measurements of fallout exposure rates made at sites in those counties using in situ gamma ray spectrometry, at least during 1962 and 1963 when the "global" fallout exposure rates were the highest. These comparisons are shown in Table 11. Since again the model results are an average for the entire county and the entire month of sampling while the measurements are instantaneous point measurements at a single location, the agreement is quite satisfying and lends confidence that the estimates for other periods of high fallout are also reasonably valid. Even though most of the exposure rate is due to Zr-95-Nb-95 and Cs-137, one can assume that the contributions to dose from other nuclides have not been drastically under- or over-estimated.

Table 11: Comparison of Measured Fallout Exposure Rates with Model Estimates

Location	Date	Measurement (: R/h)*	Model estimate (: R/h)*
Butte, MT	9/27/62	2.3	1.2
Missoula, MT	9/27/62	1.6	1.6
Ellensburg, WA	9/29/62	0.5	1.4
Seattle, WA	9/29/62	2.2	1.8
Clallam City, WA	10/1-2/62	2.0 (avg. of 5 sites)	1.8
Corvalis, OR	10/3/62	1.0	2.3
Crater Lk, OR	10/4/62	2.9	1.9
Richmond, CA	10/5/62	0.7	0.5
	10/12/63	1.4	1.2
Felton, CA	10/6/62	1.1	0.9
Santa Cruz, CA	10/6/62	1.0	0.9
Sunnyvale, CA	10/6/62	0.7	0.7
	10/12/63	0.4	1.4
Reno, NV	10/7/63	1.0	2.4
Winnemucca, NV	10/8/62	1.2	0.9
Elko, NV	10/8/62	1.8	2.2
	10/8/63	2.5	2.6
Wendover, UT	10/8/62	1.9	2.2
Salt Flats nr. Wend.	10/9/62	3.1	2.2
	10/16/63	1.7	1.8
Rawlins, WY	10/10/63	1.6	1.5
Laramie, WY	10/10/62	4.1	2.5
	10/8/63	3.6	1.8
Ft. Collins, CO	10/10/62	2.1	2.6
Denver, CO	10/10/62	1.6 (avg. of 5 sites)	2.2
	10/19/63	1.0 (avg. of 6 sites)	1.8
Colo. Springs, CO	10/11/62	2.7 (avg. of 2 sites)	2.3
	10/20/63	1.6 (avg. of 4 sites)	2.2
La Junta, CO	10/11/62	2.0	1.7
Dodge City, KS	10/12/62	3.1	2.4
	10/21/63	2.2	1.8
Wichita, KS	10/12/62	3.6	3.5
Kansas City, MO	10/13/62	4.1	3.6
Hannibal, MO	10/13/62	4.1	4.5
Springfield, IL	10/14/63	3.8	2.3
Franklin Pk., IL	10/22/63	2.5	2.5
Argonne Lab	10/15/62	2.5	2.8
	10/3/63	3.1 (2 sites)	2.8
Somerset, PA	10/16/62	3.6	3.6
	10/1/63	6.8	2.3

Location	Date	Measurement (: R/h)*	Model estimate (: R/h)*

Carlisle, PA	4/5/63	4.4	3.8
	10/1/63	1.9	1.8
Decatur, AL	4/7/63	6.0	6.0
Memphis, TN	4/8/63	5.0	5.3
Little Rock, AR	4/9/63	6.6	3.9
Houston, TX	4/10/63	5.6	1.8
Galveston, TX	4/10/63	0.5	1.2
Lake Chas., LA	4/14/63	5.2	3.1
Bay Minette, LA	4/13/63	4.6	3.2
Macon, GA	4/16/63	4.3	4.4
Aiken, SC	4/17/63	6.6	4.7
US25&SC19, SC	4/17/63	4.2 (5 sites)	4.7
Nr. Warrenton, NC	4/18/63	4.1	3.8
Madison, WI	9/22/62	2.6	3.0
Spring Valley, MN	9/22/62	2.6	3.8
	10/3/63	2.4	3.4
Sioux Falls, SD	9/23/62	5.1 (2 sites0	4.0
	10/5/63	3.6	2.6
Chamberlain, SD	9/23/62	4.6	4.2
	10/6/63	3.6	2.9
Murdo, SD	9/24/62	3.6	5.0
	10/6/63	3.7	3.0
Rapid City, SD	9/24/62	3.8 (2 sites)	5.3
	10/17/63	2.8	3.8
Spearfish, SD	9/24/62	3.7	6.6
Sundance, WY	9/25/62	2.3	5.2
	10/7/63	2.7	3.1
Moorecroft, WY	9/25/62	2.3	5.2
	10/7/63	2.7	3.1
Pelham, NY	8/63	3-5 (multiple measurements)	3.9

*Measurement results from Beck et al, (1963, 1966).
The model results are the average for the county and for the month of sampling. The measurement results are for a specific date and place(s). Measurement error was on the order of 0.2-0.4 ：R/hr. Thus the lack of agreement for any individual measurement-model pair could just reflect changes in deposition density during the month, the site precipitation not being representative of the county average, or the site itself not being representative of the general area.

The doses discussed above are from gamma irradiation. As discussed in Beck (1999), the ICRU (1997) estimated the beta skin dose rate from a plane source of fission products to be about 8-16 times the total effective dose. In Beck (1999), the ratio of dose rates for a 0.1-cm relaxation length for early arrival times was estimated to be about 3-5. The age (arrival time) of “global” fallout compared to NTS fallout was very long and most of the dose was delivered over a long period of time during which the longer-lived radionuclides penetrated further into the soil. It can thus be assumed that the beta skin dose from “global” fallout was even less significant than that estimated for NTS fallout. This is particularly true since most of the global fallout was deposited during rain and the

assumption of a 0.1-cm relaxation length for the first 30 days is thus probably conservative. Only a relatively few longer-lived nuclides emitting higher energy beta rays such as Y-90, the daughter of Sr-90, contribute significantly to the dose.

The actual impact of beta exposure is of course even less than estimated by the ICRU. The average individual would be exposed to beta radiation only for the 20% of time spent outdoors, resulting in an actual beta skin dose to gamma whole body dose ratio of about 0.2-0.4. Furthermore, since the radio-sensitivity of the skin is generally accepted to be much lower than for other organs, even the beta dose to the most exposed individuals who spend up to 70% of their time outdoors can be considered insignificant compared to their whole-body gamma exposure.

One source of beta radiation exposure that might be significant for “global” fallout in some cases is contamination to the skin from children playing in contaminated soil, both from soil adhering to the skin as well as due to a closer proximity to the source. The dose to a child playing on the ground would probably be about a factor of two higher than that to a standing adult due to the closer proximity to the source plane. However, this would still probably not constitute a significant exposure. A more significant exposure route would likely be direct ingestion of soil (NCRP, 1999).

Recommendations for Future Work and for Improving the Preliminary Estimates of This Feasibility Study

As is evident from the discussions above, the models used to estimate exposure rates and deposition densities are quite crude and monthly and individual county estimates may have large uncertainties particularly estimates for short-lived radionuclides such as I-131. Comparisons with soil sample analyses and in situ gamma spectrometric estimates of exposure rates suggest that the overall geographical distribution of external dose to the U.S. population, and the per capita or population dose, are probably quite reasonable. The per capita dose is also consistent with previous estimates made for residents of the mid latitudes of the Northern Hemisphere by the UNSCEAR (1993). Because most of the external dose was delivered after 1956, at least some data was available for the more important contributors to dose upon which to base the estimates.

However, the analysis carried out for this preliminary study suggests that considerable improvement could be made. This might allow more accurate estimates of deposition densities and doses for particular months to be made, particularly for years prior to 1958, as well as more accurate predictions of the geographical variation for any particular time. For example, by weighting the various precipitation measurements in a given county by the population one might be able to calculate a population-weighted Sr-90 deposition density that in turn would allow a better estimate of the dose to a typical resident of that county than the present estimate. An analysis of the gummed-film data for the years prior to 1958, in a manner similar to that carried out for NTS fallout, might also allow better estimates of deposition as a function of location for years prior to 1958. A further assessment of the variations in precipitation within counties might identify some populations that were exposed to much higher doses than presently estimated ("hotspots"). Areas with large amounts of thunderstorm activity during months of testing could be identified since this was believed to be one mechanism that resulted in high fallout of short-lived radionuclides such as I-131.

By assigning reasonable estimates of uncertainty and variability to critical parameters for each of the steps used in this preliminary study, one could estimate a confidence limit for the estimated monthly doses for each county in a manner similar to that provided by NCI (1997). Without such a systematic analysis it is difficult to assess the validity of any particular county's monthly dose estimate.

In addition to estimating the uncertainties in the various deposition and exposure estimates, the estimates themselves might be improved if additional data can be located, particularly data on the ratios of the deposition of the various nuclides as a function of location in the U.S. Additional data could also be used to develop a more sophisticated, higher resolution, model of the distribution of Sr-90 specific activity with latitude and longitude. This might be accomplished using a technique such as kriging to provide estimates of specific activity that vary smoothly across the country. A more sophisticated model would also attempt to account for the impact of "dry" deposition at arid locations. A thorough review and assessment of the vast amount of other scattered sources of data might also allow the estimates of isotopic ratios for particular months to be improved. It

may also allow improvements to the atmospheric model, which would then allow one to more confidently utilize the model for periods with no data. Because the current effort was limited in scope and resources, only a small subset of the vast literature could be evaluated and utilized.

I-131 may have been a significant contributor to ingestion dose. The present preliminary results suggest I-131 deposition was comparable to that from the NTS in many areas of the country. However, due to the lack of actual data, a much more comprehensive effort will be necessary to provide estimates of I-131 deposition density and associated uncertainty comparable to those estimated for NTS fallout. This effort would include development of a model for the likely geographical variation in the deposition of short-lived radionuclides across the U.S.

The estimates in this report do not include the impact from tests conducted after 1963 by China and France. The atmospheric tests by China in particular, although the total fission yield was only about 20 MT, were conducted at mid latitudes in the Northern Hemisphere and did result in additional exposures to the continental U.S. population during the 1970s and early 1980s.

A number of minor contributors to external exposure were not considered in this preliminary assessment. Small quantities of Co-60, an activation product, were measured in fallout at some sites during 1962-63, as were small quantities of Sb-124 and Cs-134. Small quantities of radioactive tracers were also released during tests in 1958 (W-185) and 1962 (Rh-102). None of these nuclides are believed to have contributed significantly to population doses. Also not considered in this study was the deposition of a few radionuclides that may contribute in a minor way to ingestion exposure such as Fe-55, Pu-239+240, Pu-241, Am-241 and Tc-99.

An additional possibility for further study would be to also estimate the doses to the populations of Alaska and Hawaii. These states were not included in the present analysis since they represent special unique situations: Hawaii due to its proximity to the Pacific weapons testing area and Alaska due to its proximity to Soviet testing sites.

The scope of work for this project requested an estimate of the time (resources) that would be required for each of the suggested improvements discussed above. It is difficult to make such an estimate at the present time. It should be noted that the NCI project to estimate the exposure of the U.S. population from I-131 required a large number of person-years of effort. An effort at least as comprehensive would be required to provide estimates of equal quality for “global” fallout along with credible estimates of uncertainty. A thorough search for additional data might require the assessment of data provided in a large subset of the thousands of publications and reports that have been published on aspects of “global” fallout. Development of more sophisticated models and assignment of realistic uncertainty estimates would be dependent on such on assessment of all retrievable data. A critical question that must be answered first is how fine a spatial and temporal resolution is desired. The present study indicates that a temporal resolution

on the order of a month is reasonable and feasible but that for some counties, the spatial variation across the county may be very large and difficult to quantity.

Summary and Conclusions

Fallout from atmospheric tests resulted in a per capita external radiation exposure of about 0.7 mSv to the population of the U.S. through the year 2000, about 1½ times that incurred from NTS fallout. However, residents in the states immediately downwind from the NTS received much higher than average exposures from NTS fallout while the exposures in the western and northwestern U.S. and some areas of the Midwest and SE were much less than the average. The doses from "global" fallout were more uniformly distributed across the U.S. with differences from place to place reflecting differences in average precipitation.

Annual per capita doses from "global" fallout were comparable to annual doses from NTS fallout during the years of testing. However, most of the exposure from the NTS tests occurred with the first 3 weeks of each test and was due to relatively short-lived radionuclides. In contrast, the exposure from "global" fallout occurred over a much greater span of time and was primarily from Zr-Nb-95 and a few long-lived radionuclides. Thus the dose rate was more uniform with time. Almost the entire whole-body effective dose to the population was from gamma rays emitted by fission products deposited on the ground. The actual dose received by any individual depended on the fraction of time he/she spent outdoors and the degree of shielding provided by his/her dwelling. The most exposed individuals at any particular location would have been outdoor workers or others who spent most of their day outdoors. The locations with the highest dose rates were those areas with high average annual precipitation. Beta radiation from fission products in the surface soil did result in additional dose to the skin when outdoors. However, this contribution was not large enough to be considered an important component of total fallout radiation and for "global" fallout was probably even less significant than it was for NTS fallout exposure. The only significant possible impact might have been for children who played in the soil for significant intervals of time.

