Appendix F

Internal Dose Estimates from NTS Fallout

Radiation Dose to the Population of the Continental United States from the Ingestion of Food Contaminated with Radionuclides from Nuclear Tests at the Nevada Test Site

Final Report

Lynn R. Anspaugh
Lynn R. Anspaugh, Consulting
Salt Lake City, UT

Report to the National Cancer Institute
Purchase Order No. 263-MQ-912901

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Part I. Estimates of Dose

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ABSTRACT

According to a Congressional request to the Department of Health and Human Services, a feasibility study has been conducted to determine if doses to the American public from radionuclides other than ^{131}I can be calculated for the tests of nuclear weapons and related devices conducted at the Nevada Test Site (NTS). Results of this feasibility study on doses received via the ingestion of contaminated foods indicate that doses from other radionuclides can be calculated, as have the doses from ^{131}I that were reported earlier by the NCI. The methods of calculation are based upon the methods developed and used earlier by the Off-Site Radiation Exposure Review Project; these methods employed seasonally adjusted values of radioecological transfer of radionuclides to humans.

Doses were calculated for 61 of the more significant events that occurred at the NTS during 1951, 1952, 1953, 1955, 1957, and 1962. Detailed results are provided in two CDs that accompany this report. Summary results in the form of coded maps for each of the above years and for the total time period are also provided. The total estimated collective effective committed dose from the ingestion of contaminated foods is 110,000±14,000 Sv; the total estimated per caput effective committed dose is 680±90 μSv. The larger fractions of dose resulted from the tests of Operation Plumbbob conducted in 1957, Operation Tumbler-Snapper in 1952, and Operation Upshot-Knothole in 1953. The largest contribution from any single event is estimated to have been from Project Sedan, a cratering experiment in 1962, although the uncertainty in dose calculated for this event is unusually large due to the absence of information regarding its fission yield and other factors; there is also concern about the validity of the input data for this event. The radionuclide ^{131}I was by far the most important contributor to collective effective dose and accounted for nearly 90% of the total age-corrected collective effective dose. The thyroid is estimated to have received by far the largest collective organ dose of 2,000,000±280,000 person Sv. Most organs received a collective dose of about 15,000 person Sv; other than the thyroid, the organs receiving the higher doses were the colon (56,000±8400 person Sv) and the bone surface (31,000±4000 person Sv).

The per caput dose calculated here is almost the same as the 670 μSv effective dose committed from the consumption of contaminated food over a comparable time period of 50 years from global fallout, as inferred from the work of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). However, the more important contributors to dose from the NTS were short-lived radionuclides (^{131}I, ^{89}Sr, and ^{140}Ba), whereas for global fallout the more important contributors were long-lived radionuclides (^{137}Cs ^{90}Sr, and ^{14}C). While the per caput doses from the two sources are about the same, doses from the NTS vary from county-to-county by a maximum factor of nearly 300; it is expected that the doses from global fallout would have been much more even due to the nature of the processes involved. Doses from the two sources also would have been received at different times—during the 1950s for NTS fallout and during 1963–1965 for global fallout. The dose from inhalation has not been calculated explicitly; rather, the relative contribution of inhalation compared to ingestion has been estimated for the ten more important radionuclides and for $^{239+240}Pu$. For the ten more important radionuclides, the relative contribution varies from about one-third to much less. For $^{239+240}Pu$ the relative contribution via inhalation is calculated to be about 2.6 times that from ingestion; however the total contribution of dose from $^{239+240}Pu$ is small.

INTRODUCTION

Congress has asked the Department of Health and Human Services (HHS) to study the health consequences to the American people of nuclear weapons tests. Within that framework a purchase order has been received to assist in the determination of radiation dose to the American people from the weapons tests conducted in Nevada.

The primary work to be performed is to "prepare crude estimates of the doses of internal radiation received by the American people as a result of the aboveground tests carried out at the Nevada Test Site (NTS)." These estimates are to be:

- Based upon 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;
- Based upon an electronic data base of radionuclide-deposition densities prepared by Beck (1999);
- Averaged over large regions of the continental United States with indications of how the high-risk populations could be identified. However, primary calculations should be carried out on a county-by-county basis and averaged only for presentation purposes;
- Calculated separately for the more important radionuclides produced in nuclear weapons tests of the types carried out at the Nevada Test Site. Radionuclides should include ^{90}Sr, ^{137}Cs, and ^{106}Ru; if sufficient information is available from Beck and other sources doses from additional radionuclides should be calculated.
- Provided in terms of absorbed dose for some of the more radiosensitive organs and tissues (red bone marrow, gastrointestinal tract, etc.);
- Calculated by year of testing (1951, 1952, 1953, 1955, 1957, and 1962) and summed over all tests at the Nevada Test Site (NTS) with a comparison to the published latitudinal average doses (UNSCEAR 1993) for all tests; and
- Provided both in written form and in an electronic version.

Additional work to be performed included the provision of a list of references regarding (1) networks performing measurements of fallout radionuclides in air and foodstuffs and (2) the assessment of doses from internal radiation. The funds made available to accomplish this work consisted of $25,000. Thus, it was necessary to find very efficient means to accomplish this complex task.

The purpose of this report is to describe the results of the study outlined above. Based upon the deposition-density values provided by Beck (1999), dose commitments to internal organs that originated from the ingestion of contaminated food have been estimated for adults in each of approximately 3,100 counties in the continental United States. Estimates are made for 20 parent radionuclides from 61 events that took place at the NTS from 1951 through 1962. For this feasibility study not all organs have been considered; rather, effective doses have been calculated and organ doses have been considered only in those cases where the organ-dose

coefficient for a particular radionuclide is more than twice the dose coefficient for effective dose. According to this criterion, organ doses are estimated for bone surface, colon, kidneys, liver, red marrow, and thyroid. Results of the calculations are summarized for each county by year of test (1951, 1952, 1953, 1955, 1957, and 1962) and for the total series. Collective effective dose commitments are calculated for each year and for the total. These summary results are presented in the main report in the form of maps and tables. The attachments to this report provide results for other tasks.

The detailed results of the calculations by county for each test and with yearly and total summaries by county are attached in the form of spreadsheets on two compact discs (CDs).

METHODS

Nuclear events of interest

There were 100 nuclear events conducted in the atmosphere at the NTS (DOE 1994). These tests ranged in yield from extremely small (<1 t) to a maximum of 74 kt (Shot Hood on 5 July 1957). In addition there were "cratering" events that released significant amounts of debris; the most notable was the 104-kt Project Sedan detonated on 6 July 1962. Not all of these events produced fallout that was measured or measurable beyond the confines of the NTS; thus Beck's and this investigation have focused on those more meaningful events in terms of releases to the offsite environment. Beck (1999) has reported results for a total of 61 events: eight in 1951, eight in 1952, 11 in 1953, 13 in 1955, 19 in 1957, and two in 1962 (including Sedan). Some of these events were detonated so close together in time that it has been impossible to distinguish the debris. Thus, results for Bee and Ess (both fired on 22 March 1955); Apple and Wasp (both fired on 29 March 1955); Kepler (24 July 1957) and Owens (25 July 1957); and Wheeler (6 September 1957), Coulomb (6 September 1957), and Laplace (8 September 1957) were combined in Beck (1999). Results are thus reported here for 56 calculations. A complete list of these events with dates and yields is given in Table 1.

General system of dose calculation

The method of calculation used for this report was derived from that used for the Off-Site Radiation Exposure and Review Project (ORERP), which was performed during the time period of approximately 1979 through 1987 (Church et al. 1990).[*] The ORERP study was designed to calculate external and internal doses from the tests of nuclear weapons at the NTS, but the focus was on populations living in the near downwind regions. Originally, the assessment domain consisted of several counties in Nevada and one county in Utah that were known to have received higher depositions. Eventually, the assessment domain was expanded to include the entire states of Nevada, Utah, Arizona, and New Mexico, and portions of several additional states [western Colorado, southwestern Wyoming, southern Idaho, southeastern Oregon,

[*] The author of the current report was the Scientific Director of the ORERP.

Table 1. A list and some parameters of the nuclear explosions at the Nevada Test Site that are included in this assessment of dose from the ingestion of food contaminated by these events. Some events were so close together in time that they were considered together for the estimates of deposition densities tabulated by Beck (1999).

Calculation number	Operation	Test	Type	Date	Yield, kt
1	Ranger	Baker	Airdrop	28-Jan-51	8
2		Baker-2	Airdrop	2-Feb-51	8
3	Buster	Baker	Airdrop	28-Oct-51	3.5
4		Charlie	Airdrop	30-Oct-51	14
5		Dog	Airdrop	1-Nov-51	21
6		Easy	Airdrop	5-Nov-51	31
7	Jangle	Sugar	Surface	19-Nov-51	1.2
8		Uncle	Crater	29-Nov-51	1.2
9	Tumbler-	Able	Airdrop	1-Apr-52	1
10	Snapper	Baker	Airdrop	15-Apr-52	1
11		Charlie	Airdrop	22-Apr-52	31
12		Dog	Airdrop	1-May-52	19
13		Easy	Tower	7-May-52	12
14		Fox	Tower	25-May-52	11
15		George	Tower	1-Jun-52	15
16		How	Tower	5-Jun-52	14
17	Upshot-	Annie	Tower	17-Mar-53	16
18	Knothole	Nancy	Tower	24-Mar-53	24
19		Ruth	Tower	31-Mar-53	0.2
20		Dixie	Airdrop	6-Apr-53	11
21		Ray	Tower	11-Apr-53	0.2
22		Badger	Tower	18-Apr-53	23
23		Simon	Tower	25-Apr-53	43
24		Encore	Airdrop	8-May-53	27
25		Harry	Tower	19-May-53	32
26		Grable	Airburst	25-May-53	15
27		Climax	Airdrop	4-Jun-53	61
28	Teapot	Wasp	Airdrop	18-Feb-55	1
29		Moth	Tower	22-Feb-55	2
30		Tesla	Tower	1-Mar-55	7
31		Turk	Tower	7-Mar-55	43
32		Hornet	Tower	12-Mar-55	4
33		Bee}Ess			
		Bee	Tower	22-Mar-55	8
		Ess	Crater	23-Mar-55	1

Table 1. (concluded).

Calculation number	Operation	Test	Type	Date	Yield, kt
34		Apple}Wasp’			
		Apple-1	Tower	29-Mar-55	14
		Wasp'	Airdrop	29-Mar-55	3
35		Post	Tower	9-Apr-55	2
36		Met	Tower	15-Apr-55	22
37		Apple-2	Tower	5-May-55	29
38		Zucchini	Tower	15-May-55	28
39	Plumbbob	Boltzmann	Tower	28-May-57	12
40		Wilson	Balloon	18-Jun-57	10
41		Priscilla	Balloon	24-Jun-57	37
42		Hood	Balloon	5-Jul-57	74
43		Diablo	Tower	15-Jul-57	17
44		Kepler}Owens			
		Kepler	Tower	24-Jul-57	10
		Owens	Balloon	25-Jul-57	9.7
45		Shasta	Tower	18-Aug-57	17
46		Doppler	Balloon	23-Aug-57	11
47		Smoky	Tower	31-Aug-57	44
48		Galileo	Tower	2-Sep-57	11
49		WCL			
		Wheeler	Balloon	6-Sep-57	0.197
		Coulomb-B	Surface	6-Sep-57	0.3
		Laplace	Balloon	8-Sep-57	1
50		Fizeau	Tower	14-Sep-57	11
51		Newton	Balloon	16-Sep-57	12
52		Whitney	Tower	23-Sep-57	19
53		Charleston	Balloon	28-Sep-57	12
54		Morgan	Balloon	7-Oct-57	8
55	Storax	Sedan	Crater	6-Jul-62	104
56		Small Boy	Tower	14-Jul-62	Low

and nearby areas of California (including Los Angeles)]. Given that appropriate input data are available, it is a logical extension to apply the ORERP methodology to a broader assessment domain.

The general ORERP methodology for calculating internal dose from the consumption of contaminated foods has been described by Whicker and Kirchner (1987), Breshears et al. (1989), Whicker et al. (1990, 1996), Ng et al. (1990), and Kirchner et al. (1996). A modular system[†] was developed that depended upon three things:

[†] The modular system was necessitated by the fact that many different organizations at several locations had responsibilities for the conduct of the project.

- Estimating the deposition per unit area of individual radionuclides on the ground. This was done either through evaluation of exposure-rate measurements with conversion to radionuclide deposition (Beck 1980; Hicks 1982, 1990), or through inference of the deposition of one or more of the important radionuclides (Beck and Anspaugh 1991).
- Estimating the total amount of an individual radionuclide that might be ingested by humans of differing ages. This simple statement covers a very complex undertaking of estimating the dynamics of radionuclide contamination of foods and age-dependent human-consumption rates of food (Whicker and Kirchner 1987).
- Estimating the amount of age-dependent dose that would be received by a member of the public from the ingestion of a unit activity of a particular radionuclide. When the ORERP work was started, the International Commission on Radiological Protection (ICRP) had not yet published their work on this subject, and such calculations were performed within the project (Ng et al. 1990; Kirchner et al. 1996).

Thus, the modular system used can be written as a simple equation:

$$D = P \times I \times F_g \,, \tag{1}$$

where D = Absorbed dose, Gy, or equivalent/effective dose, Sv;
P = Deposition density of the radionuclide of interest at time of fallout arrival, Bq m^{-2};
I = Integrated intake by ingestion of the radionuclide per unit deposition, Bq per Bq m^{-2}; and
F_g = Ingestion-dose coefficient for the radionuclide, Gy Bq^{-1} or Sv Bq^{-1}.