The deposition of fission products contributed to internal radiation exposure via ingestion as well as external exposure. The deposition densities of several nuclides that could contribute significantly to ingestion doses were calculated for this study although the internal doses via ingestion will be treated in a separate report.

Comparisons with soil sample data and exposure rate measurements at a large number of sites in the U.S. during 1963-65 indicate that the model predictions reliably represent the overall pattern of total fallout and resultant population doses. Due to the sparseness of data prior to 1956, estimates of deposition and doses for 1953-56 are more uncertain than for years where fallout was monitored more extensively. However, the contribution to the total population dose from fallout in those years was relatively small.

This report has demonstrated that it is feasible to grossly estimate the external exposure of the population of the U.S. as a function of location and time. However, the monthly

estimates for any particular county are probably quite uncertain and the exposure rate probably varied significantly from place to place within a county, particularly for counties with large variations in topography. If more precise estimates of exposure are required for particular times and places, a more exhaustive study will be required. Such a study would need to carry out an intensive investigation to locate and evaluate additional measurement data, particularly for the shorter-lived radionuclides. A more sophisticated model would need to be developed those accounts for variations in the specific activity of Sr-90 deposition with latitude and longitude and accounts for any variations in this quantity with time. Geographic variations in isotopic ratios need to be investigated in greater detail, especially for the shorter-lived radionuclides such as I-131 that likely contributed significantly to ingestion doses to children. Variations in precipitation across a given county will also need to be considered in much more detail in order to obtain a better estimate of dose rates to an individual living in any particular county. Finally, uncertainty estimates need to be incorporated into the various components of the dose assessment model used here in order to allow reasonable estimates to be made of the relative uncertainties in the estimates as a function of location and time.

The database annex to this report, in the form of Excel spreadsheet files, gives the calculated deposition densities of all the radionuclides considered for each test for each county of the U.S. The whole-body effective dose to a typically exposed adult for each month is also tabulated for each county. By accessing the data for their particular county of residence for any given year(s), and applying the appropriate correction factor to adjust the tabulated doses for the actual fraction of time spent outdoors, the interested reader can estimate his/her whole body dose for any particular time interval and location.

List of Figures

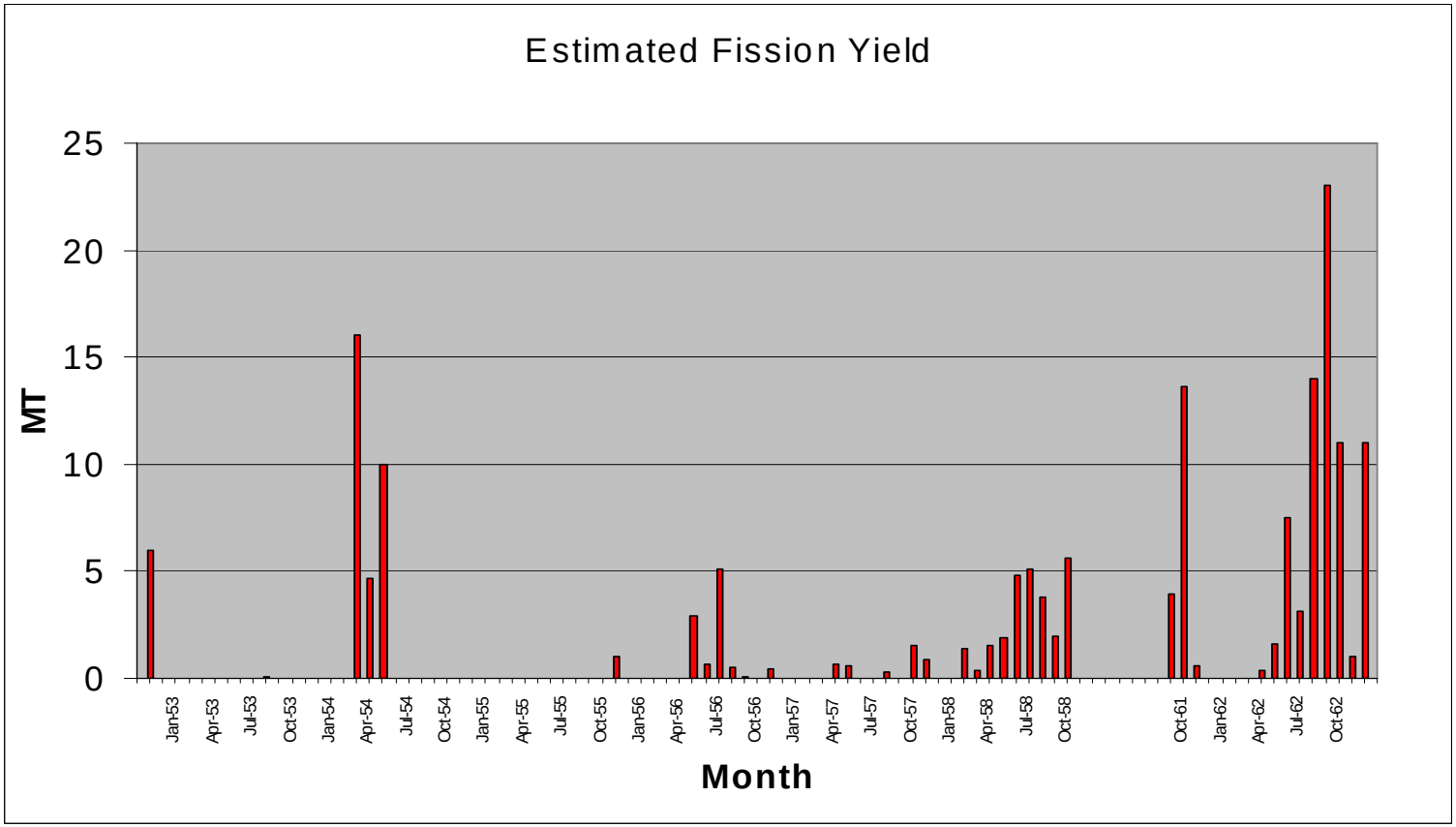


Figure 1: Estimated fission yield of tests conducted by the U.S., U.K. and U.S.S.R. for each month from 1952 through 1962.

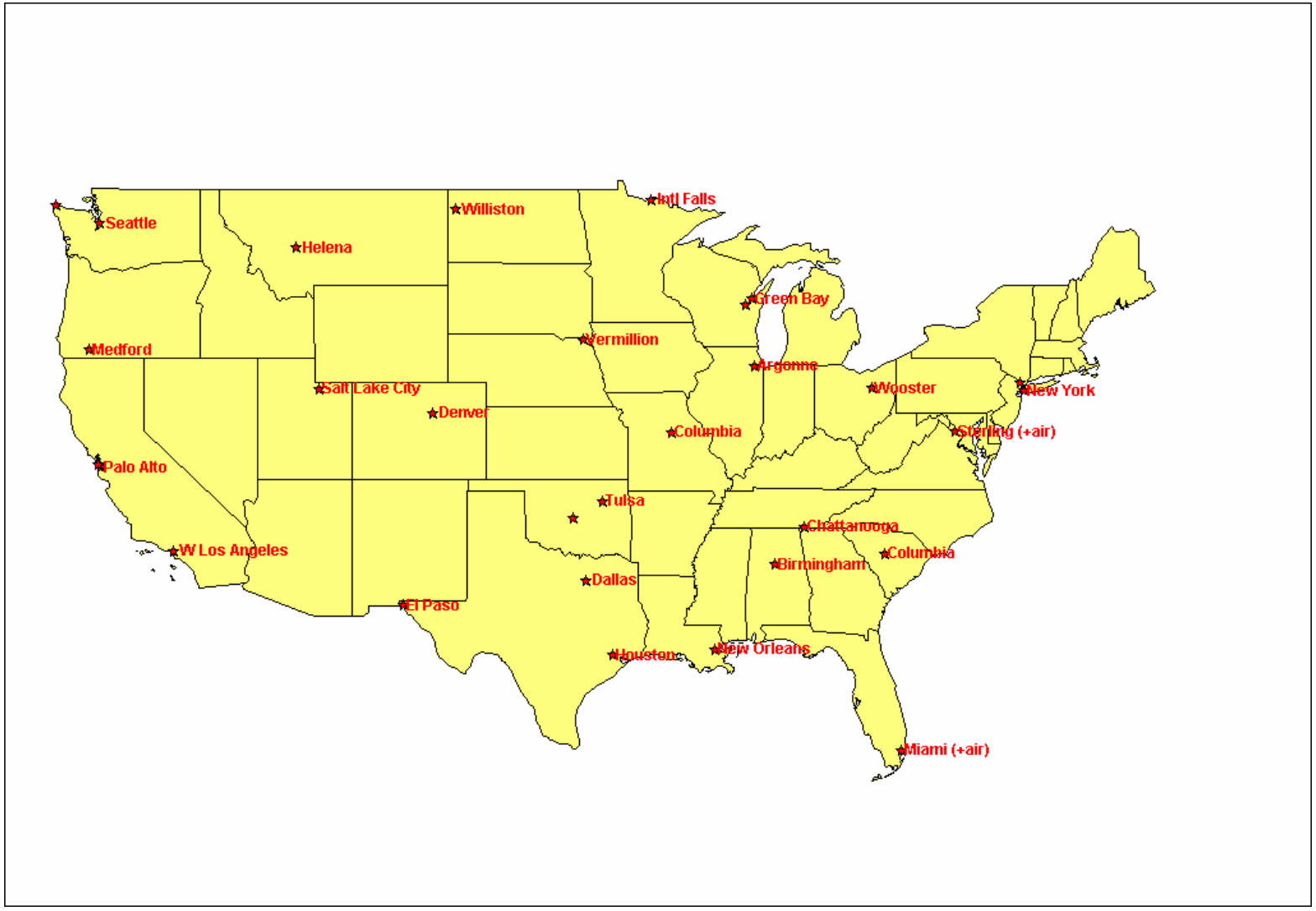
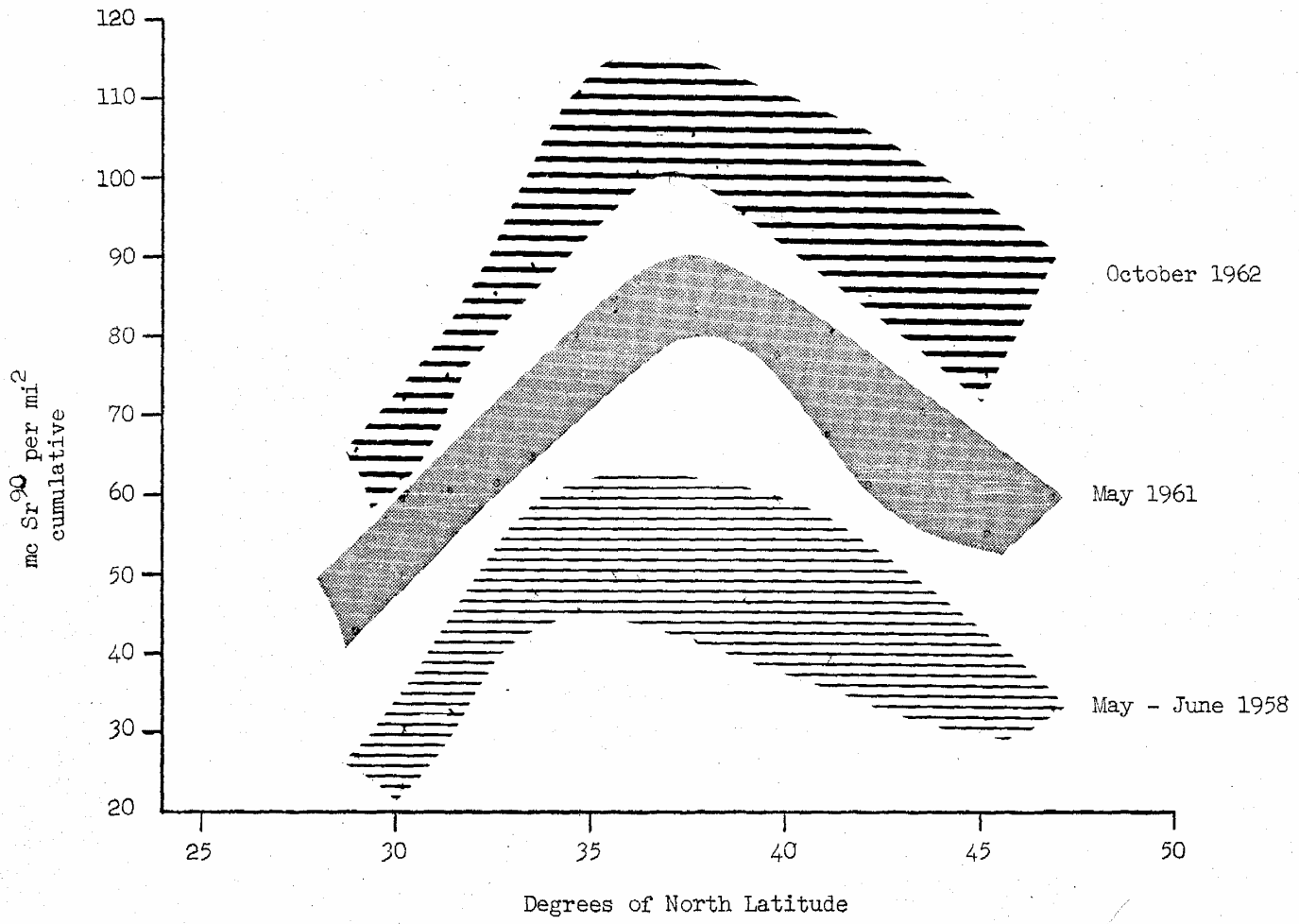


Figure 2: HASL and NRL Precipitation and Air Sampling Sites in 1962.