Equivalent and effective doses were not calculated for the ORERP, but such calculations are performed and reported here for this task. This requires additional specification of the values and units for F_g and subsequently for D.

Radionuclides of interest

A great many fission-product radionuclides are created by a nuclear explosion. Due to the extremely short reaction time, long-lived radionuclides do not accumulate as they do during the operation of a nuclear reactor. Thus, much of the dose from small nuclear weapons tests (<100 kt) in the atmosphere arises from fairly short-lived radionuclides. The situation is rather different for the large U.S. tests that were conducted in the Pacific or for the large Russian tests conducted near the Arctic Circle. Those tests were powerful enough to inject most of their debris into the stratosphere from which it devolved with a half time of at least one year. Thus, most of the short-lived radionuclides had already decayed by the time this global fallout was deposited. In addition, the large nuclear explosions were mainly of fusion devices with a rather small fission trigger (and with perhaps a tertiary fission stage); these kinds of devices produced and/or spilled large amounts of ^{3}H. The intense flux of neutrons from these devices also produced large amounts of ^{14}C through the reaction $^{14}N(n,p)^{14}C$. The amount of ^{14}C produced by the fusion explosions is so large that this radionuclide produces the largest portion of dose commitment from the ingestion of foods contaminated by global[‡] fallout (UNSCEAR 1993).

[‡] Debris injected into the high troposphere or the stratosphere circulates in a latitudinal band around the entire globe and eventually deposits on the earth. Hence, the term “global” fallout.

At the NTS the atmospheric tests were small in comparison; the debris from the tests was not injected into the stratosphere to a significant extent; and the amounts of ^{3}H and ^{14}C released were sufficiently small that the resulting doses from these two radionuclides were trivial in comparison to doses from other radionuclides.

For the ORERP, screening calculations (Ng et al. 1990) were performed for more than 100 radionuclides in order to focus on the more important. Beck (1999) has generally followed the results of this procedure and has provided estimates of the deposition per unit area for this same group of radionuclides. The radionuclides for which it is possible to estimate internal doses without undertaking significant new work are ^{89}Sr, ^{90}Sr, ^{91}Sr, ^{97}Zr, ^{99}Mo, ^{103}Ru, ^{105}Rh, ^{106}Ru, ^{131}I, ^{132}Te, ^{133}I, ^{135}I, ^{136}Cs, ^{137}Cs, ^{140}Ba, ^{143}Ce, ^{144}Ce, ^{147}Nd, ^{239}Np, $^{239+240}Pu$, and ^{241}Pu.[§] Based upon the screening calculations performed for ORERP for its assessment domain, this group of radionuclides accounts for at least 95% of the dose to each organ through ingestion of contaminated foods. Due to the fact that the current assessment domain is much larger and the average travel time of the debris is longer, the importance of some of the shorter lived radionuclides (e.g., ^{91}Sr, ^{97}Zr, ^{133}I, ^{135}I, and ^{143}Ce) is less than it was for the ORERP assessment domain. For this work dose calculations were performed for 19 of the 21 radionuclides listed above; ^{135}I and ^{239}Np were not included, as deposition densities were not reported in Beck (1999).

In addition to the parent radionuclides listed in the above paragraph, doses from decay products were also included in the calculation to the extent that the product arises from the decay of the parent radionuclide after it has entered the body. For example, the decay product of ^{132}Te is ^{132}I, which has a half life of 2.30 h (ICRP 1983). Any ^{132}I that originates in the body from the decay of ^{132}Te is included in the dose calculation; but any ^{132}I on food at the time of consumption is not included. Additional parent-progeny pairs are $^{90}Sr(^{90}Y)$, $^{97}Zr(^{97}Nb)$, $^{103}Ru(^{103m}Rh)$, $^{106}Ru(^{106}Rh)$, $^{137}Cs(^{137m}Ba)$, $^{140}Ba(^{140}La)$, and $^{144}Ce(^{144}Pr)$.

Estimates of deposition per unit area (deposition density)

The first parameter in eqn (1) is *P*, the deposition per unit area. For the radionuclides indicated above as being included in this assessment, Beck (1999) has provided estimates of the deposition densities of each radionuclide in each of the approximately 3,100 counties in the contiguous United States. Nearby the NTS where some of the larger counties experienced considerable gradations in deposition, counties have been broken into subparts. In all, estimates are provided for 3,094 geographic units (counties or subparts of counties). These estimates of deposition are based primarily on measurements made at the time and reported by the "gummed-film" network operated by the Department of Energy's (DOE's) Environmental Measurements Laboratory (EML), which was then known as the Atomic Energy Commission's (AEC's) Health and Safety Laboratory (HASL). As the measurements occurred at a finite number (which varied from year to year) of locations and the amount of fallout within a small geographic area could be influenced significantly by rainfall, the measured data were analyzed through a complex process known as "kriging." This process is an unbiased interpolator that is capable of correlating with other data such as rainfall rate; the latter data were available on essentially a county-by-county basis. This complex process has been described in general by Beck et al. (1990) and Beck

[§] Plutonium-241 was not included in the ORERP calculations, but deposition densities were provided in Beck (1999); ^{241}Pu was assumed to have the same value of *I* as does $^{239+240}Pu$.

(1999), and for the important radionuclide, ^{131}I, by the NCI (1997). In some cases additional data, such as the experimentally measured residual levels of ^{137}Cs in the soil column, have been used to validate results or to provide additional information (Beck et al. 1990; Beck and Anspaugh 1991). Estimates of radionuclide-deposition density are provided in Beck (1999) as geometric mean estimates along with the estimated geometric standard deviations.

Age groups to be considered

The detailed calculations of dose were performed for adults only. This choice was necessitated by the limited resources available for this study and because adults constitute by far the largest segment of the population. Suggestions are provided below for how an interested reader might convert the doses reported here for adults to doses for other age groups. The specific situation of age differences in doses to the thyroid from ^{131}I has been treated extensively by the NCI (1997). In addition, some calculations presented below of per caput and collective dose commitment have been adjusted for the effect of age.

Estimates of integrated intake

For the radionuclides listed above, seasonally-dependent values of *I*, the integrated intake per unit deposition, have been published by Whicker and Kirchner (1987) based on their development of the PATHWAY model for the ORERP. "Integrated intake" is an estimate of the normalized (to deposition density) total amount of a radionuclide that will enter a person's mouth over time subsequent to the initial deposition of the radionuclide. Thus, the units of *I* are Bq per Bq m^{-2}. This is a very complex function that includes the two major components of 1) seasonally dependent rate of radioecological transfer of radionuclides through food chains and 2) the age-dependent rates of consumption of differing types of food. These estimates are also equivalent to geometric means (Breshears et al. 1989), and estimates of geometric standard deviations have been published by Breshears et al. (1989). Values of both geometric means and geometric standard deviations vary according to a radionuclide's chemical characteristics, including half life, and the season. As milk is generally a critical pathway, a key factor that varies with season is whether cows are grazing on fresh pasture (or being fed green chop) or are being fed stored feed.

For this assessment, the values published in Whicker and Kirchner (1987) were used. In their Table 9, values of integrated intakes by adults for 20 radionuclides are given for eight nuclear shots that occurred over a range of seasonal times. Based upon these published values for the eight times, values for other times were interpolated or extrapolated. Examples of input data for four of the more significant radionuclides are shown in Fig. 1.

Plots of the actual data used in this assessment for 19 radionuclides are shown in Figs. 2 through 19. Each point in the plots of Figs. 2 through 19 represents one of the "calculation numbers" indicated in Table 1. Estimates of the geometric standard deviations that accompany these values were taken from Table 5 of Breshears et al. (1989); these values are reproduced here as Table 2.

The radioecological component of PATHWAY is complex and includes many factors:

- Initial retention of radionuclides by vegetation;

- Loss of radionuclides from vegetation;
- Dilution of radionuclide concentration in fresh vegetation by plant growth;
- Movement through several soil compartments;
- Uptake of a radionuclide through the soil-root system; and
- Recontamination of plant surfaces by resuspension and redeposition and by rain splash.

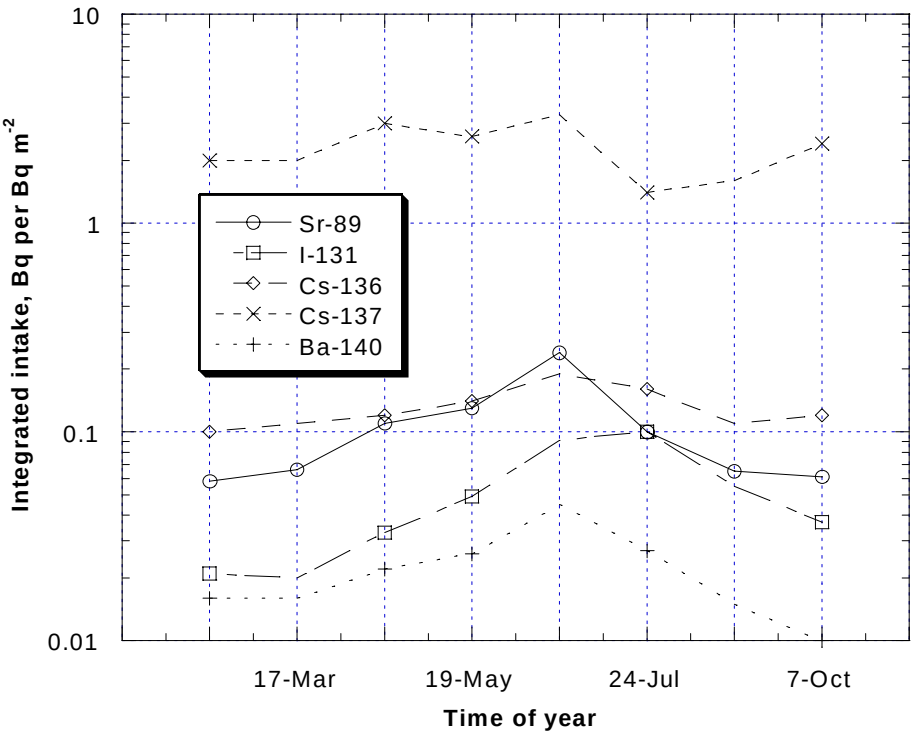

Fig. 1. Examples of the seasonally dependent values of integrated intake reported by Whicker and Kirchner (1987) for four of the more important radionuclides.

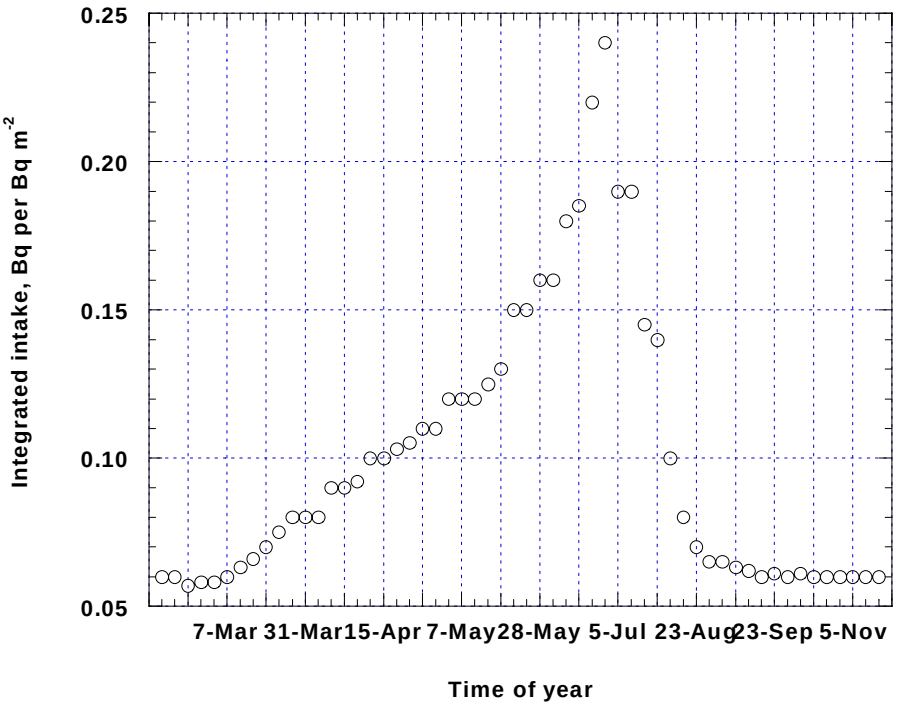

Fig. 2. Values for integrated intake used for ^{89}Sr.

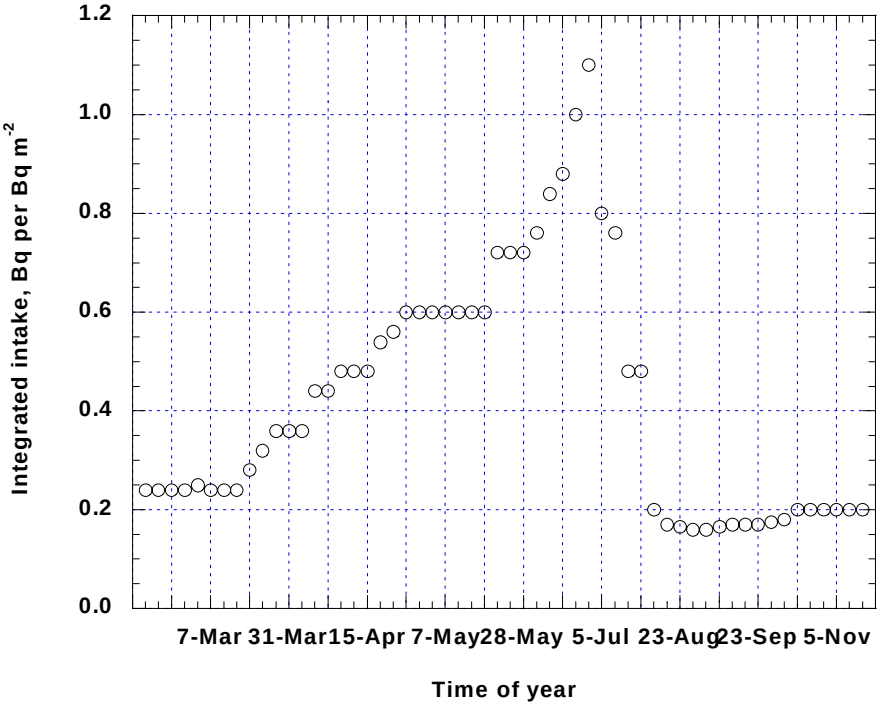

Fig. 3. Values for integrated intake used for ^{90}Sr.