Figure 3 - Cumulative Deposition of Strontium-90 Along a Mid-United States Constant Precipitation Transect



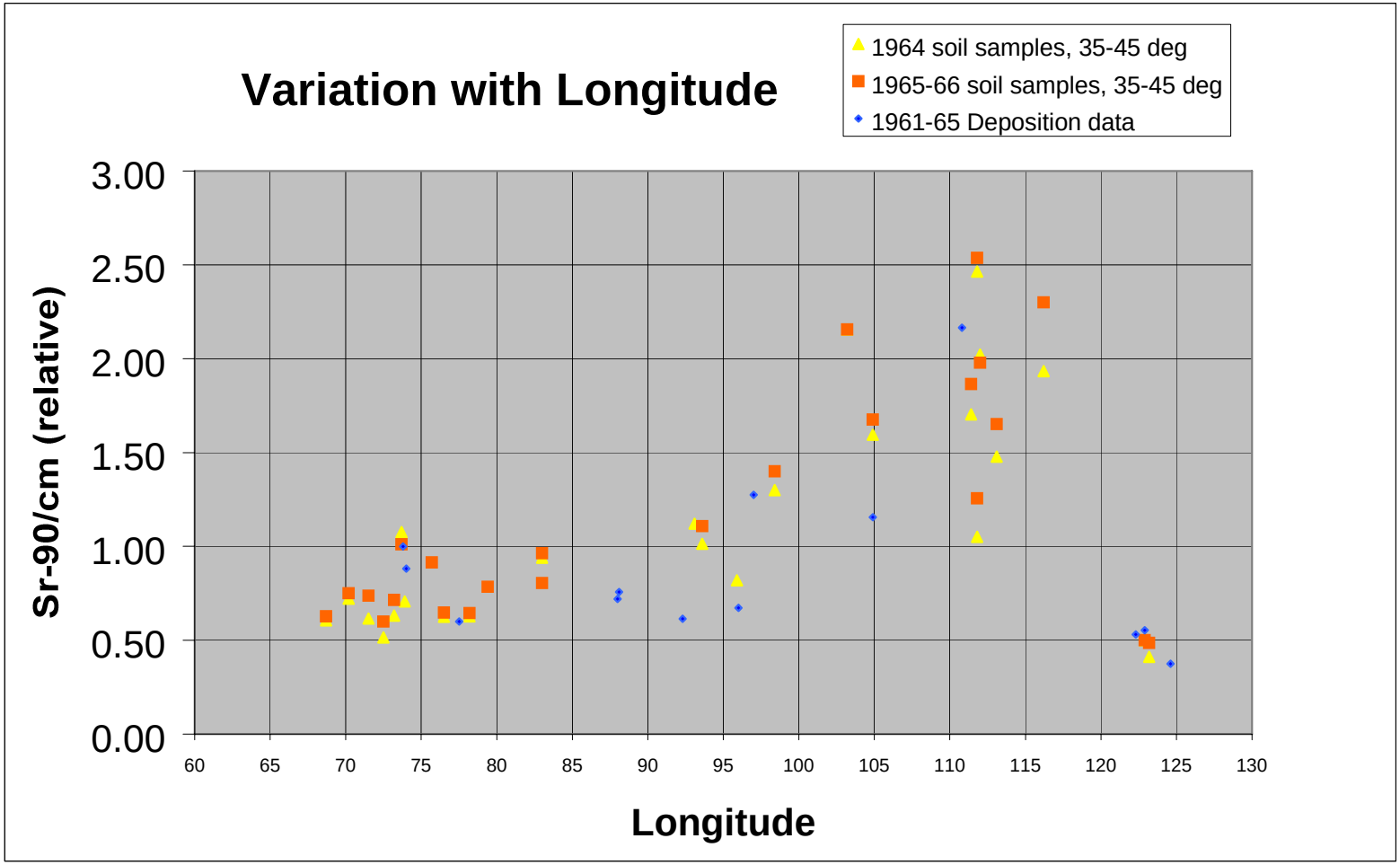


Figure 4: Variation of Sr-90 Deposition Density per cm of rain with longitude. The ordinate values for the deposition data have been normalized to those for the soil data since the soil data represent cumulate deposition at the time of sampling.

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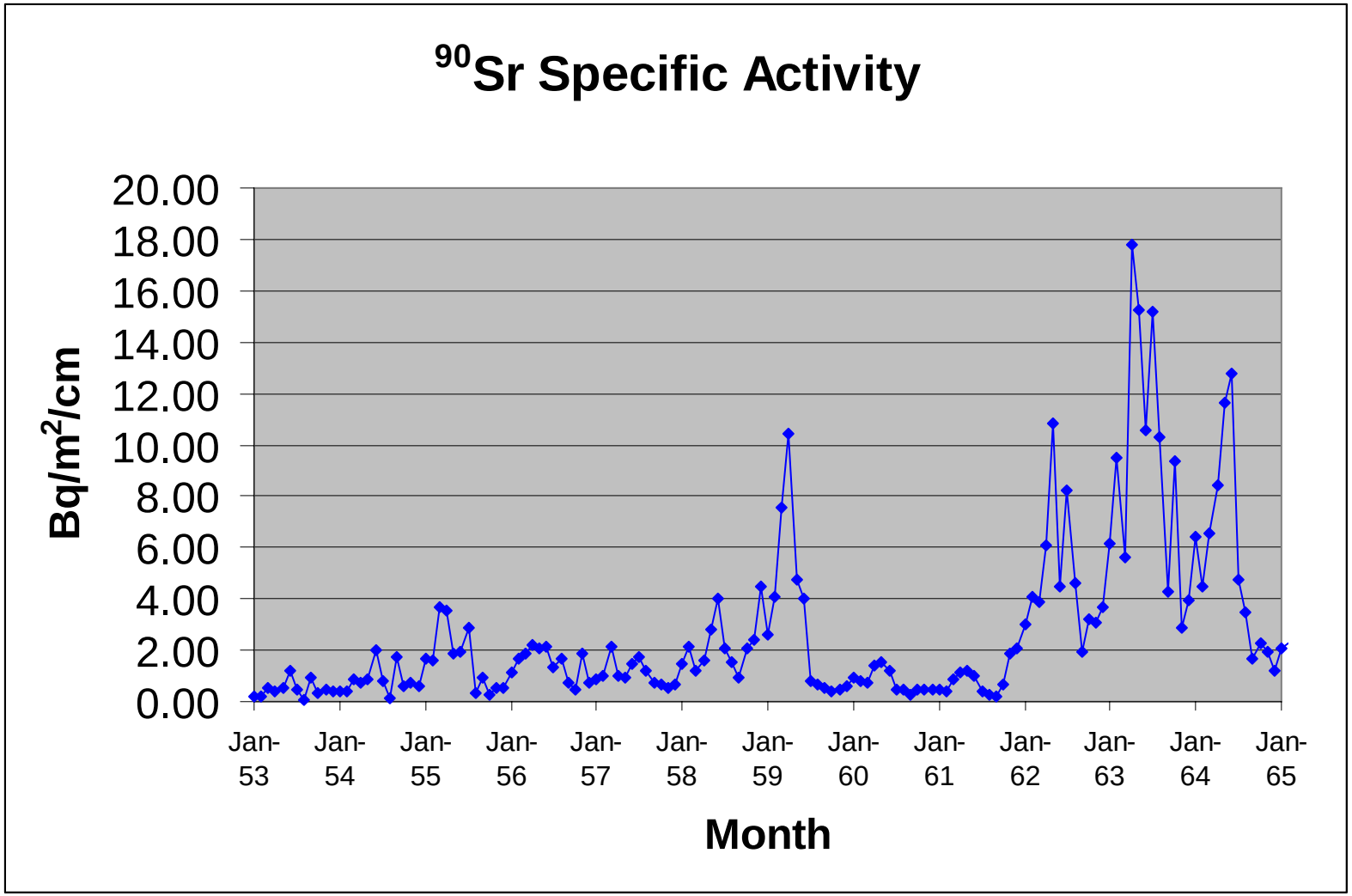
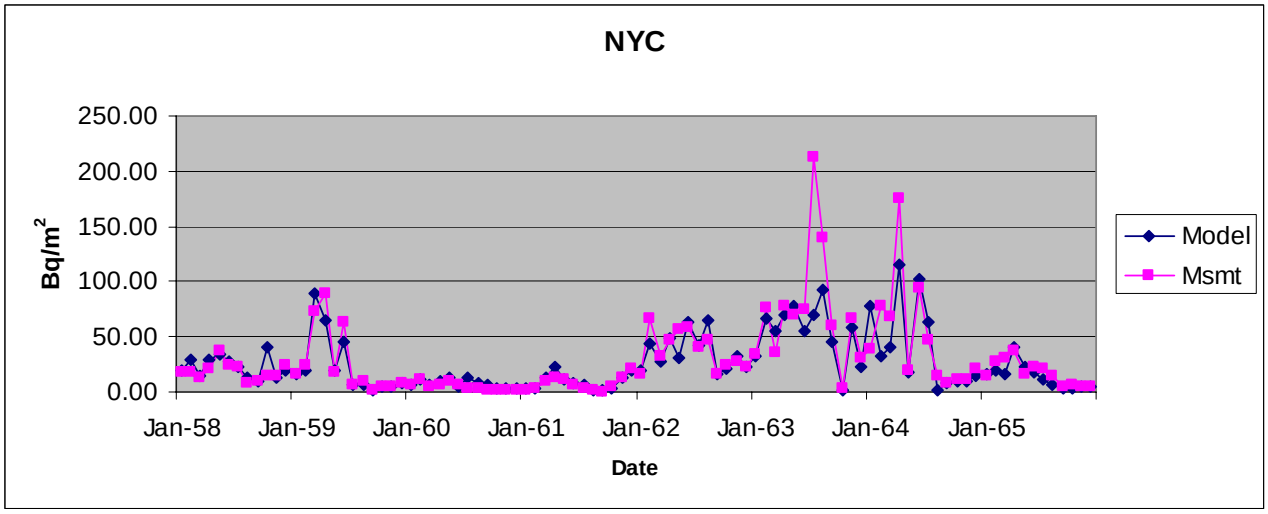
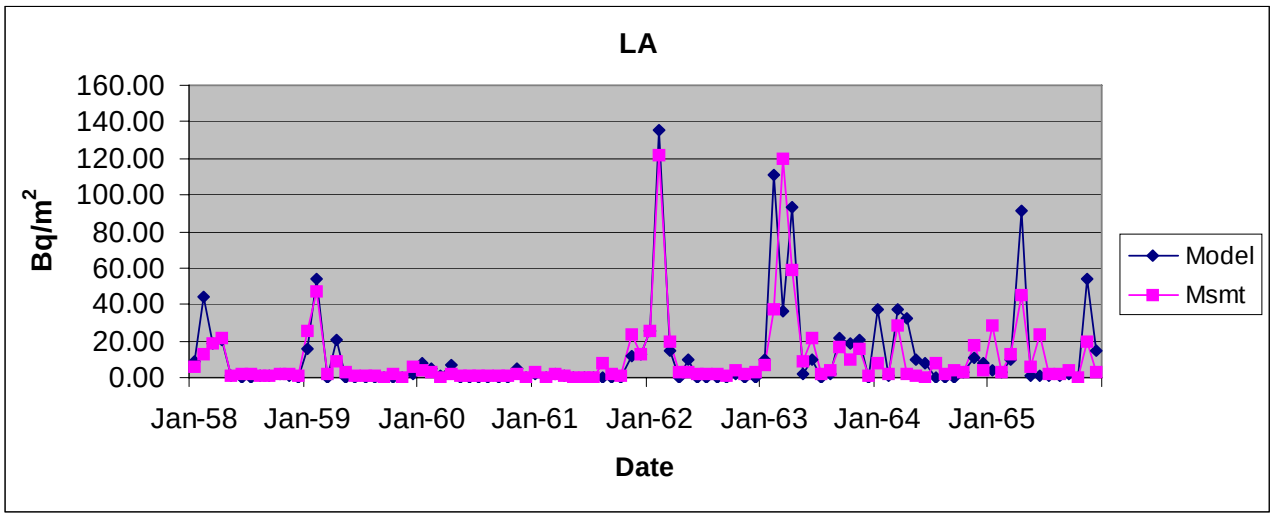


Figure 5: Specific activity of Sr-90 in precipitation (deposition density per cm of rain) for N.E. U.S. baseline sites for each month from 1953-1965.





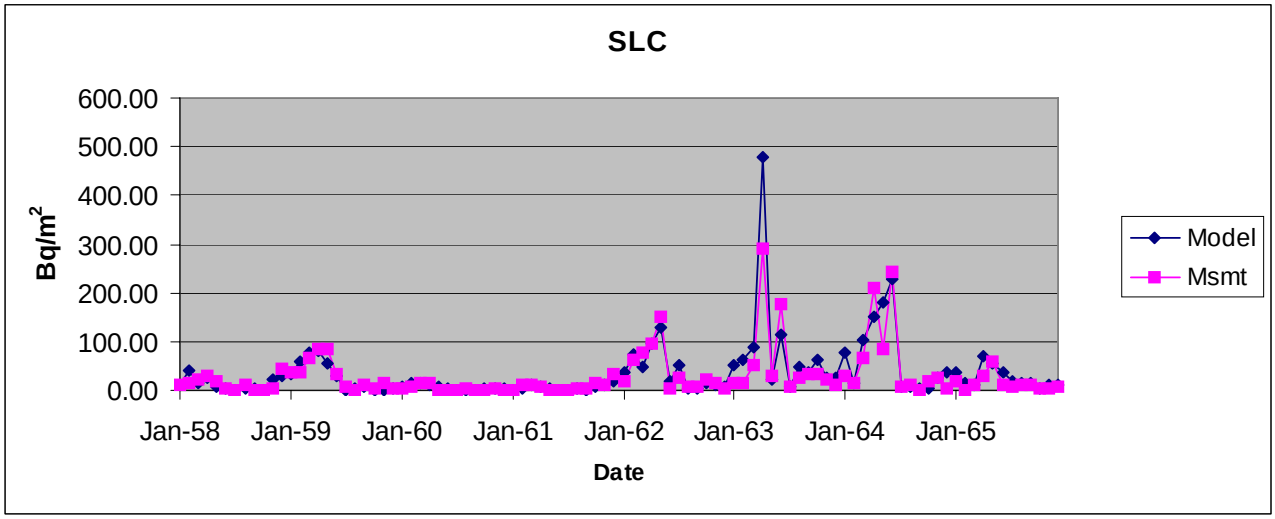
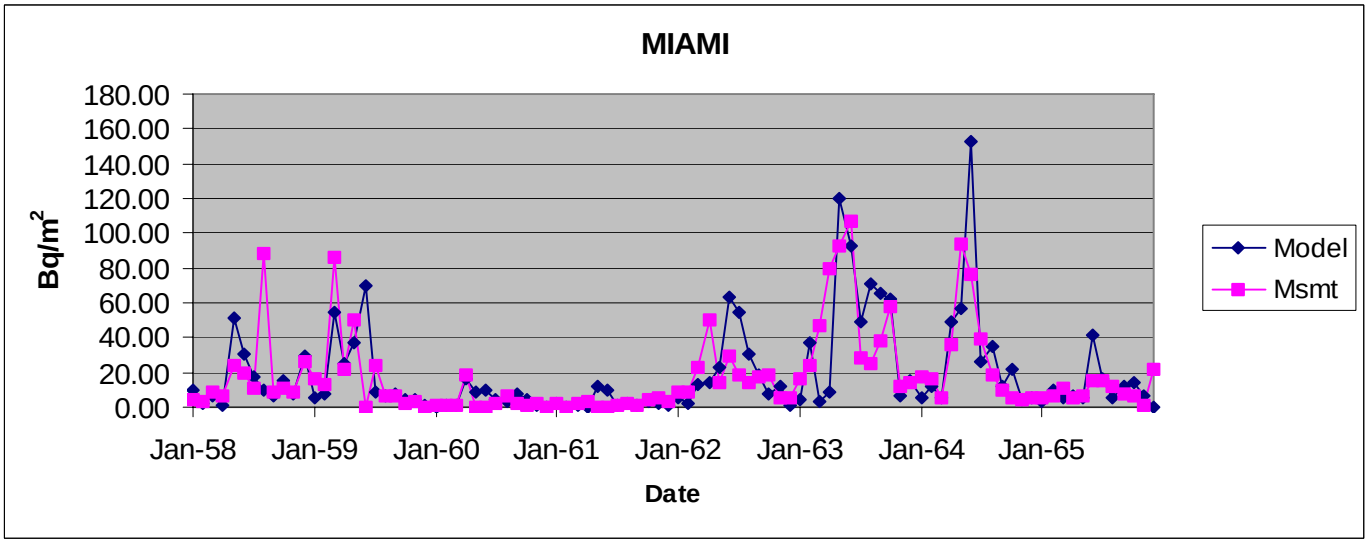


Figure 6a-6f. Comparisons of monthly model estimates of Sr-90 deposition density with measurements for selected cities. The model estimate is the average for the entire county in which the measurement site is located.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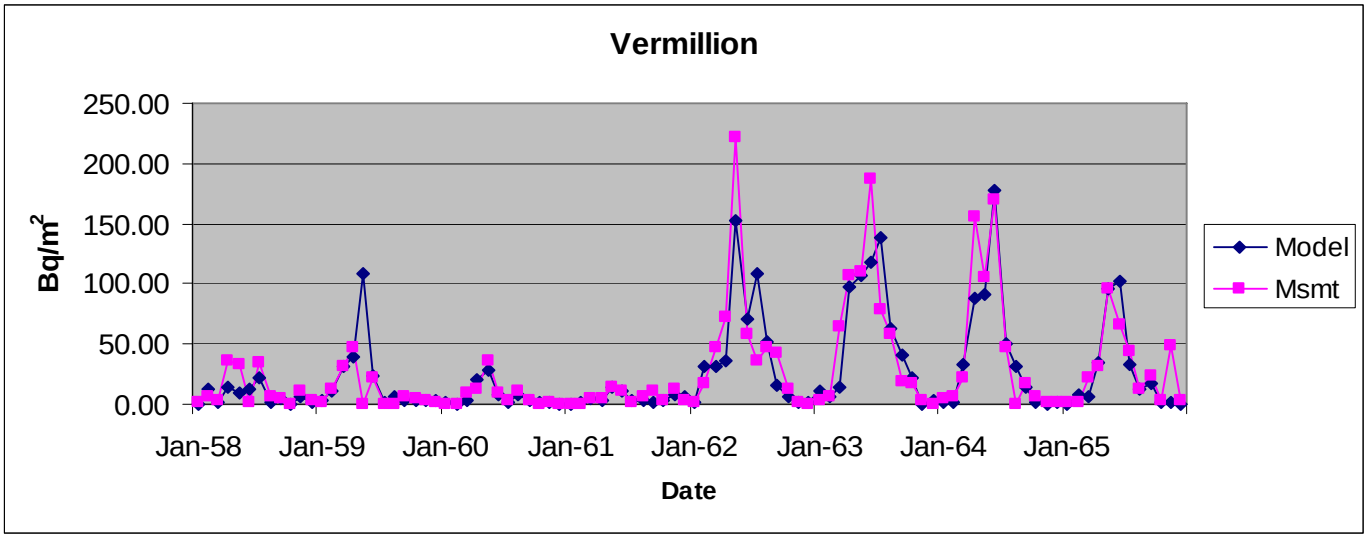
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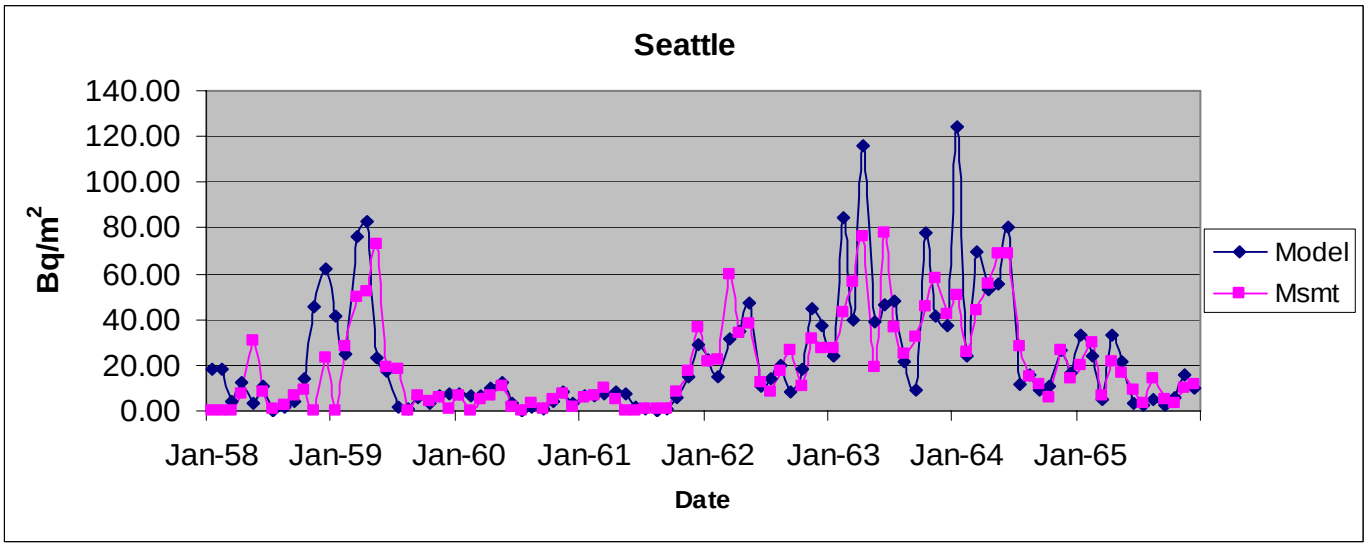
Date
Model
Msmt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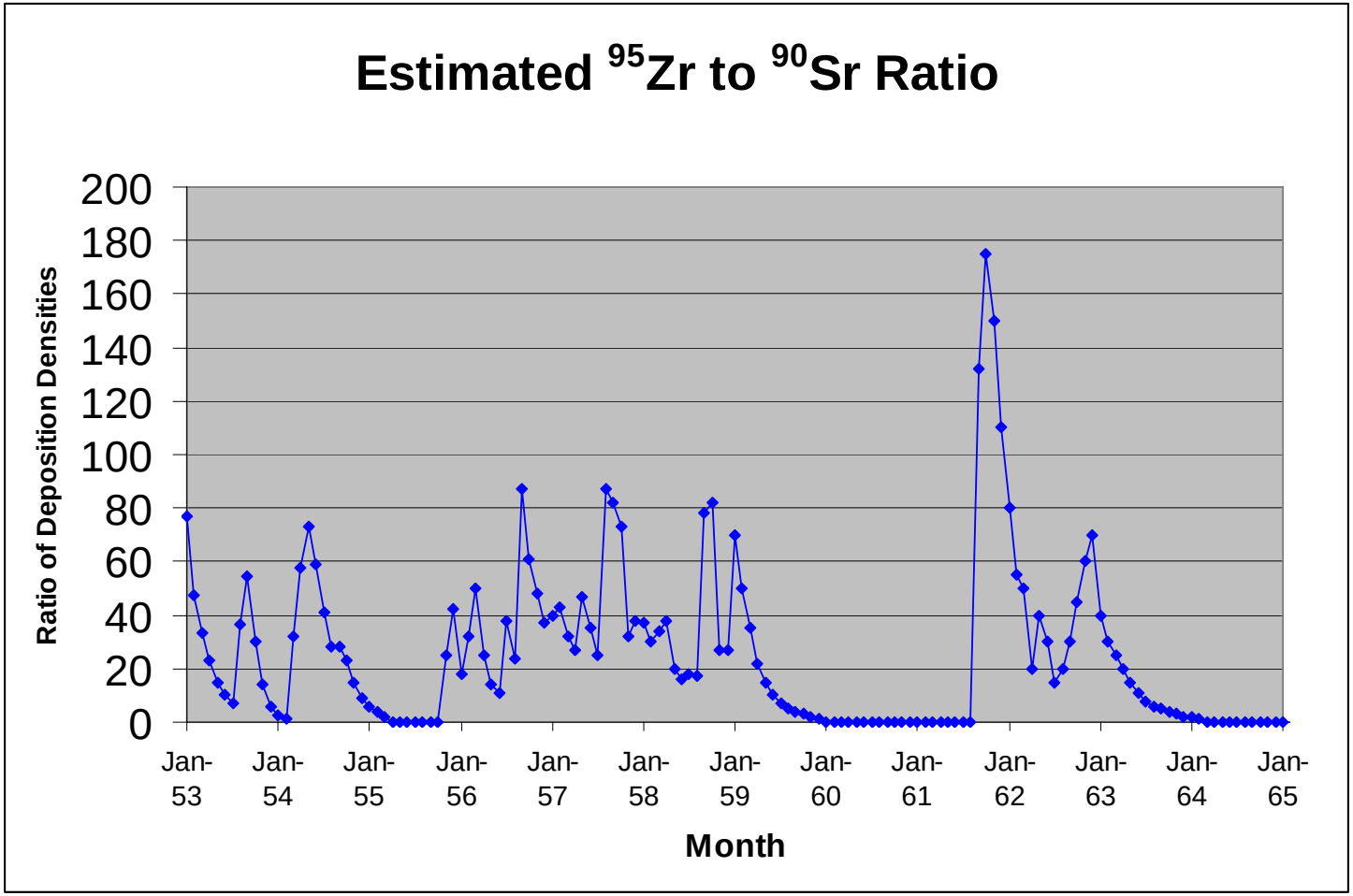