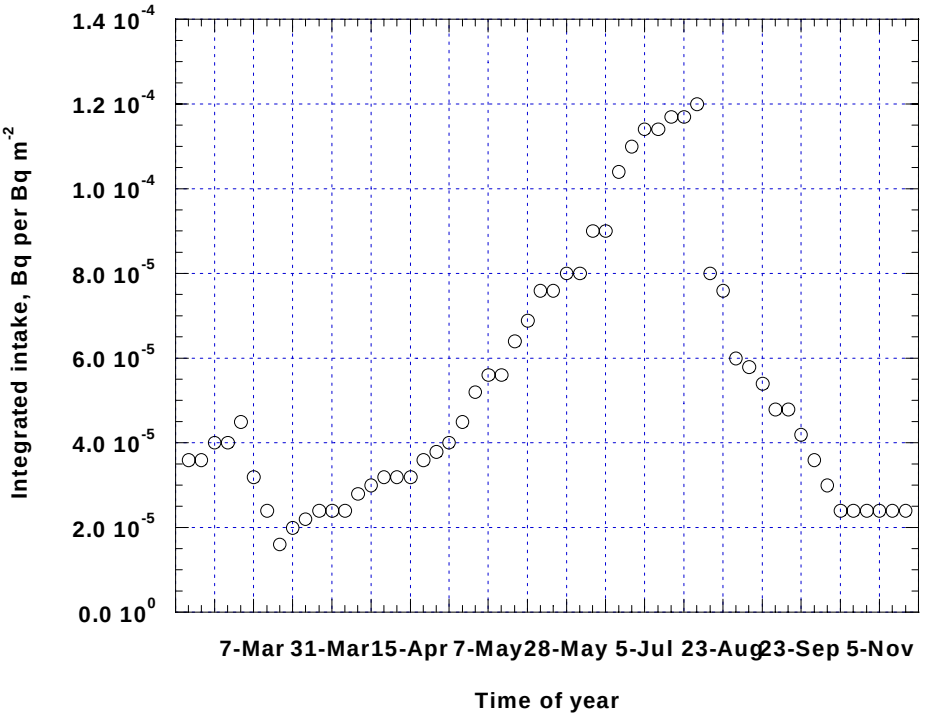

Fig. 4. Values for integrated intake used for ^{91}Sr.

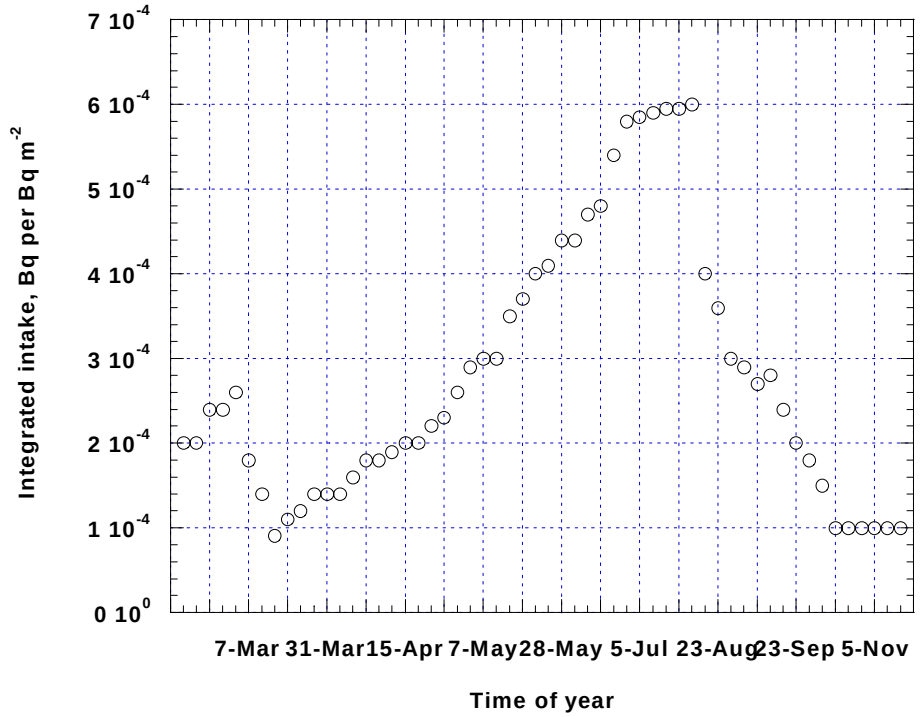

Fig. 5. Values for integrated intake used for ^{97}Zr.

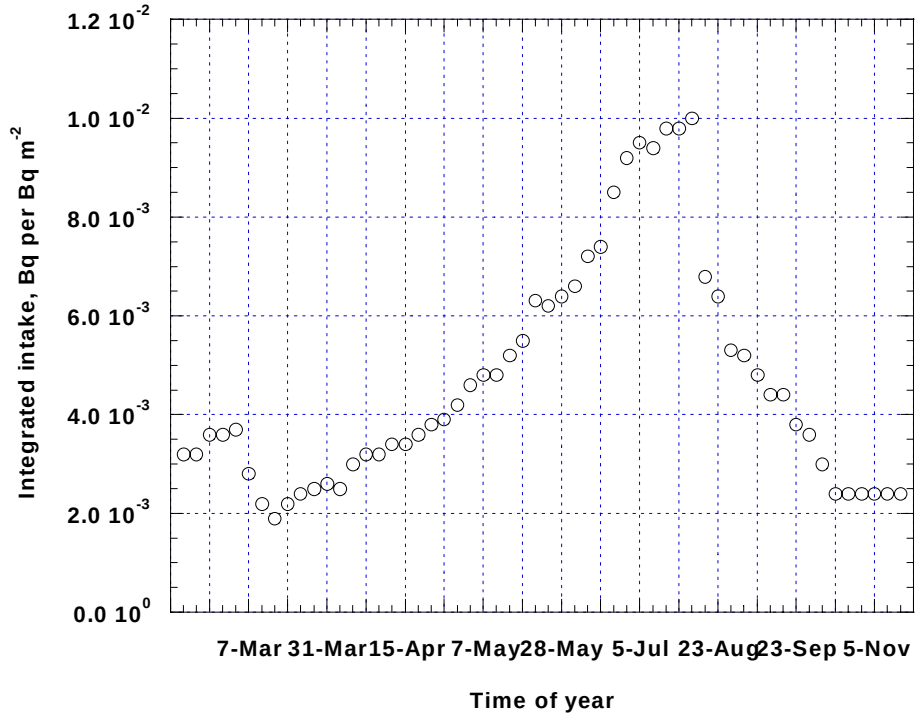

Fig. 6. Values for integrated intake used for ^{99}Mo.

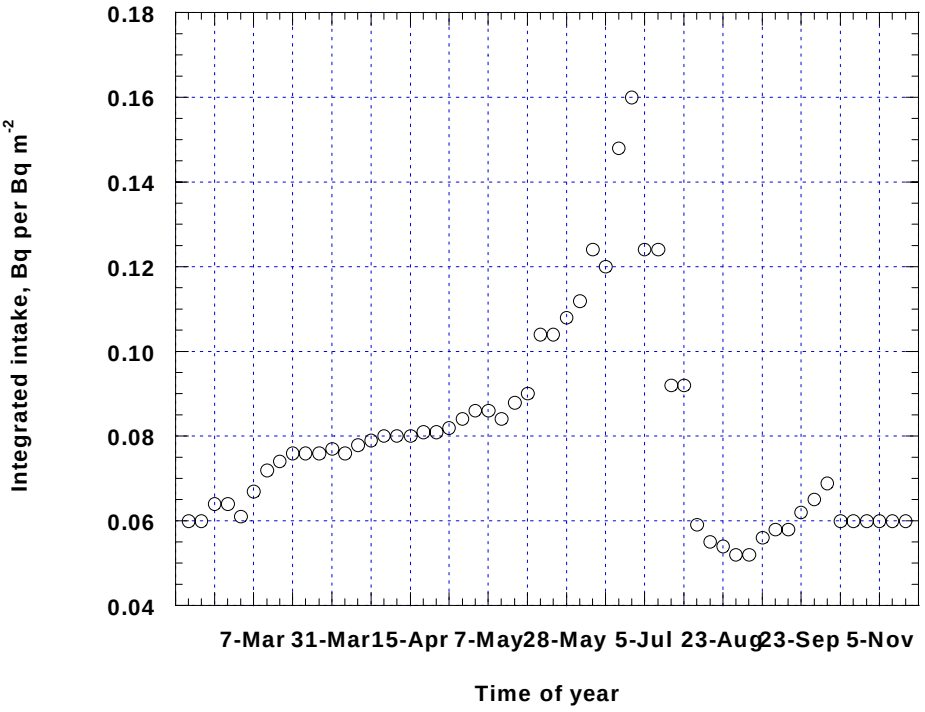

Fig. 7. Values for integrated intake used for ^{103}Ru.

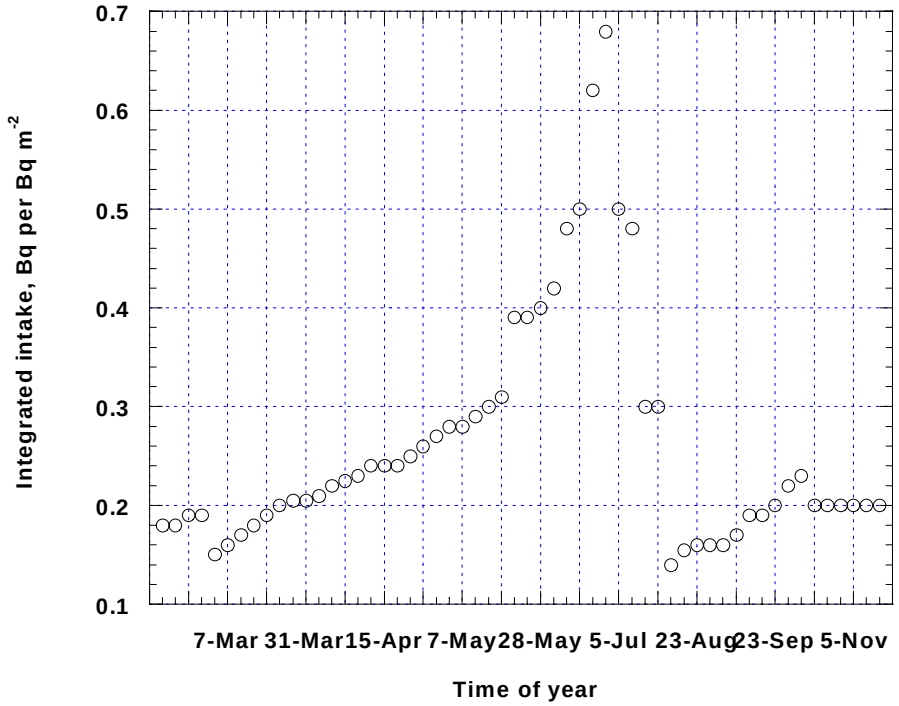

Fig. 8. Values for integrated intake used for ^{106}Ru.

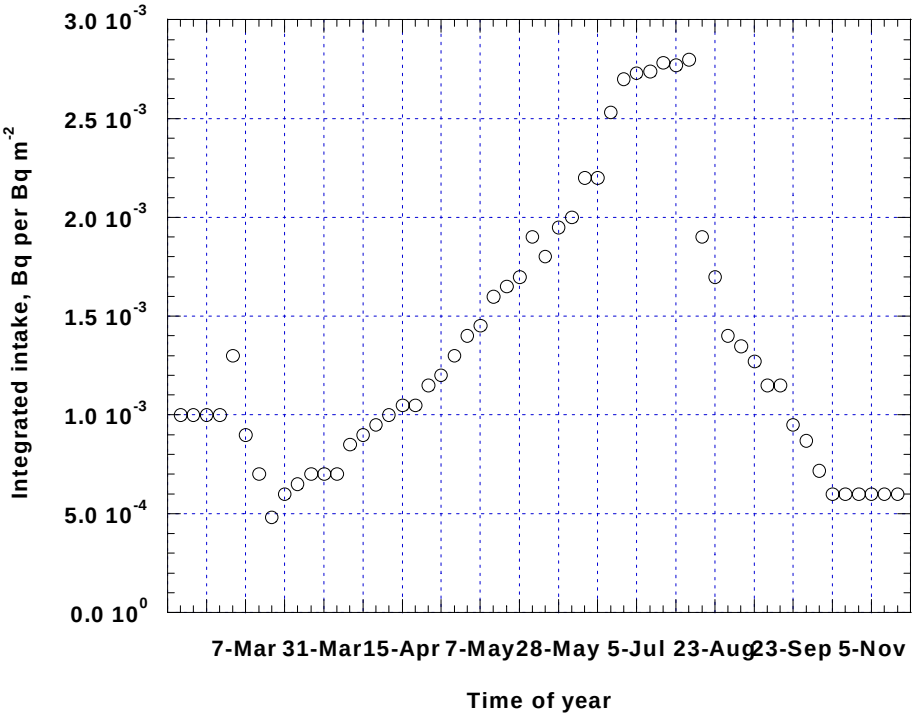

Fig. 9. Values for integrated intake used for ^{105}Rh.

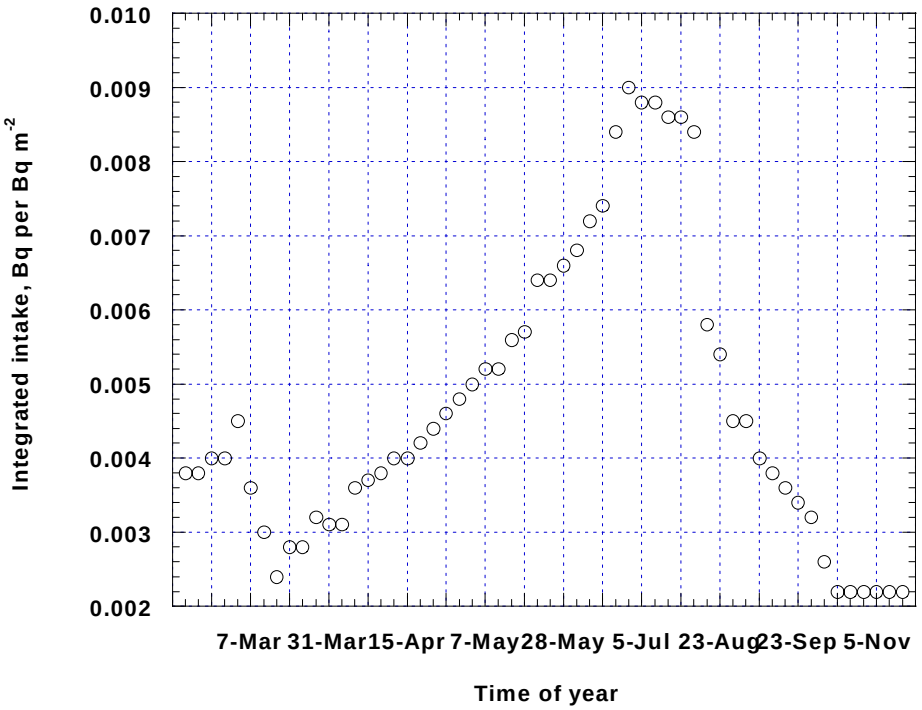

Fig. 10. Values for integrated intake used for ^{132}Te.

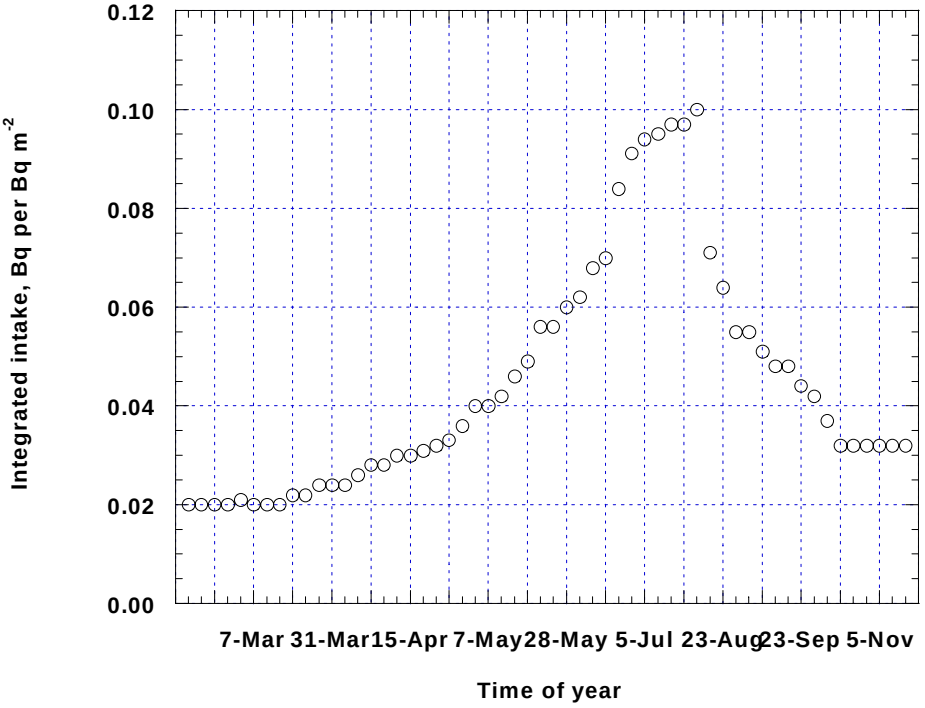

Fig. 11. Values for integrated intake used for ^{131}I.

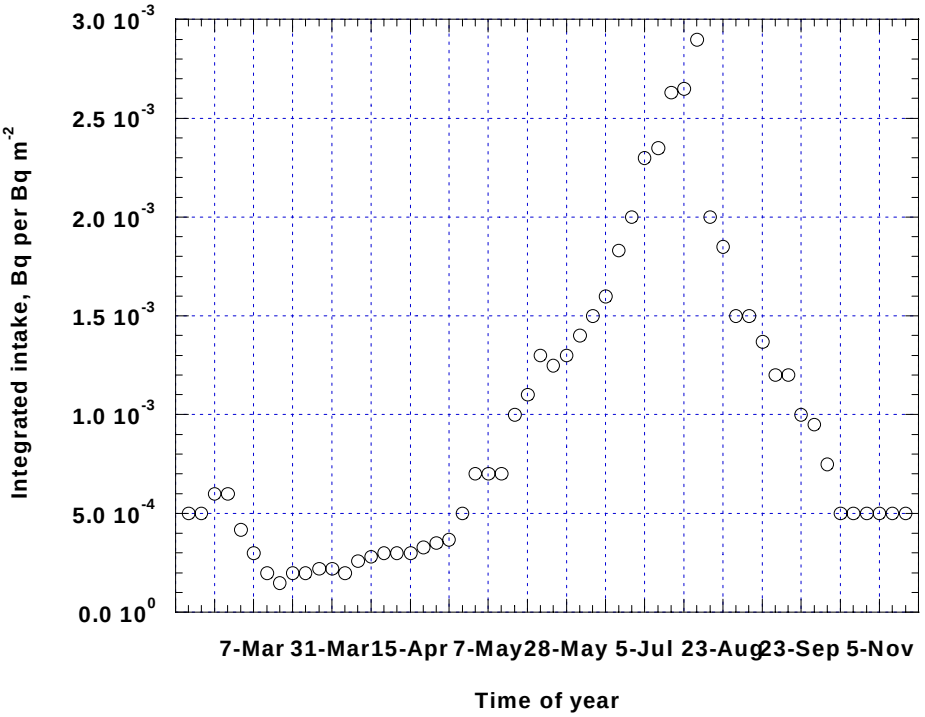

Fig. 12. Values for integrated intake used for ^{133}I.

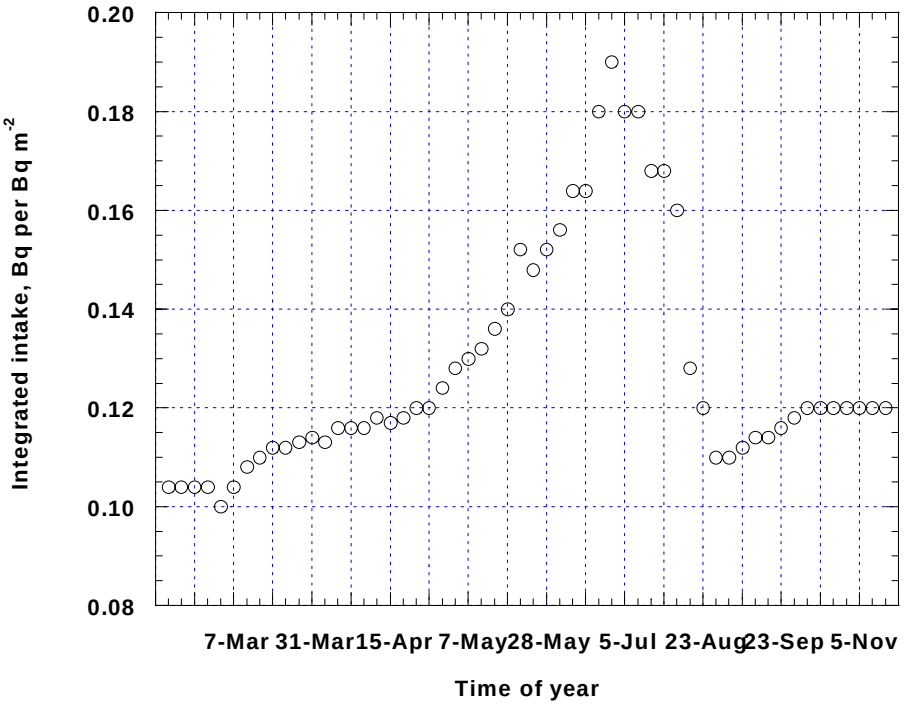

Fig. 13. Values for integrated intake used for ^{136}Cs.

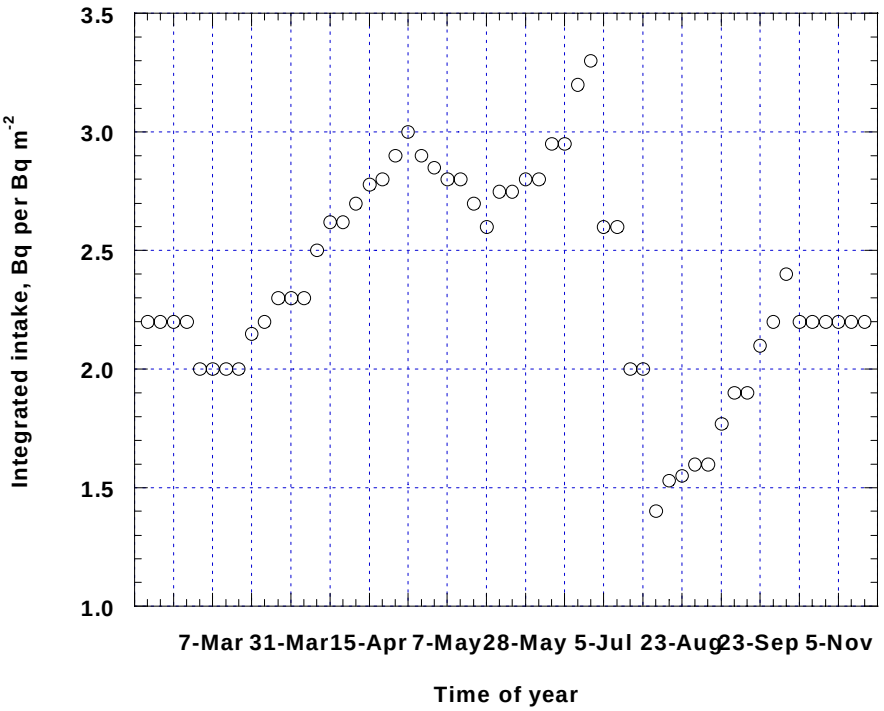

Fig. 14. Values for integrated intake used for ^{137}Cs.

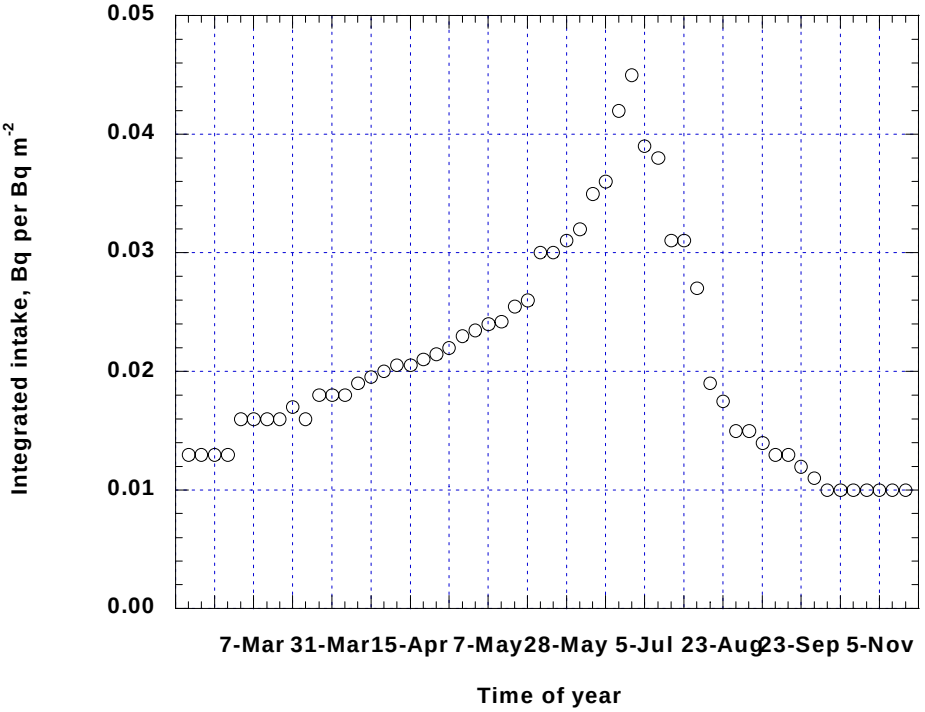

Fig. 15. Values for integrated intake used for ^{140}Ba.