Figure 7: Estimated deposition density ratio of Zr-95 to Sr-90 for each month from 1953-1965.

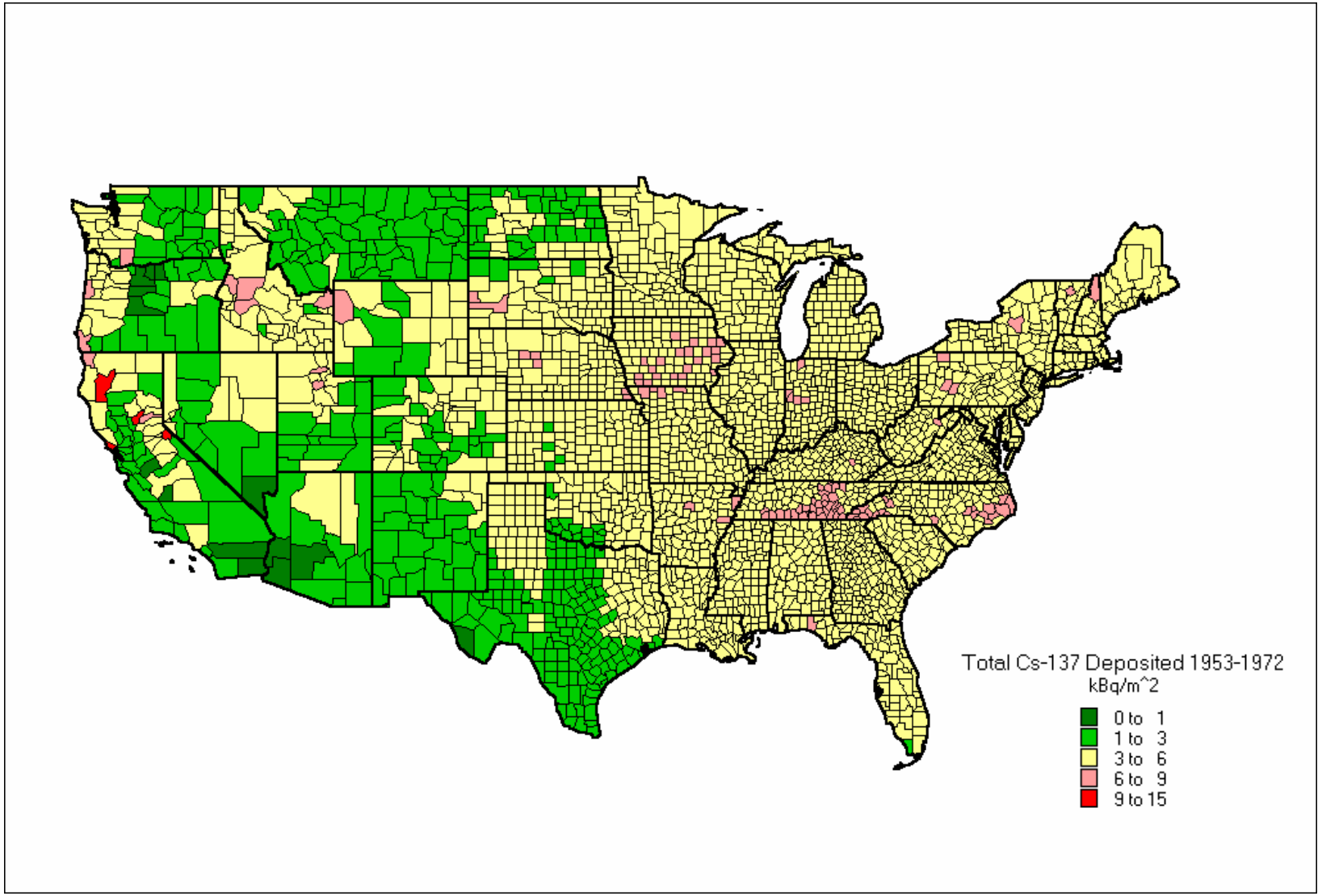

Figure 8: Total Cs-137 deposited from 1953-72 in each county.

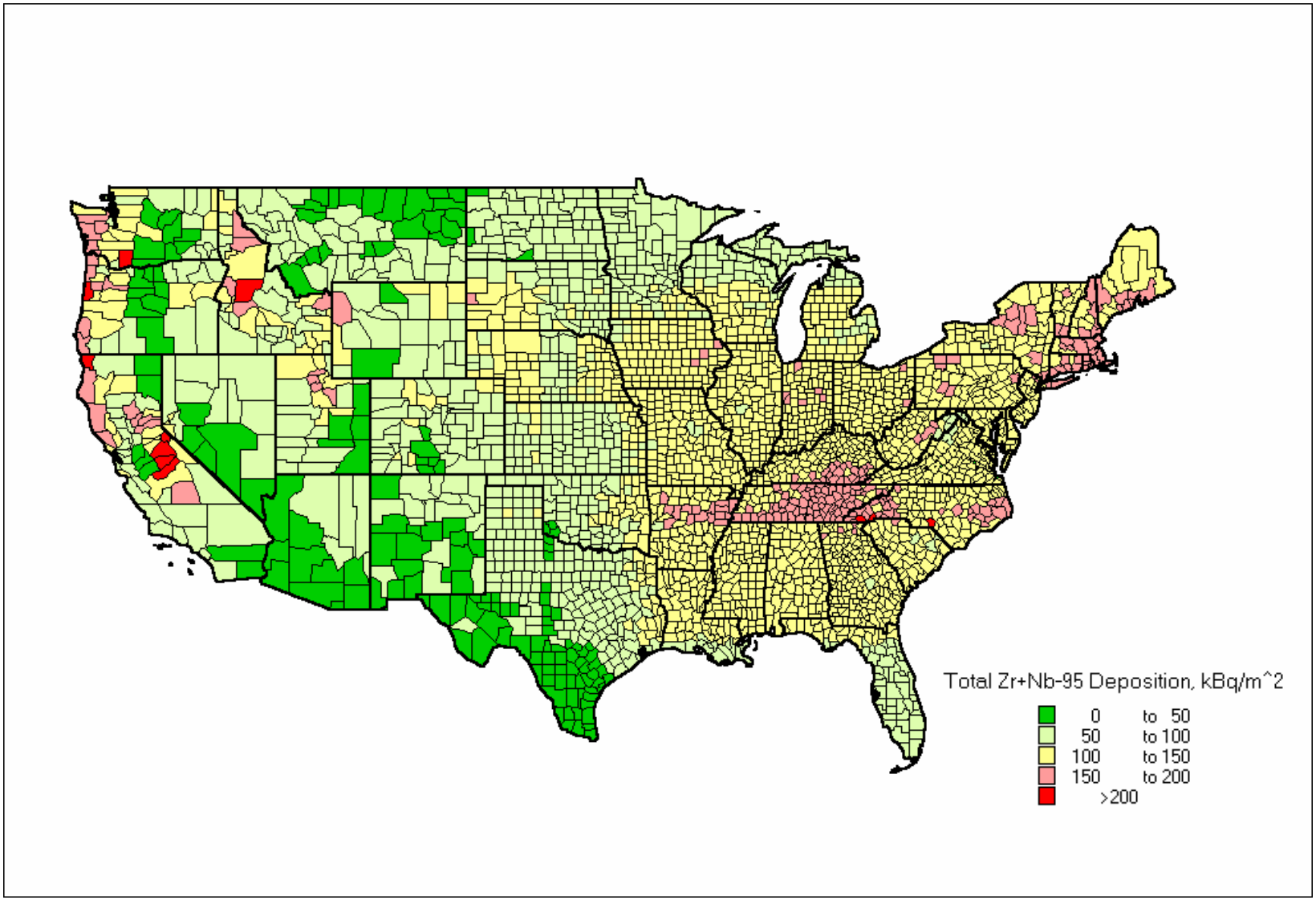

Figure 9: Total deposition of Zr-95+Nb-95 from 1953-1965 for each county.

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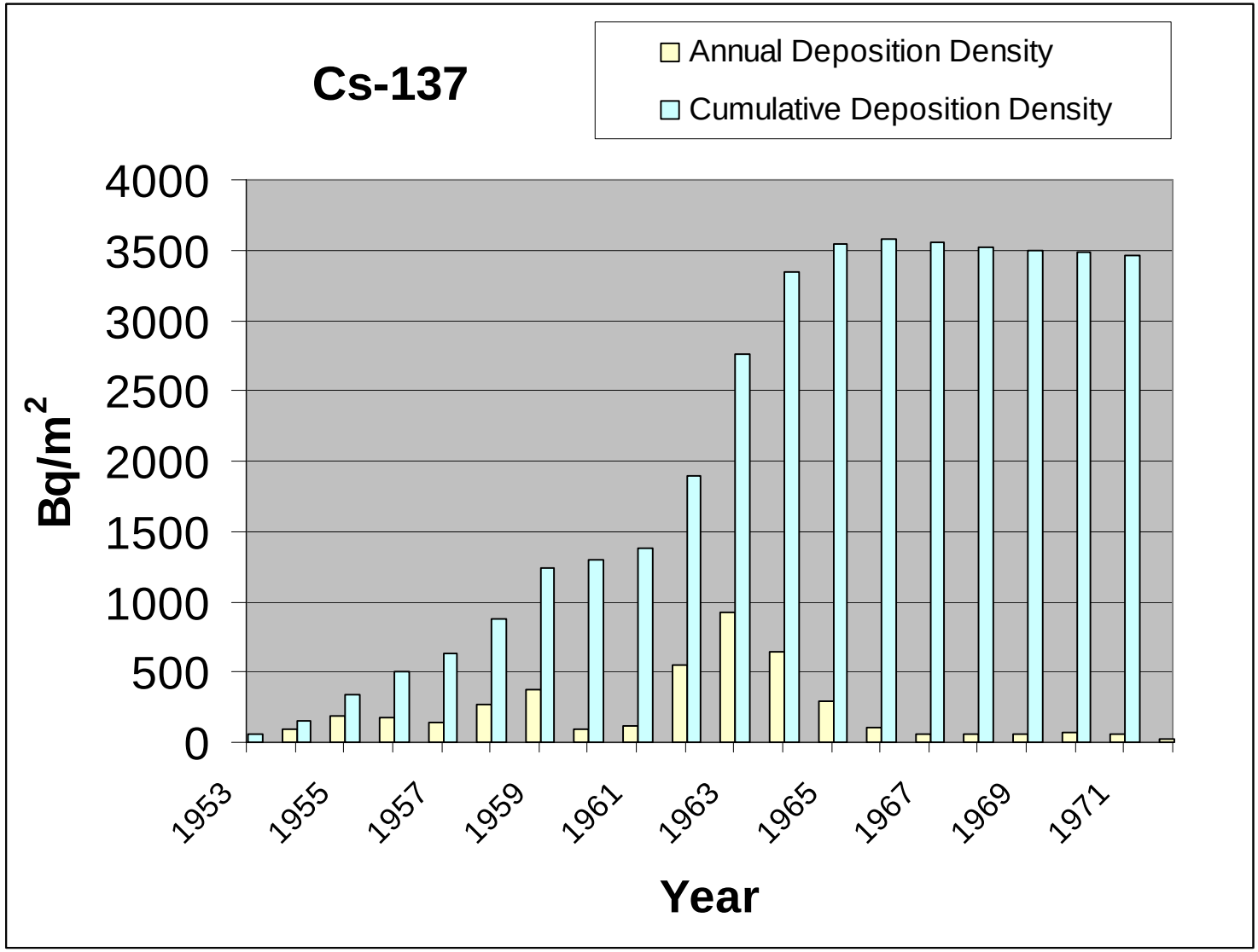

Figure 10: Annual population-weighted deposition density of Cs-137 and cumulative activity in soil at the end of each year.