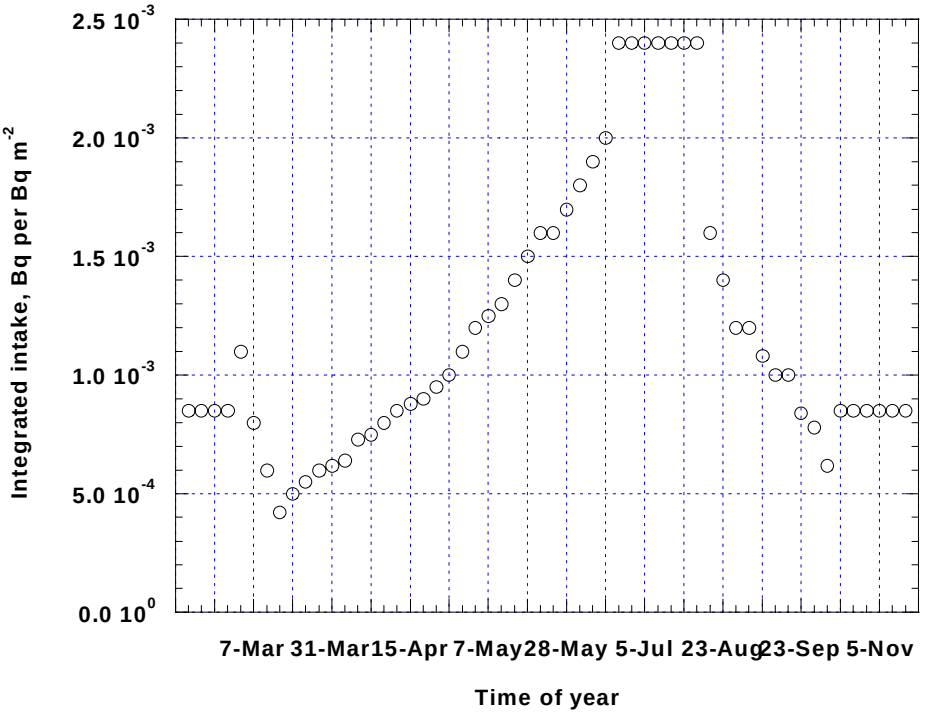

Fig. 16. Values for integrated intake used for ^{143}Ce.

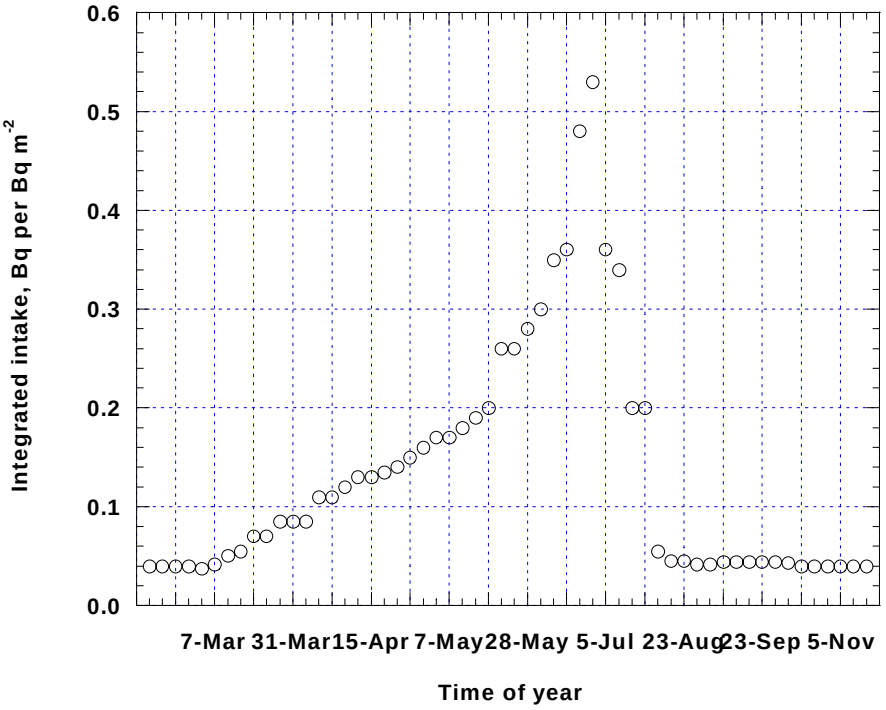

Fig. 17. Values for integrated intake used for ^{144}Ce.

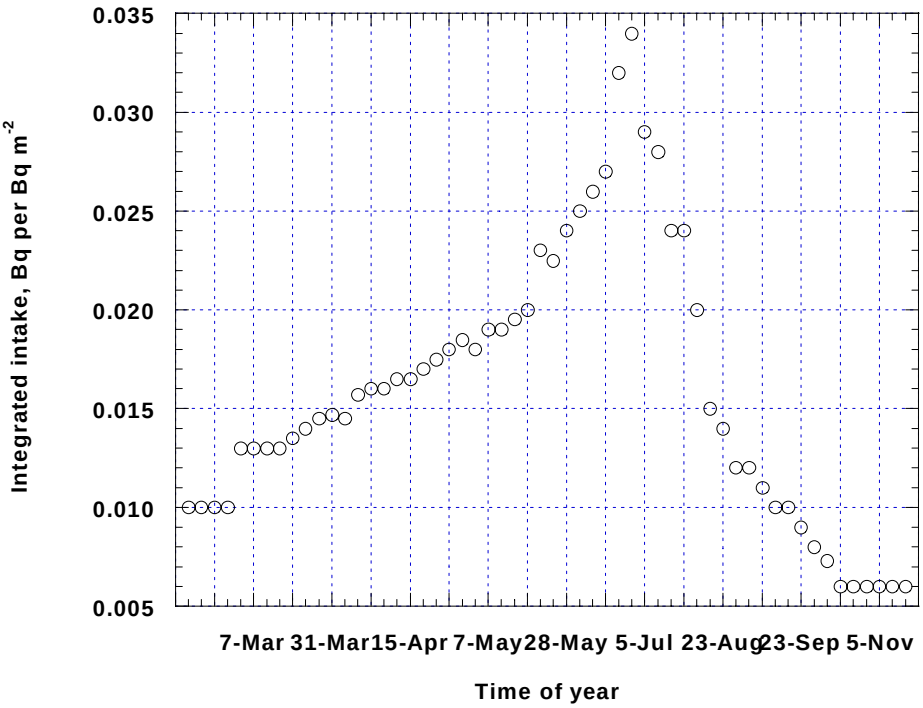

Fig. 18. Values for integrated intake used for ^{147}Nd.

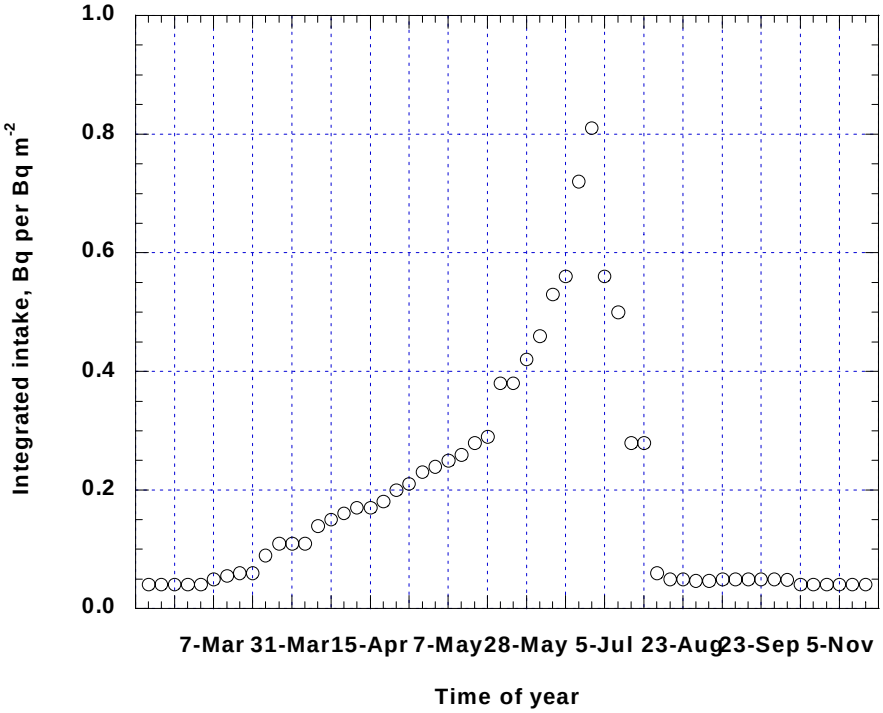

Fig. 19. Values for integrated intake used for $^{239+240}$Pu and ^{241}Pu.

Table 2. Values of geometric standard deviation associated with the values of the geometric means of integrated deposition shown in Figs. 2–19. Values are from table 5 of Breshears et al. (1989).

Month of fallout deposition	Physical half life		
	<30 d	30–500 d	>500 d
January	1.7	1.9	2.1
February	1.7	1.9	2.1
March	1.7	1.9	2.1
April	1.9	2.0	2.1
May	2.3	2.2	2.1
June	2.1	2.1	2.1
July	2.1	2.1	2.1
August	2.1	2.1	2.0
September	2.7	2.3	2.0
October	1.7	1.8	1.9
November	1.7	1.8	1.9
December	1.7	1.8	1.9

One of the critical factors that is known to vary substantially is the initial retention of fallout by fresh vegetation, particularly when deposition occurs with precipitation (Anspaugh 1987; NCI 1997). The value used for this parameter in PATHWAY is 0.39 m^2 kg^{-1}. The value of this parameter is known to vary with particle size (and distance from the site of detonation) for dry deposition and with rainfall rate for wet deposition. In addition, values vary substantially for reasons that are not yet explicable. Thus, uncertainty in this parameter contributes substantially to the uncertainty in the estimates of internal dose. Some reduction in uncertainty might be achieved, if the county-by-county estimates of rainfall for each day following each shot were retrieved and used to adjust this value, as was done in NCI (1997) for dose from ^{131}I. This effort was beyond the scope of the present study, and it is not clear from the data in NCI (1997) that this laborious process resulted in a substantial reduction in uncertainty.

Thus, while the discussed values of integrated intake were originally derived for dry deposition in the semi-arid western areas of the U.S. nearby the NTS, this same value has been used for the entire study performed here. Based upon the experimental data reported by Hoffman et al. (1989), the value of 0.39 m^2 kg^{-1} is actually a reasonable value for retention during rainfall, except during conditions of very light rainfall when higher values have been observed.

Dose coefficients

The ICRP (1989, 1993, 1995, 1996) has provided compilations of dose coefficients, F_g, for ingestion of radionuclides by members of the general public. These published values, however, are incomplete in the sense that dose coefficients are not listed for all organs for all age

groups. Recently, the ICRP (1998) has made available a CD-ROM system that allows the calculation of equivalent and effective doses for all organs for the six age groups** considered by the ICRP. The dose values provided by the ICRP represent the dose from a given intake that will occur over the next 50 years for adults or until age 70 y for the younger age groups.

The ICRP-tabulated values are the basic source of dose coefficients used for this dose assessment. As for previously performed assessments (Ng et al. 1990), the ICRP dose coefficients have been considered to be average values (or arithmetic means). Thus, in order to be consistent and to allow for the analytical propagation of error, the ICRP values have been converted to geometric means, $\bar{x}_g$, by the use of eqn (2):

$$\bar{x}_g = \exp[(\ln(\bar{x}) - \ln^2(\sigma_g)], \tag{2}$$

where $\bar{x}$ is the arithmetic mean (from the ICRP tabulation) and σ_g is the estimated geometric standard deviation. The latter values have been taken from Kirchner et al. (1996). The estimated values of σ_g for adults are 1.6 for ^{89}Sr and ^{91}Sr, 1.4 for ^{90}Sr, 1.5 for ^{136}Cs, 1.3 for ^{137}Cs, and 1.8 for all other radionuclides. These values were used for all target organs and for effective dose.

The dose coefficients actually used for this study are shown in Table 3 along with the original values taken from ICRP (1998).

Organs of interest

In principle, doses can be calculated for the 22 organs considered by the ICRP and dose coefficients are available (ICRP 1998). However, experience from ORERP (Ng et al. 1990) is that only the thyroid would be expected to receive a higher dose from the ingestion of fallout compared to the dose received from external exposure to the same fallout. For this and reasons of efficiency, calculations are provided here in terms of effective dose. In addition, if the dose to any organ for any radionuclide is more than twice that of the effective dose, calculations for those organs are also provided. For example, for ^{137}Cs, which is distributed throughout the body, calculations are provided only for effective dose. On the other hand, for plutonium radionuclides doses are also provided for the bone surface and the liver, which are organs where plutonium concentrates. An approximation of the dose to any organ from all of the radionuclides considered would be to sum doses for all radionuclides for which that organ is specifically listed and to add the effective dose for any radionuclide for which calculations for a specific organ have not been provided. Alternatively, a more accurate calculation for a specific situation could be done by using a ratio of the dose coefficients found in ICRP (1998).

As the effective dose is a weighted sum of the dose to all organs, where the weights represent the estimated probability of the occurrence of a "stochastic" effect in that organ, the effective dose is the most efficient choice of an input parameter for the estimation of health

** The six age groups considered by the ICRP are 1) three months [0 to 12 months], 2) one y [from 1 y to 2 y], 3) five y [>2 y to 7 y], 4) 10 y [>7 y to 12 y], 5) 15 y [>12 y to 17 y], and 6) adult [>17 y].

Table 3. Dose coefficients used in this study. The arithmetic mean values ($\bar{x}$) are taken from ICRP (1998), the geometric standard deviations (σ_g) are from Kirchner et al. (1996), and the geometric means ($\bar{x}_g$) are calculated according to eqn (2).