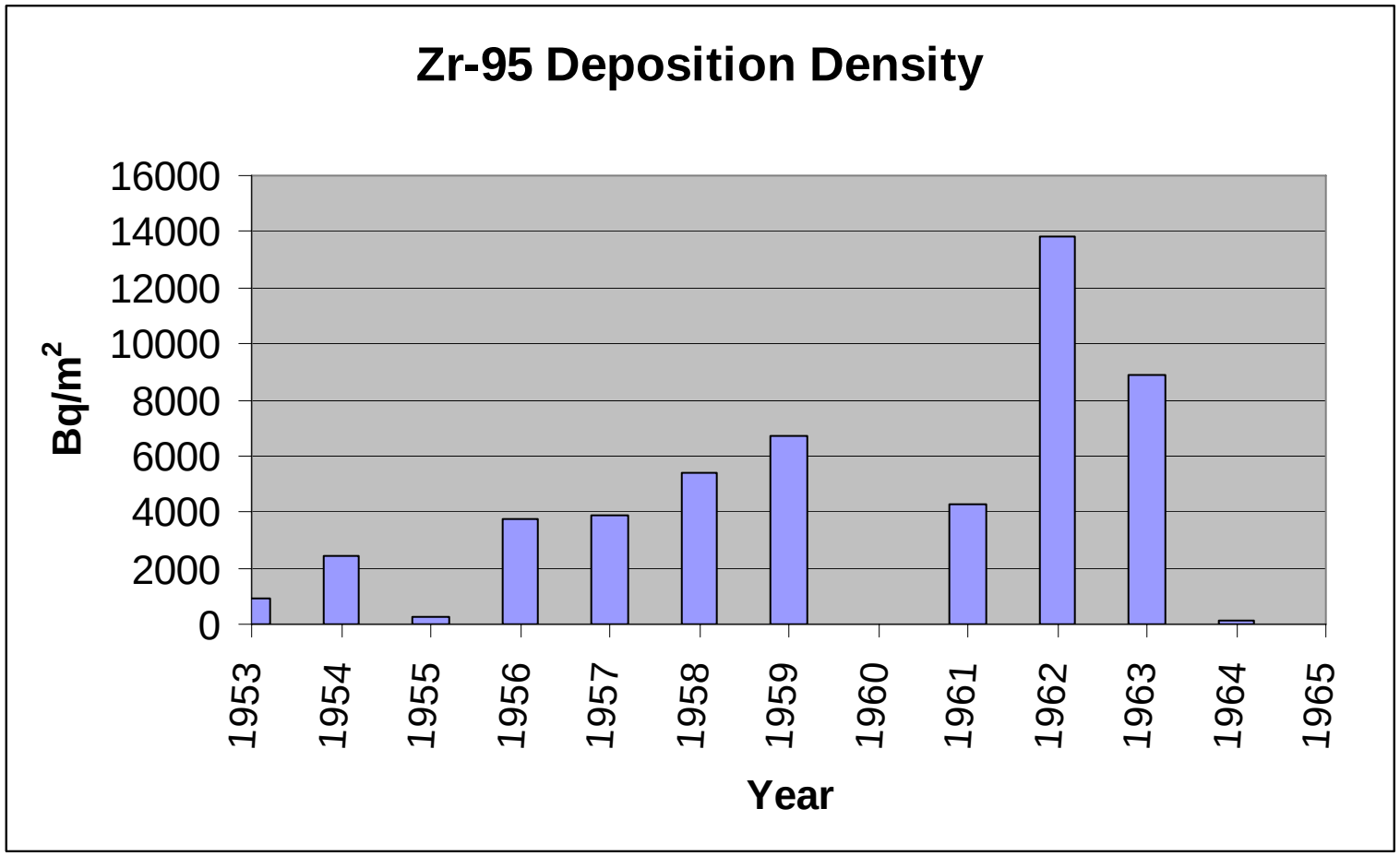

Figure 11: Annual population-weighted deposition density of Zr-95.

.

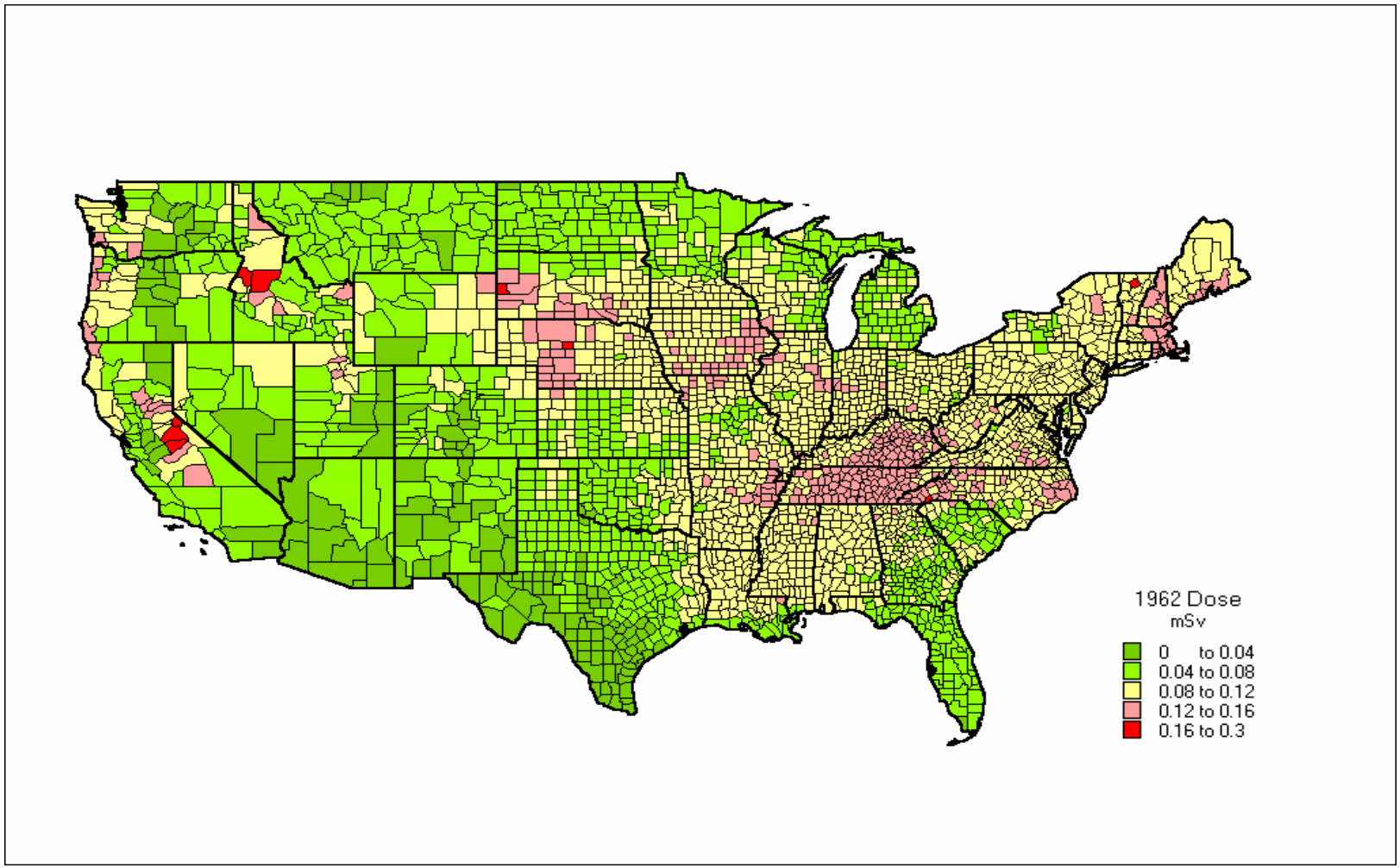

Figure 12: Dose received by typically exposed adults for each county during 1962.

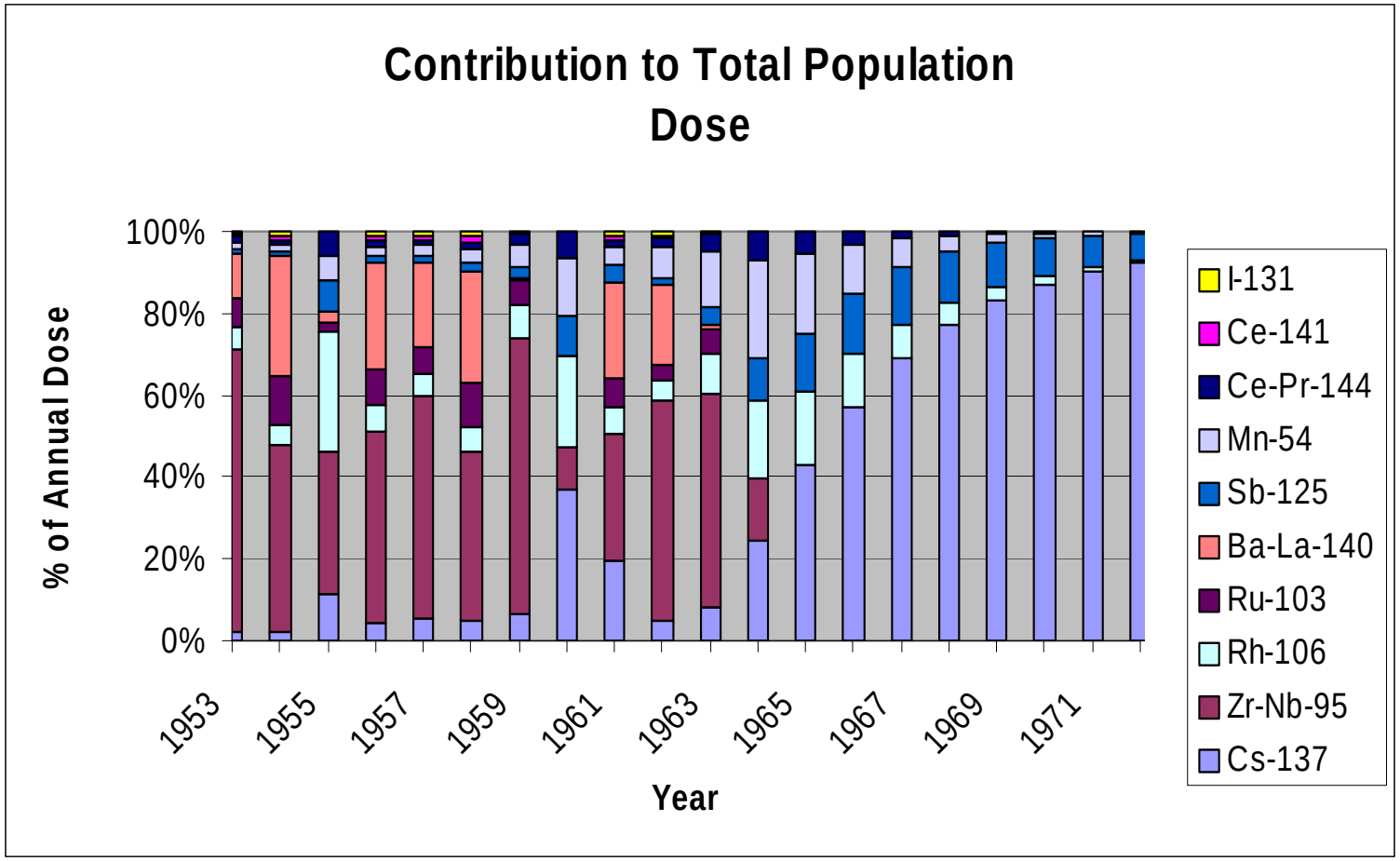

Figure 13: Fraction (%) of total annual population dose from each radionuclide; 1953-1972.

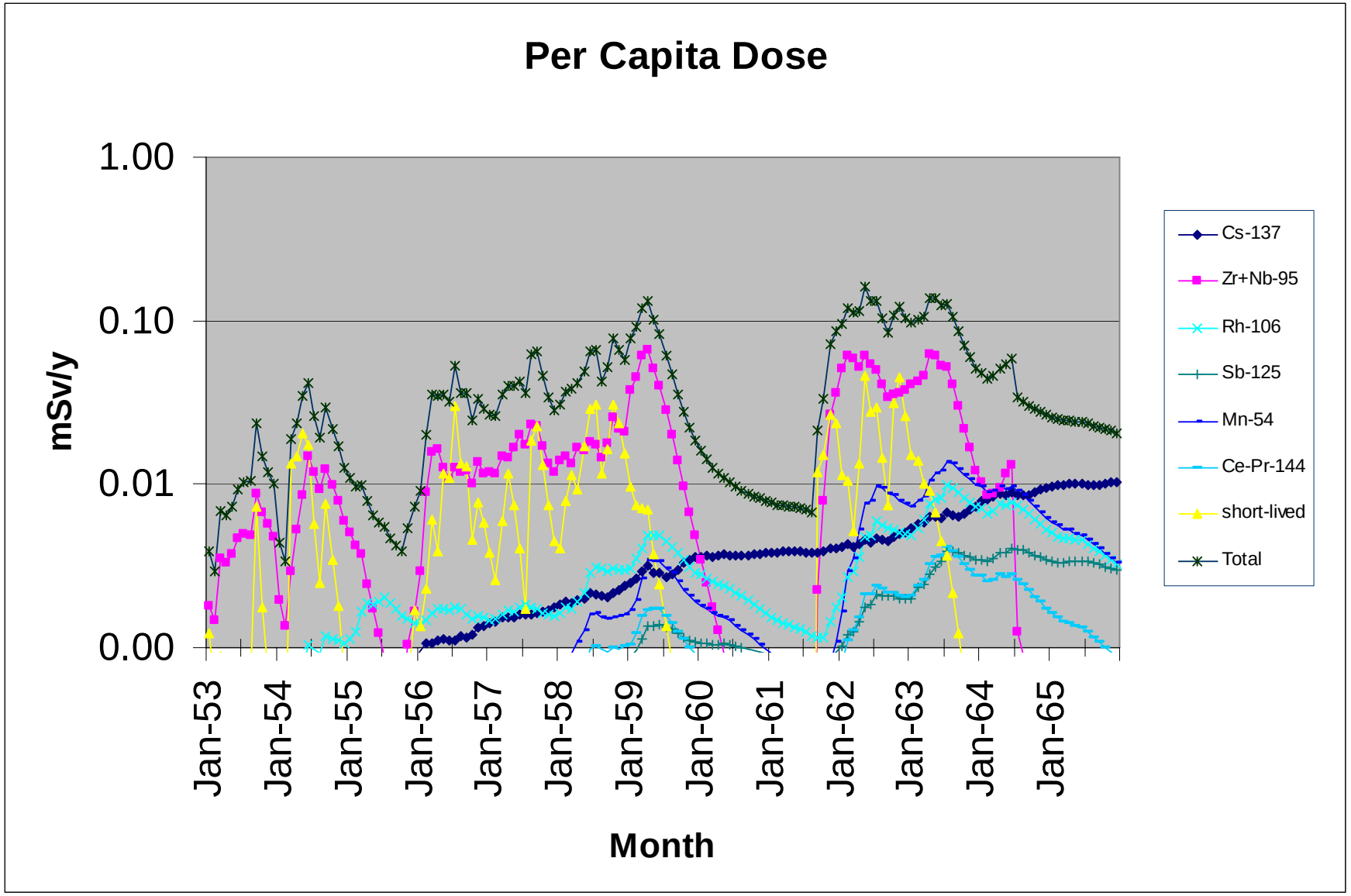

Figure 14: Monthly variations in Per Capita Dose from specific radionuclides. The short-lived radionuclides (I-131, Ba-La-140, Ru-103, and Ce-141) are grouped together.

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Appendix 1: Nuclide Ratios Used in This Preliminary Assessment

Month	95/90	103/90	106/90	125/90	131/90	140/90	141/90	144/90	54/90	Nb/Zr
Jan-53	77.08	76.33	17.09	1.14	2.56	31.03	68.45	28.00	2.18	0.90
2	47.69	42.94	16.19	1.12	0.14	5.11	29.80	23.00	1.73	1.20
3	33.54	31.61	15.66	1.10	0.00	0.00	19.37	20.00	1.39	1.50
4	23.00	12.58	15.13	1.09	0.00	0.00	10.00	19.00	1.12	1.60
5	15.00	5.99	13.64	1.08	0.00	0.00	6.00	18.00	0.93	1.80
6	10.00	2.31	10.94	1.08	0.00	0.00	3.00	17.00	0.73	1.90
7	7.00	1.69	10.07	1.06	0.00	0.00	2.00	15.00	0.72	1.90
8	36.65	34.31	8.93	1.04	40.13	83.03	40.40	13.00	1.33	2.00
9	54.51	51.84	13.50	1.04	43.64	116.39	70.46	22.00	1.23	2.10
10	30.20	23.45	12.24	1.01	3.47	20.19	28.90	18.00	1.06	2.10
11	13.88	13.94	10.83	0.97	0.14	2.26	15.00	14.00	0.94	2.10
12	5.59	8.78	9.67	0.94	0.01	0.21	8.00	11.00	0.84	2.10
Jan-54	2.40	5.54	8.60	0.91	0.00	0.02	4.00	9.00	0.77	2.10
2	1.29	3.62	8.99	0.89	0.00	0.00	2.00	9.00	0.72	2.10
3	32.00	62.01	11.67	0.98	52.12	146.42	46.12	13.00	0.87	0.50
4	58.00	92.87	14.18	1.06	50.69	158.86	75.84	18.00	0.93	0.70
5	73.00	102.77	15.88	1.10	68.87	186.57	93.41	22.00	1.25	0.70
6	59.00	74.14	15.58	1.10	12.01	63.15	60.24	21.00	1.18	0.90
7	41.00	43.47	14.85	1.08	0.82	11.81	29.83	19.00	1.03	1.20
8	28.00	25.16	13.97	1.06	0.05	2.11	14.55	17.00	0.90	1.50
9	28.00	24.12	13.63	1.05	16.60	35.28	22.48	17.00	0.76	1.60
10	23.00	18.06	13.00	1.04	6.63	19.77	17.08	16.00	0.68	1.80
11	15.00	10.65	12.90	1.02	3.44	9.72	8.20	15.00	0.64	1.90
12	9.00	4.39	11.78	1.00	0.00	0.00	2.38	13.00	0.61	1.90
Jan-55	6.00	2.58	11.24	0.98	0.00	0.00	1.00	12.00	0.57	2.00
2	4.00	1.41	10.52	0.96	0.00	0.00	0.64	11.00	0.54	2.10
3	2.00	0.41	10.63	0.95	0.00	0.00	0.30	11.00	0.49	2.10
4	0.00	0.00	9.79	0.93	0.00	0.00	0.00	10.00	0.46	2.20
5	0.00	0.00	9.91	0.92	0.00	0.00	0.00	10.00	0.43	2.20
6	0.00	0.00	9.09	0.90	0.00	0.00	0.00	9.00	0.40	2.20
7	0.00	0.00	8.26	0.88	0.00	0.00	0.00	8.00	0.38	2.20

Month	95/90	103/90	106/90	125/90	131/90	140/90	141/90	144/90	54/90	Nb/Zr
8	0.00	0.00	8.37	0.87	0.00	0.00	0.00	8.00	0.36	2.20
9	0.00	0.00	7.49	0.85	0.00	0.00	0.00	7.00	0.34	2.20
10	0.00	0.79	6.55	0.83	0.31	1.00	0.53	6.00	0.32	2.20
11	25.00	4.02	9.32	0.90	5.86	13.00	6.16	15.00	0.68	0.50
12	42.00	37.01	8.89	0.88	14.12	56.00	52.50	14.00	0.77	0.90
Jan-56	18.00	13.34	8.14	0.85	0.87	8.00	17.20	12.00	0.75	1.20
2	32.00	19.41	7.08	0.83	0.17	4.00	22.57	10.00	0.70	1.50
3	50.00	29.90	11.27	0.82	10.54	23.00	27.34	16.00	0.72	1.60
4	25.00	13.14	8.49	0.81	2.10	7.00	10.32	12.00	0.71	1.80
5	14.00	14.77	6.13	0.82	23.04	47.00	16.64	9.00	0.87	0.50
6	11.00	15.54	3.93	0.89	18.42	43.00	15.06	6.00	1.38	0.70
7	38.00	65.95	8.75	0.99	70.94	171.00	52.12	12.00	1.49	0.70
8	24.00	35.51	6.61	0.98	11.47	45.00	25.89	9.00	1.45	0.90
9	87.00	96.78	7.48	0.98	66.07	167.00	103.44	12.00	1.40	0.90
10	61.00	54.72	7.52	0.96	6.18	35.00	53.10	12.00	1.48	1.00
11	48.00	37.19	8.78	0.94	17.21	40.00	37.84	14.00	1.62	1.20
12	37.00	29.27	12.47	0.94	20.69	52.00	36.61	21.00	1.66	1.50
Jan-57	40.00	27.04	8.44	0.92	8.49	28.00	31.88	14.00	1.60	1.60
2	43.00	23.91	13.70	0.90	3.01	13.00	25.32	22.00	1.54	1.80
3	32.00	18.00	9.35	0.89	11.40	26.00	20.96	15.00	1.47	1.90
4	27.00	20.57	11.89	0.91	31.29	68.00	36.67	23.00	1.39	1.90
5	47.00	18.33	8.63	0.89	11.50	44.00	33.00	17.00	1.39	2.00
6	35.00	11.05	8.58	0.87	4.16	10.00	17.00	16.00	1.27	2.10
7	25.00	6.13	10.67	0.90	0.85	2.00	9.00	21.00	1.03	2.10
8	87.00	56.57	10.56	0.90	85.03	195.00	80.00	21.00	1.08	2.20
9	82.00	141.01	12.00	0.96	102.38	243.00	170.00	23.00	1.10	2.20
10	73.00	75.83	9.11	0.97	47.28	141.00	95.00	18.00	1.14	0.60
11	32.00	28.36	9.60	1.01	27.00	66.00	40.00	21.00	2.12	0.60
12	38.00	27.03	9.23	0.97	4.76	25.00	35.00	20.00	2.13	0.80
Jan-58	37.00	36.39	9.50	0.93	1.10	7.00	42.00	20.00	1.95	0.90
2	30.00	15.38	10.08	0.91	16.01	30.00	19.00	21.00	1.85	1.20
3	34.00	32.04	9.76	0.99	32.48	78.00	47.00	22.00	2.08	1.00
4	38.00	30.93	11.15	0.98	6.66	25.00	42.00	25.00	2.17	1.00
5	20.00	15.82	11.17	1.01	23.95	54.00	16.00	22.00	2.11	1.00
6	16.00	24.36	13.53	1.04	22.08	53.00	20.00	23.00	1.80	1.00