Radionuclide	Organ	Dose coefficient		
		$\bar{x}$, Sv Bq^{-1}	σ_g	$\bar{x}_g$, Sv Bq^{-1}
^{89}Sr	Effective	2.6×10^{-9}	1.4	2.5×10^{-9}
	Bone surface	5.9×10^{-9}	1.4	5.6×10^{-9}
	Colon	1.4×10^{-8}	1.4	1.3×10^{-8}
^{90}Sr	Effective	2.8×10^{-8}	1.3	2.7×10^{-8}
	Bone surface	4.1×10^{-7}	1.3	4.0×10^{-7}
	Red marrow	1.8×10^{-7}	1.3	1.7×10^{-7}
^{91}Sr	Effective	6.5×10^{-10}	1.8	5.5×10^{-10}
	Colon	3.8×10^{-9}	1.8	3.2×10^{-9}
^{97}Zr	Effective	2.1×10^{-9}	1.8	1.8×10^{-9}
	Colon	1.5×10^{-8}	1.8	1.3×10^{-8}
^{99}Mo	Effective	6.0×10^{-10}	1.8	5.0×10^{-10}
	Kidneys	3.1×10^{-9}	1.8	2.6×10^{-9}
	Liver	2.8×10^{-9}	1.8	2.4×10^{-9}
^{103}Ru	Effective	7.3×10^{-10}	1.8	6.1×10^{-10}
	Colon	4.3×10^{-9}	1.8	3.6×10^{-9}
^{106}Ru	Effective	7.0×10^{-9}	1.8	5.9×10^{-9}
	Colon	4.5×10^{-8}	1.8	3.8×10^{-8}
^{105}Rh	Effective	3.7×10^{-10}	1.8	3.1×10^{-10}
	Colon	2.7×10^{-9}	1.8	2.3×10^{-9}
^{132}Te	Effective	3.8×10^{-9}	1.8	3.2×10^{-9}
	Colon	1.3×10^{-8}	1.8	1.1×10^{-8}
	Thyroid	3.1×10^{-8}	1.8	2.6×10^{-8}
^{131}I	Effective	2.2×10^{-8}	1.8	1.9×10^{-8}
	Thyroid	4.3×10^{-7}	1.8	3.6×10^{-7}
^{133}I	Effective	4.3×10^{-9}	1.8	3.6×10^{-9}
	Thyroid	8.2×10^{-8}	1.8	6.9×10^{-8}
^{136} Cs	Effective	3.0×10^{-9}	1.4	2.8×10^{-9}
^{137}Cs	Effective	1.3×10^{-8}	1.3	1.3×10^{-8}
^{140}Ba	Effective	2.6×10^{-9}	1.8	2.2×10^{-9}
	Colon	1.7×10^{-8}	1.8	1.4×10^{-8}
^{143}Ce	Effective	1.1×10^{-9}	1.8	9.3×10^{-10}
	Colon	8.3×10^{-9}	1.8	7.0×10^{-9}
^{144}Ce	Effective	5.2×10^{-9}	1.8	4.4×10^{-9}
	Colon	4.2×10^{-8}	1.8	3.5×10^{-8}
^{147}Nd	Effective	1.1×10^{-9}	1.8	9.3×10^{-10}
	Colon	8.2×10^{-9}	1.8	6.9×10^{-9}

Table 3. (concluded).

Radionuclide	Organ	Dose coefficient		
		$\bar{x}$, Sv Bq^{-1}	σ_g	$\bar{x}_g$, Sv Bq^{-1}
$^{239+240}$Pu	Effective	2.5×10^{-7}	1.8	2.1×10^{-7}
	Bone surface	8.2×10^{-6}	1.8	6.9×10^{-6}
	Liver	1.7×10^{-6}	1.8	1.4×10^{-6}
^{241}Pu	Effective	4.8×10^{-9}	1.8	4.0×10^{-9}
	Bone surface	1.6×10^{-7}	1.8	1.3×10^{-7}
	Liver	3.4×10^{-8}	1.8	2.9×10^{-8}

effects to the U.S. population from the radionuclides released by the Nevada tests. As noted in the paragraph above, past experience has shown the thyroid is the only organ anticipated to receive a dose from the ingestion of contaminated foods that would exceed the dose from external exposure.

In Table 3, dose coefficients are given for the colon, and this corresponds to the values given in ICRP (1998). This represents a change in the usual practice of the ICRP, which was not to give dose coefficients for the colon but for the Upper Large Intestine (ULI) and the Lower Large Intestine (LLI) separately. This new procedure is more consistent with the practice of the ICRP in assigning a weighting factor (for the purpose of calculating effective dose) to the colon. In practice the LLI had been used for this, and the ULI had been considered a "remainder" organ. Now the colon dose is considered as the mass average of the equivalent dose in the walls of the upper and lower large intestine (ICRP 1995). Thus, with H representing equivalent dose, the dose coefficient for the colon is defined in terms of the dose coefficients for the ULI and LLI as

$$H_{\text{colon}} \equiv 0.57 H_{\text{ULI}} + 0.43 H_{\text{LLI}} \ . \tag{3}$$

Periods of summation

For each county (or part of a county) the dose commitments for a given radionuclide received within the years of major testing have been summed for those tests that took place in the years of 1951, 1952, 1953, 1955, 1957, or 1962. In order to achieve this summation, the individual estimates of geometric mean dose and geometric standard deviation for each test during the year have been converted to arithmetic means and variances, summed, and then reconverted to estimates of geometric mean and geometric standard deviation. The equations used for this purpose are as given in Ng et al. (1990).

The sum of effective doses from all radionuclides for each geographical unit has also been calculated for each test, for each year, and for the total time period by use of the same methodology as indicated in the paragraph above.

Collective dose

Estimates of collective dose to the entire contiguous U.S. were calculated by multiplying the arithmetic mean dose for each county by its estimated 1954 population and summing over all counties. The sums of collective effective doses for all radionuclides have been calculated for each test and summed for each year of testing. For the total summary over all years, additional

tabulations of collective dose were calculated by summing collective effective dose and the collective dose to each organ indicated in Table 3. If the organ dose had not been calculated for a particular radionuclide, the effective dose for that radionuclide was included instead. This procedure overestimates the actual collective organ dose, and some corrections to this overestimation are considered and presented in the results discussed below. This correction is useful, as the great majority of effective dose is contributed by the dose from ^{131}I to the thyroid. Even though the tissue-weighting factor for the thyroid is only 0.05, the dose to many organs is less than 0.001 of that of the thyroid.

RESULTS AND DISCUSSION

The results of the basic calculations made for this project are provided on two CDs that accompany this report. Information on the CDs is organized with a folder containing all data for each year of significant tests at the NTS: 1951, 1952, 1953, and 1955 on the first CD; and 1957 and 1962 on the second CD. Within the folder for each year is a workbook for each event shown in Table 1. Each workbook contains two spreadsheets: "S1" contains data on geometric means and geometric standard deviations, and "S2" contains data on arithmetic means and arithmetic variances and collective effective dose. The data available for each event are indicated in Table 4. In addition, there is a summary workbook for each year that includes three spreadsheets. Spreadsheet "AM" contains the sum of doses for each geographic unit by arithmetic means and arithmetic standard deviations, whereas spreadsheet "GM" contains similar data according to geometric means and geometric standard deviations. These values of dose and effective dose are in units of mSv. The third spreadsheet, "Coll," contains information on the collective dose for each geographic unit summed over all events that took place during that year. Units for the third spreadsheet are person Sv. At the bottom of the latter spreadsheet is the sum of collective effective dose over all geographic units.

Information on these spreadsheets is coded according to the geographic location. An explanation of these codes is provided in the "FIPS" spreadsheet found on the first CD. In addition to providing the name of the county, the area of the county in km^2 and the estimated population in 1954 are given. The FIPS spreadsheet was provided by Beck (1999) and is reproduced from that report.

A final workbook is provided on the second CD that is labeled "TotalSummary." This contains three spreadsheets as for the yearly summaries. In addition, the total collective dose for effective dose and for each organ for all tests is summarized at the bottom of the "Coll" spreadsheet.

Table 4. Dose calculations provided for every significant nuclear test at the NTS. For each indicated calculation, data are provided on the geometric mean estimate, the geometric standard deviation, the arithmetic mean, and the arithmetic standard deviation. Effective doses are calculated for all radionuclides. In cases where the dose coefficient for an organ was more than twice that for effective dose, an additional calculation was made for that organ.

Radionuclide	Doses calculated
^{89}Sr	Effective, bone surface, colon
^{90}Sr	Effective, bone surface, red marrow
^{91}Sr	Effective, colon
^{97}Zr	Effective, colon
^{99}Mo	Effective, kidneys, liver
^{103}Ru	Effective, colon
^{106}Ru	Effective, colon
^{105}Rh	Effective, colon
^{132}Te	Effective, colon, thyroid
^{131}I	Effective, thyroid
^{133}I	Effective, thyroid
^{136}Cs	Effective
^{137}Cs	Effective
^{140}Ba	Effective, colon
^{143}Ce	Effective, colon
^{144}Ce	Effective, colon
^{147}Nd	Effective, colon
$^{239+240}$Pu	Effective, bone surface, liver
^{241}Pu	Effective, bone surface, liver
All	Effective
All	Collective effective

Effective dose commitments for individuals

Such large amounts of data are more easily summarized graphically. Figs. 20 through 25 consist of color-coded maps that provide information on the effective dose summed over all radionuclides for each year of testing. Fig. 26 is a summary over all years. For these plots the best estimator of effective dose is considered to be the geometric means, as tabulated in the spreadsheets contained in the CDs. Some dose was estimated to have occurred in every county considered; the highest total dose (3.0 mSv) occurred in part of Nye County, Nevada, and the lowest (0.011 mSv) in Wahkiakum County, Washington. Data for the 80 counties or parts of counties with higher estimates of total individual effective dose are given in Table 5. It is not surprising to see a large representation from Nevada (11) and Utah (31), but 21 counties from Colorado also appear on the list. This is apparently due to two reasons: These locations are downwind from many fallout tracks that passed over Utah, and there was enhanced deposition with rain after some clouds passed over the Rocky Mountains (see Beck 1984).

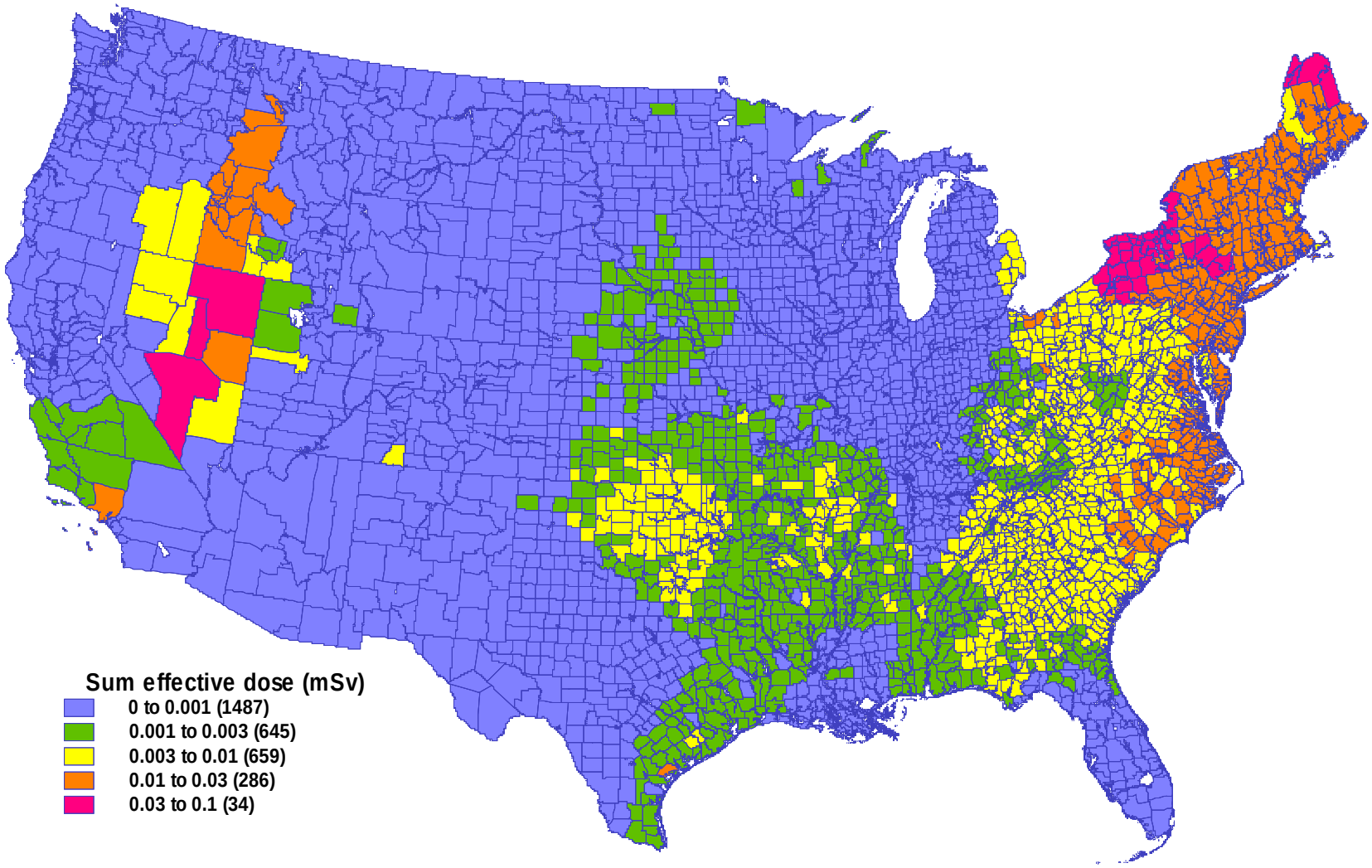

Fig. 20. Map of the effective dose by geographical area for the tests conducted in the year 1951.

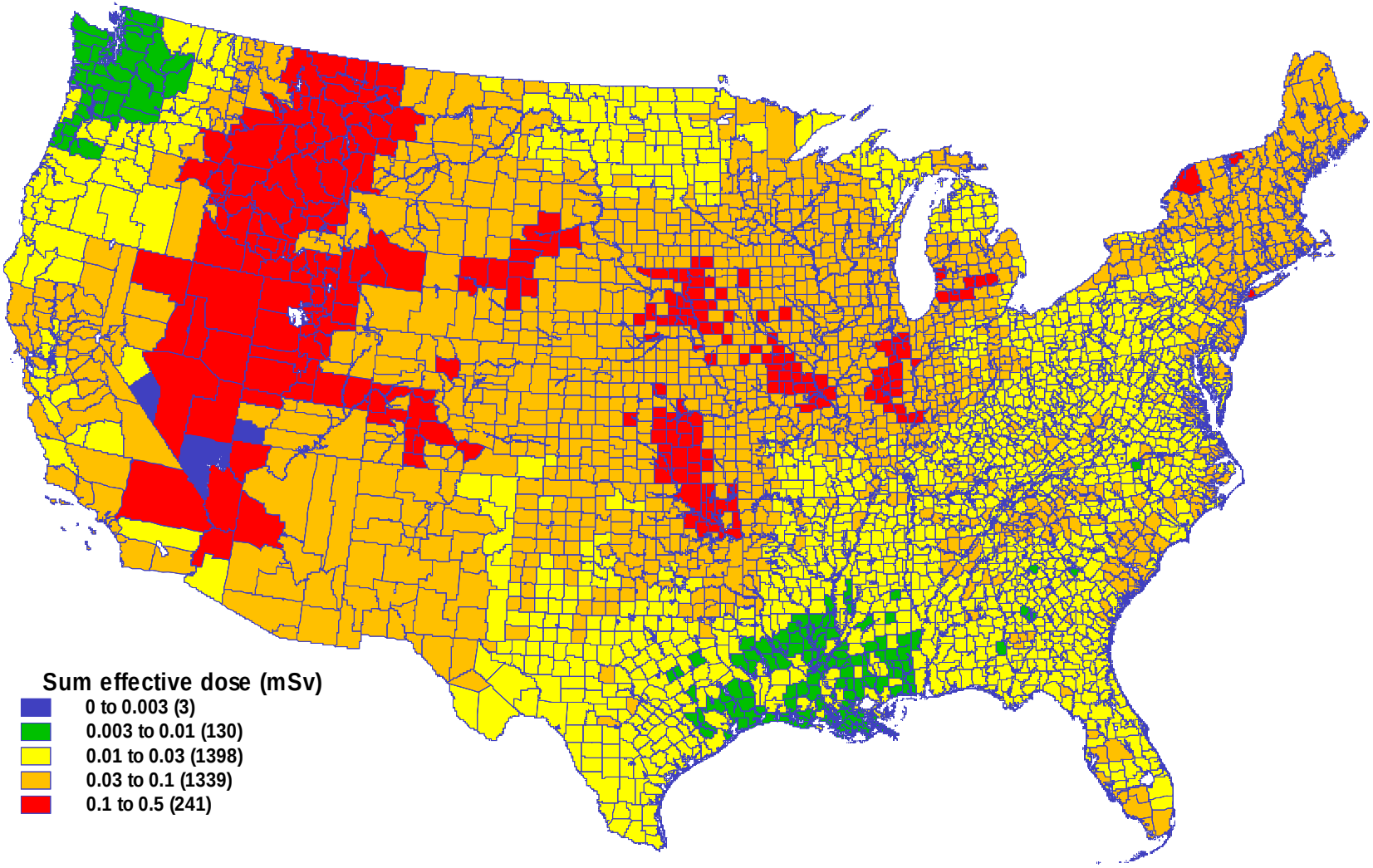

Fig. 21. Map of the effective dose by geographical area for the tests conducted in the year 1952.

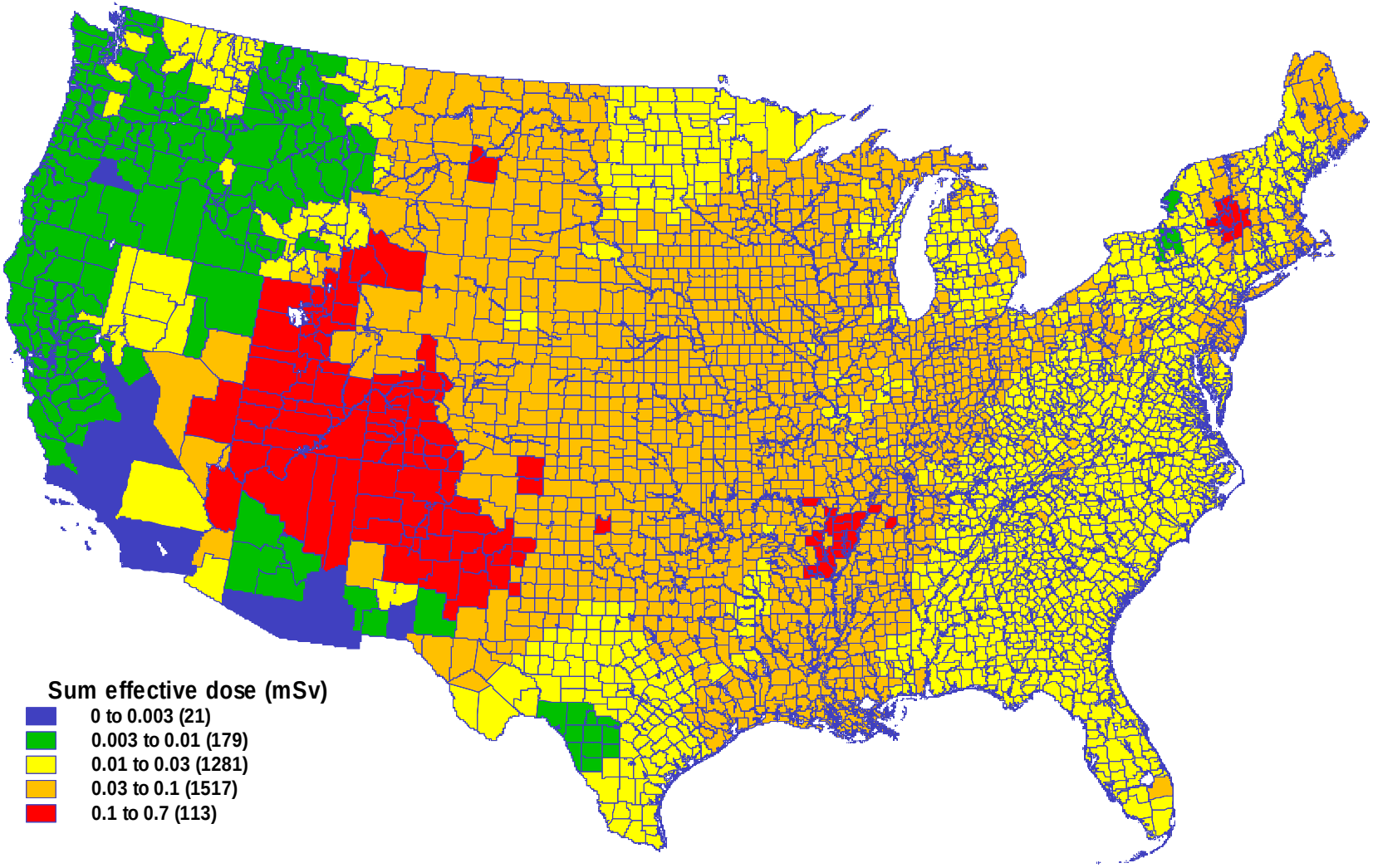

Fig. 22. Map of the effective dose by geographical area for the tests conducted in the year 1953.

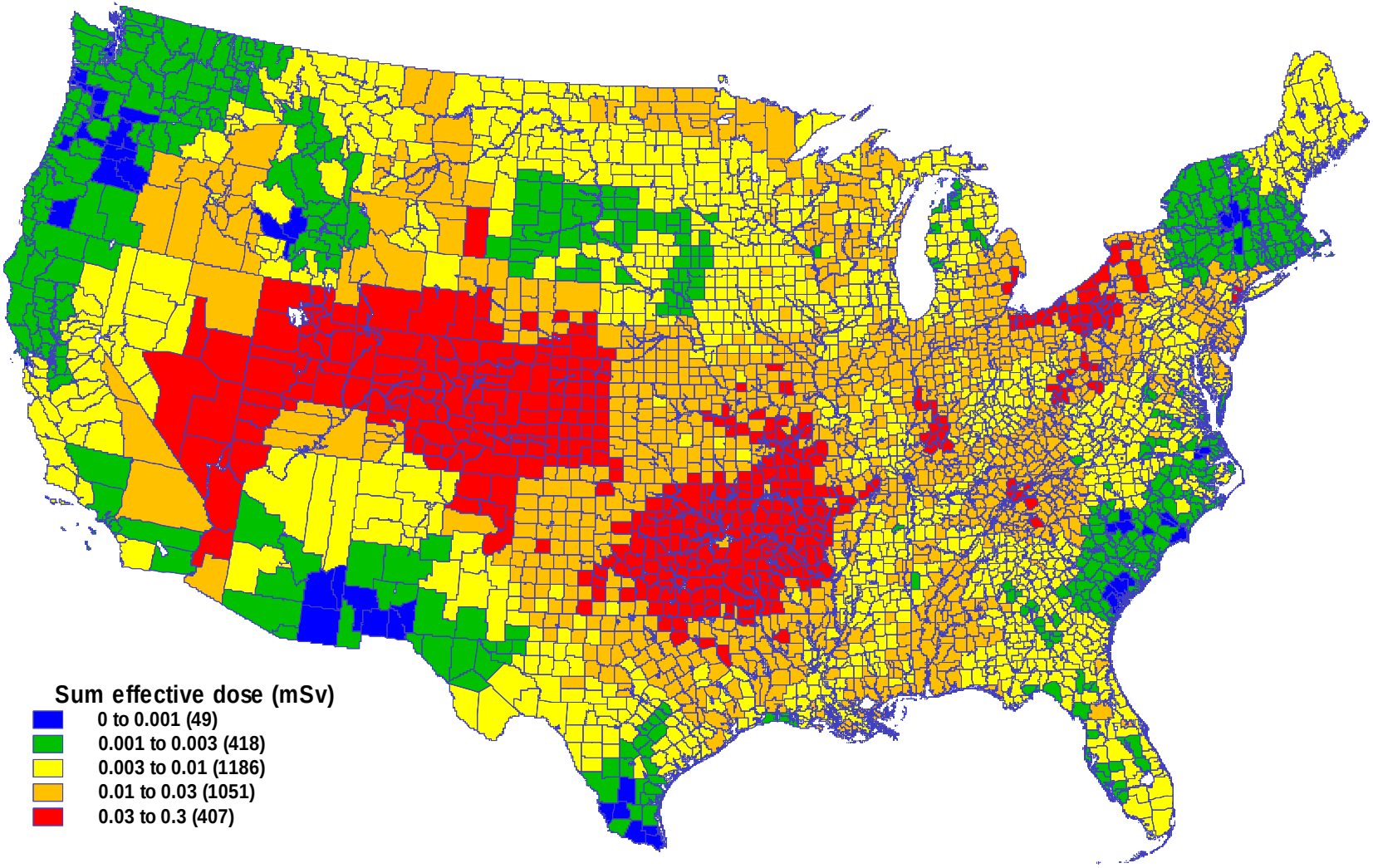

Fig. 23. Map of the effective dose by geographical area for the tests conducted in the year 1955.