Month	95/90	103/90	106/90	125/90	131/90	140/90	141/90	144/90	54/90	Nb/Zr
7	18.00	49.59	14.13	1.07	28.33	70.00	36.00	21.00	1.59	1.00
8	17.00	44.24	14.97	1.06	5.97	20.00	31.00	22.00	1.58	1.00
9	78.00	55.23	11.71	1.06	50.12	118.00	66.00	21.00	2.14	1.00
10	82.00	64.11	15.48	1.08	69.12	160.00	90.00	32.00	2.00	1.20
11	27.00	109.30	10.66	1.09	18.96	65.00	150.00	23.00	2.13	1.50
12	27.00	60.40	14.80	1.06	3.59	33.00	74.00	31.00	2.30	1.60
Jan-59	70.00	44.16	11.85	1.03	0.28	7.00	48.00	24.00	2.31	1.80
2	50.00	23.72	14.19	1.01	0.03	2.00	23.00	28.00	2.23	1.90
3	35.00	16.01	9.00	0.99	0.00	0.00	14.00	22.00	2.18	1.90
4	22.00	11.43	9.00	0.98	0.00	0.00	9.00	13.00	2.09	2.00
5	15.00	2.83	10.00	0.96	0.00	0.00	2.00	19.00	1.97	2.10
6	10.00	3.16	9.56	0.94	0.00	0.00	2.00	18.00	1.85	2.10
7	7.00	1.76	8.06	0.93	0.00	0.00	1.00	15.00	1.75	2.20
8	5.00	1.97	5.99	0.91	0.00	0.00	1.00	11.00	1.64	2.20
9	4.00	0.00	6.12	0.89	0.00	0.00	0.00	11.00	1.54	2.20
10	3.00	0.00	4.58	0.87	0.00	0.00	0.00	8.00	1.43	2.20
11	2.00	0.00	4.71	0.86	0.00	0.00	0.00	8.00	1.33	2.20
12	1.00	0.00	3.05	0.84	0.00	0.00	0.00	5.00	1.22	2.20
Jan-60	0.00	0.00	5.65	0.82	0.00	0.00	0.00	9.00	1.13	2.20
2	0.00	0.00	5.25	0.82	0.00	0.00	0.00	8.00	1.02	2.20
3	0.00	0.00	4.62	0.80	0.00	0.00	0.00	7.00	0.97	2.20
4	0.00	0.00	3.96	0.78	0.00	0.00	0.00	6.00	0.93	2.20
5	0.00	0.00	4.01	0.76	0.00	0.00	0.00	6.00	0.88	2.20
6	0.00	0.00	3.39	0.75	0.00	0.00	0.00	5.00	0.83	2.20
7	0.00	0.00	3.43	0.74	0.00	0.00	0.00	5.00	0.78	2.20
8	0.00	0.00	2.78	0.72	0.00	0.00	0.00	4.00	0.74	2.20
9	0.00	0.00	2.83	0.71	0.00	0.00	0.00	4.00	0.69	2.20
10	0.00	0.00	2.89	0.69	0.00	0.00	0.00	4.00	0.65	2.20
11	0.00	0.00	2.21	0.68	0.00	0.00	0.00	3.00	0.60	2.20
12	0.00	0.00	3.01	0.67	0.00	0.00	0.00	4.00	0.56	2.20
Jan-61	0.00	0.00	3.07	0.65	0.00	0.00	0.00	4.00	0.52	2.20
2	0.00	0.00	3.12	0.64	0.00	0.00	0.00	4.00	0.49	2.20
3	0.00	0.00	2.37	0.63	0.00	0.00	0.00	3.00	0.46	2.20
4	0.00	0.00	2.40	0.62	0.00	0.00	0.00	3.00	0.44	2.20
5	0.00	0.00	2.44	0.61	0.00	0.00	0.00	3.00	0.41	2.20

Month	95/90	103/90	106/90	125/90	131/90	140/90	141/90	144/90	54/90	Nb/Zr
6	0.00	0.00	3.30	0.60	0.00	0.00	0.00	4.00	0.38	2.20
7	0.00	0.00	4.19	0.58	0.00	0.00	0.00	5.00	0.36	2.20
8	0.00	0.00	4.00	0.57	0.00	0.00	0.00	4.10	0.34	2.20
9	132.00	138.55	10.00	0.97	240.03	500.00	215.00	25.00	1.25	0.50
10	175.00	188.93	14.00	1.60	96.10	250.00	280.00	33.00	1.89	0.70
11	150.00	76.09	13.00	1.60	46.45	120.00	110.00	32.00	2.30	0.70
12	110.00	73.83	17.00	1.60	11.16	75.00	95.00	40.00	3.29	0.90
Jan-62	80.00	31.00	12.00	1.40	0.62	12.00	32.00	35.00	4.46	1.20
2	55.00	31.45	13.00	1.50	0.07	4.00	32.00	29.00	5.36	1.50
3	50.00	7.68	13.00	1.50	0.01	1.00	7.00	37.00	6.67	1.60
4	20.00	2.90	13.00	1.60	11.88	22.00	3.00	28.00	7.25	1.80
5	40.00	5.49	13.00	1.60	24.78	56.00	8.00	31.00	6.55	0.70
6	30.00	9.61	12.00	1.70	17.32	41.00	14.00	26.00	6.18	0.90
7	15.00	2.82	13.00	1.50	12.21	32.00	4.00	22.00	5.86	1.00
8	20.00	3.68	11.00	1.50	8.92	24.00	5.00	21.00	5.87	0.70
9	30.00	14.39	11.00	1.60	7.49	22.00	20.00	26.00	5.43	0.70
10	45.00	27.00	11.00	1.40	43.78	100.00	66.00	28.00	4.59	0.70
11	60.00	50.00	11.00	1.30	58.53	156.00	73.00	30.00	3.91	0.70
12	70.00	45.00	12.00	1.50	23.91	72.00	61.00	32.00	3.93	0.70
Jan-63	40.00	62.00	11.00	1.40	1.99	7.00	34.00	30.00	3.87	0.70
2	30.00	41.00	12.00	2.40	0.22	2.00	22.00	30.00	3.89	0.90
3	25.00	18.00	13.00	1.40	0.04	1.00	9.00	27.00	3.98	1.20
4	20.00	9.89	11.00	1.20	0.00	0.00	8.96	24.00	3.92	1.50
5	15.00	5.92	9.00	1.40	0.00	0.00	4.84	22.00	3.77	1.60
6	11.00	3.53	8.00	1.60	0.00	0.00	2.60	20.00	3.60	1.80
7	8.00	2.60	10.00	1.50	0.00	0.00	1.72	19.00	3.44	1.90
8	6.00	1.40	9.00	1.50	0.00	0.00	0.83	15.00	3.29	1.90
9	5.00	0.62	8.00	1.70	0.00	0.00	0.33	16.00	3.11	2.00
10	4.00	0.30	8.00	1.30	0.00	0.00	0.00	13.00	2.92	2.10
11	3.00	0.15	6.00	1.10	0.00	0.00	0.00	13.00	2.74	2.10
12	2.00	0.08	6.00	1.30	0.00	0.00	0.00	14.00	2.55	2.10
Jan-64	2.00	0.05	7.00	1.27	0.00	0.00	0.00	16.00	2.36	2.10
2	1.00	0.03	6.00	1.25	0.00	0.00	0.00	14.00	2.21	2.10
3	0.00	0.02	7.00	1.22	0.00	0.00	0.00	13.00	2.11	
4	0.00	0.01	7.00	1.19	0.00	0.00	0.00	12.00	2.00	

Month	95/90	103/90	106/90	125/90	131/90	140/90	141/90	144/90	54/90	Nb/Zr
5	0.00	0.00	6.00	1.17	0.00	0.00	0.00	11.00	1.89	
6	0.00	0.00	6.00	1.15	0.00	0.00	0.00	11.00	1.77	
7	0.00	0.00	6.00	1.12	0.00	0.00	0.00	10.00	1.67	
8	0.00	0.00	5.00	1.10	0.00	0.00	0.00	9.00	1.58	
9	0.00	0.00	5.00	1.08	0.00	0.00	0.00	9.00	1.48	
10	0.00	0.00	5.00	1.05	0.00	0.00	0.00	8.00	1.37	
11	0.00	0.00	5.00	1.03	0.00	0.00	0.00	7.00	1.28	
12			5.00	1.00				7.00	1.25	
Jan-65			4.73	1.01				6.63	1.20	
2			4.72	0.98				6.63	1.17	
3			4.47	0.99				6.28	1.12	
4			4.46	0.96				6.28	1.10	
5			4.23	0.97				5.94	1.05	
6			4.22	0.94				5.94	1.03	
7			3.99	0.95				5.63	0.98	
8			3.99	0.93				5.63	0.96	
9			3.77	0.94				5.33	0.92	
10			3.77	0.91				5.33	0.90	
11			3.57	0.92				5.04	0.86	
12			3.56	0.89				5.04	0.84	
Jan-66			3.37	0.90				4.78	0.81	
2			3.36	0.87				4.78	0.79	
3			3.18	0.88				4.52	0.76	
4			3.18	0.86				4.52	0.74	
5			3.01	0.87				4.28	0.71	
6			3.00	0.84				4.28	0.69	
7			2.84	0.85				4.06	0.66	
8			2.84	0.83				4.06	0.65	
9			2.69	0.84				3.84	0.62	
10			2.68	0.81				3.84	0.61	
11			2.54	0.82				3.64	0.58	
12			2.53	0.80				3.64	0.57	
Jan-67			2.40	0.80				3.44	0.55	
2			2.39	0.78				3.44	0.54	
3			2.27	0.79				3.26	0.51	

Month	95/90	103/90	106/90	125/90	131/90	140/90	141/90	144/90	54/90	Nb/Zr
4			2.26	0.77				3.26	0.50	
5			2.14	0.77				3.09	0.48	
6			2.14	0.75				3.09	0.47	
7			2.02	0.76				2.92	0.45	
8			2.02	0.74				2.92	0.44	
9			1.91	0.75				2.77	0.42	
10			1.91	0.72				2.77	0.41	
11			1.81	0.73				2.62	0.39	
12			1.80	0.71				2.62	0.39	
Jan-68			1.71	0.72				2.48	0.37	
2			1.70	0.70				2.48	0.36	
3			1.61	0.70				2.35	0.35	
4			1.61	0.68				2.35	0.34	
5			1.53	0.69				2.22	0.32	
6			1.52	0.67				2.22	0.32	
7			1.44	0.68				2.11	0.30	
8			1.44	0.66				2.11	0.30	
9			1.36	0.66				1.99	0.28	
10			1.36	0.64				1.99	0.28	
11			1.29	0.65				1.89	0.27	
12			1.28	0.63				1.89	0.26	
Jan-69			1.22	0.64				1.79	0.25	
2			1.21	0.62				1.79	0.24	
3			1.15	0.63				1.69	0.23	
4			1.15	0.61				1.69	0.23	
5			1.09	0.62				1.60	0.22	
6			1.08	0.60				1.60	0.21	
7			1.03	0.60				1.52	0.21	
8			1.02	0.59				1.52	0.20	
9			0.97	0.59				1.44	0.19	
10			0.97	0.57				1.44	0.19	
11			0.92	0.58				1.36	0.18	
12			0.91	0.56				1.36	0.18	
Jan-70			0.87	0.57				1.29	0.17	
2			0.86	0.55				1.29	0.17	

Month	95/90	103/90	106/90	125/90	131/90	140/90	141/90	144/90	54/90	Nb/Zr
3			0.82	0.56				1.22	0.16	
4			0.82	0.54				1.22	0.15	
5			0.77	0.55				1.16	0.15	
6			0.77	0.53				1.16	0.15	
7			0.73	0.54				1.09	0.14	
8			0.73	0.52				1.09	0.14	
9			0.69	0.53				1.04	0.13	
10			0.69	0.51				1.04	0.13	
11			0.65	0.52				0.98	0.12	
12			0.65	0.50				0.98	0.12	
Jan-71			0.62	0.51				0.93	0.11	
2			0.62	0.49				0.93	0.11	
3			0.58	0.50				0.88	0.11	
4			0.58	0.48				0.88	0.10	
5			0.55	0.49				0.83	0.10	
6			0.55	0.47				0.83	0.10	
7			0.52	0.48				0.79	0.09	
8			0.52	0.47				0.79	0.09	
9			0.49	0.47				0.75	0.09	
10			0.49	0.46				0.75	0.09	
11			0.46	0.46				0.71	0.08	
12			0.46	0.45				0.71	0.08	
Jan-72			0.44	0.45				0.67	0.08	
2			0.44	0.44				0.67	0.08	
3			0.41	0.44				0.63	0.07	
4			0.41	0.43				0.63	0.07	
5			0.39	0.44				0.60	0.07	
6			0.39	0.42				0.60	0.07	
7			0.37	0.43				0.57	0.06	
8			0.37	0.42				0.57	0.06	
9			0.35	0.42				0.54	0.06	
10			0.35	0.41				0.54	0.06	
11			0.33	0.41				0.51	0.06	
12			0.33	0.40				0.51	0.05	

Appendix 2: Classified Data That Could be of Use in Assessing Fallout Impact on U.S. Population

The ability to estimate fallout deposition from NTS shots was made possible by the calculations of Hicks based on cloud measurements of the relative production of the various fission products from each test. The composition of debris is very dependent on the spectrum of neutrons produced in the device and the composition of the fuel. Similar data for test carried out by the U.S. and U.K. in the Pacific as well as for tests carried out in the Soviet Union would be useful for making comparable estimates of fallout deposition for tests carried out outside the U.S. Such data, if available, is classified.

Also classified is the fraction of the total yield of individual shots that resulted from fission versus fusion. Again, this information is needed to make reasonable estimates of deposition and resultant doses from tests held outside the U.S. The atmospheric model developed by Bennett (1980) described in this report requires estimates of the fission yield to estimate the amount of debris injected into various compartments of the atmosphere. This model in turn is useful for estimating nuclide deposition ratios as described in this report.