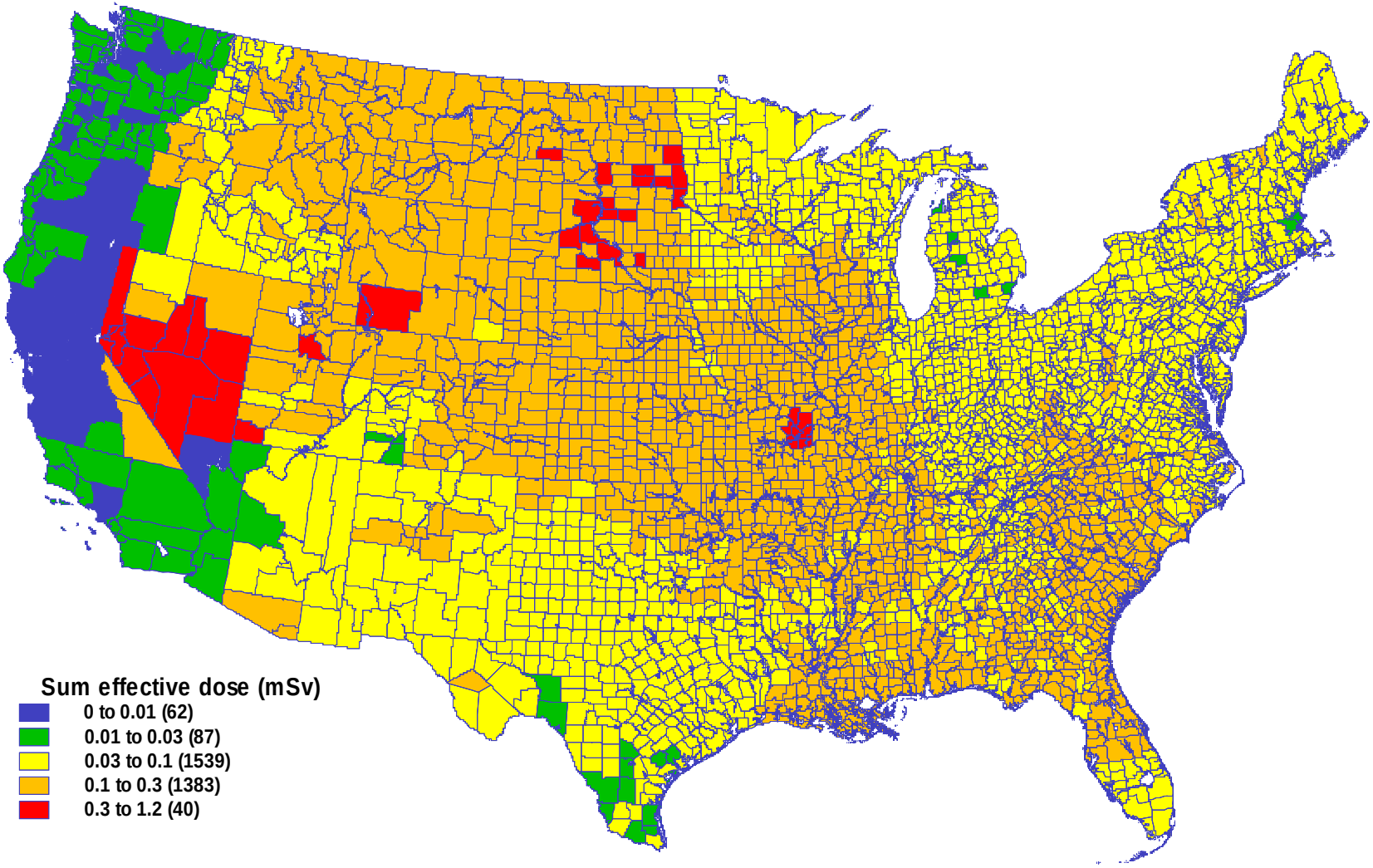

Fig. 24. Map of the effective dose by geographical area for the tests conducted in the year 1957.

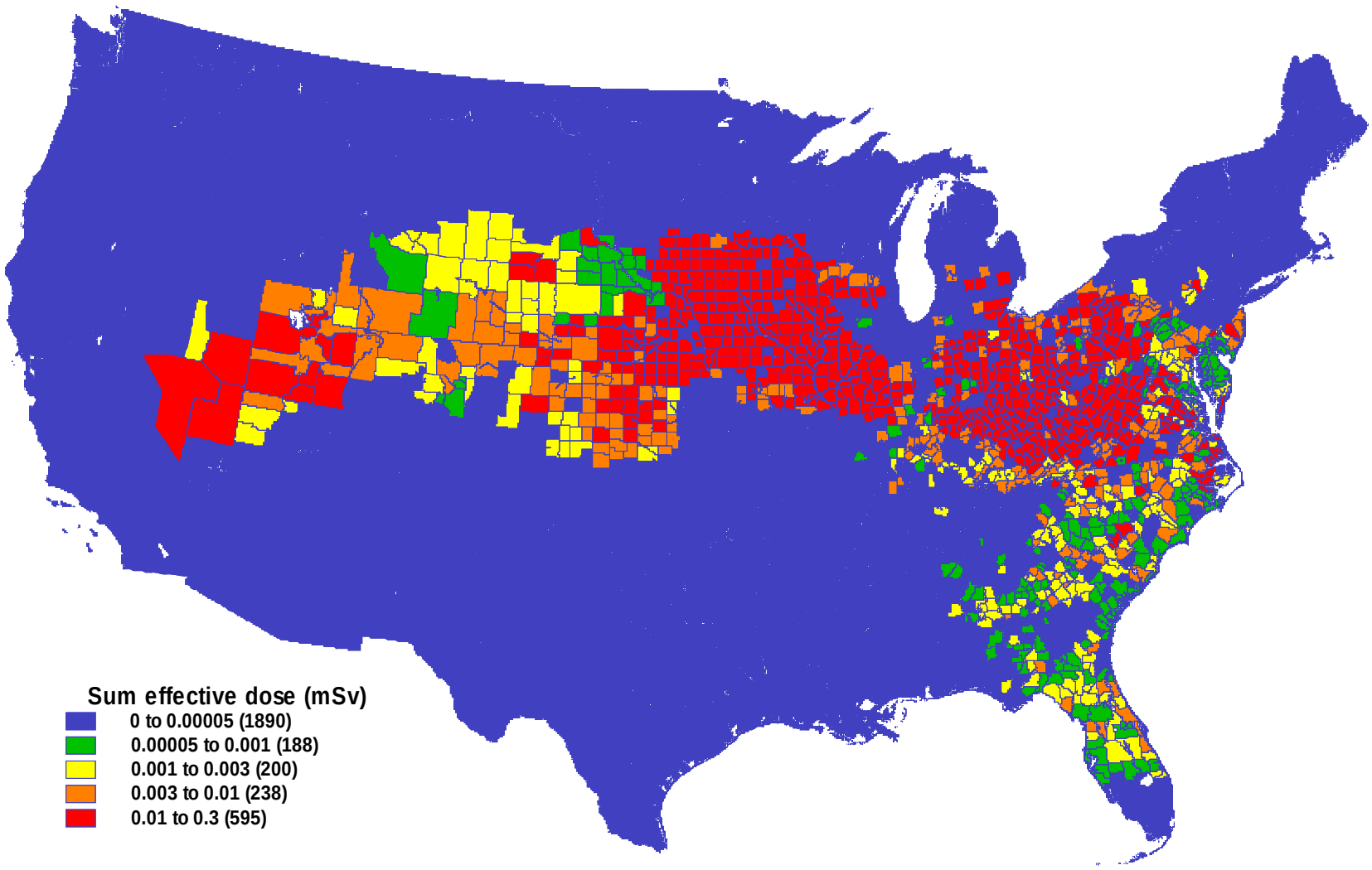

Fig. 25. Map of the effective dose by geographical area for the tests conducted in the year 1962.

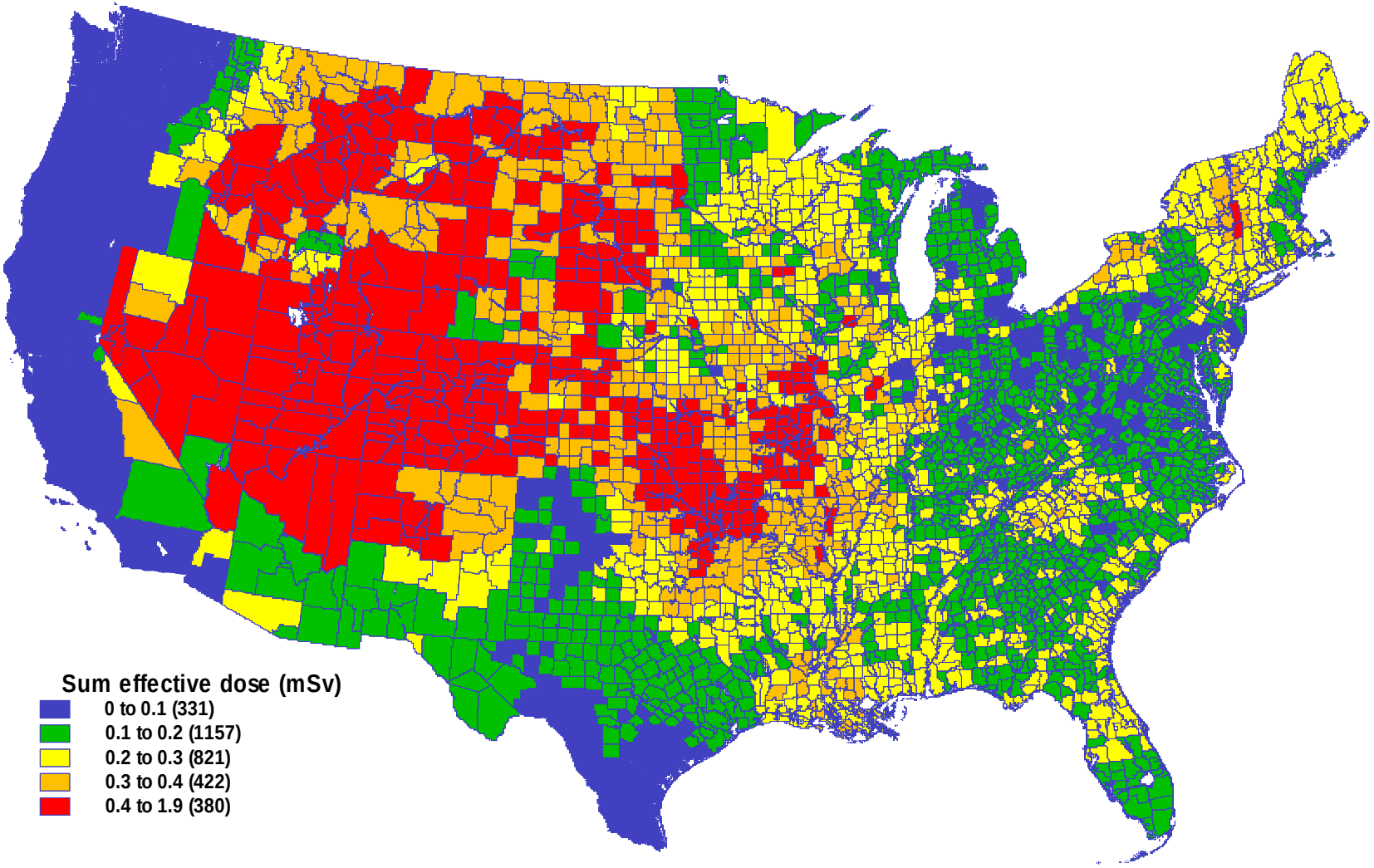

Fig. 26. Map of the effective dose by geographical area for the tests conducted from 1951 through 1962.

Table 5. Counties or subcounties with higher estimates of total individual effective dose.

State	County	$\bar{x}_g$, mSv	σ_g	State	County	$\bar{x}_g$, mSv	σ_g
NV	Nye 2	3.0	1.5	UT	Box Elder 2	0.72	1.5
NV	White Pine 2	1.8	1.5	CO	Eagle	0.71	2.1
NV	Lincoln 1	1.4	1.8	CO	Lake	0.71	2.3
NV	White Pine 3	1.4	1.5	UT	Rich	0.71	1.5
UT	Utah	1.2	1.5	UT	Garfield	0.71	2.4
AZ	Mohave 2	1.2	1.8	CO	Saguache	0.70	2.2
NV	White Pine 1	1.1	1.5	NV	Lander 2	0.70	1.8
UT	Washington 3	1.1	1.7	UT	Sanpete	0.70	1.6
CA	Inyo 3	1.1	2.0	CO	Clear Creek	0.70	1.8
UT	Wasatch	1.0	1.5	UT	Uintah	0.70	1.6
UT	Tooele 1	0.99	1.7	UT	Beaver	0.69	1.6
NV	Eureka	0.99	1.7	WY	Sweetwater	0.69	1.7
UT	Millard	0.97	1.5	MO	Audrain	0.69	2.5
UT	Washington 2	0.97	1.7	UT	Grand	0.68	1.6
UT	Kane 2	0.93	2.3	UT	Cache	0.67	1.5
UT	Tooele 2	0.91	1.5	NV	Lincoln 2	0.67	3.9
CO	Conejos	0.91	3.2	UT	Iron 2	0.66	2.3
UT	Davis	0.90	1.5	NV	Mineral	0.66	1.9
UT	Morgan	0.89	1.5	CO	Rio Blanco	0.66	1.5
UT	Washington 1	0.88	2.3	NV	Elko	0.66	1.6
UT	Juab	0.88	1.5	CO	Delta	0.65	1.6
UT	Weber	0.88	1.5	CO	Montrose	0.65	1.8
UT	Salt Lake	0.87	1.4	NM	McKinley	0.64	1.7
UT	Iron 1	0.86	2.1	UT	Dagget	0.64	1.6
CO	Archuleta	0.86	2.8	CO	Pitkin	0.64	2.9
UT	Summit	0.84	1.4	ID	Custer	0.63	3.7
CO	Hinsdale	0.82	2.7	WY	Carbon	0.63	1.4
AZ	Mohave 1	0.81	2.2	UT	Iron 3	0.62	2.6
CO	Gunnison	0.80	3.7	CO	Rio Grande	0.62	2.8
CO	Mineral	0.80	2.7	SD	Haakon	0.62	2.0
UT	Kane 1	0.80	2.4	CO	Douglas	0.62	1.9
WY	Fremont	0.79	1.5	WY	Uinta	0.62	1.5
AZ	Coconino 2	0.77	1.7	CO	Summit	0.61	2.5
NV	Washoe	0.76	1.6	UT	Sevier	0.61	1.5
CO	Garfield	0.76	1.5	CO	Grand	0.61	2.6
CO	Mesa	0.75	1.6	CO	Gilpin	0.60	1.8
AZ	Apache	0.75	1.7	MT	Meagher	0.60	2.7
UT	Duchesne	0.74	1.6	CO	Boulder	0.60	2.0
MO	Knox	0.73	3.4	WY	Sublette	0.60	1.5
UT	Emery	0.72	1.6	ID	Gem	0.59	3.8

Collective dose commitments

The collective effective dose commitments and the per caput[6] effective dose commitments for all years are summarized in Table 6, where the internal doses are compared to the recent calculations of Beck (1999) for external dose commitments. As considered in more detail later, the values for internal dose in the middle column of Table 6 are dominated by the value of effective dose from ^{131}I, which in turn is dominated by the dose from ^{131}I to the thyroid. The dose from ^{131}I to the thyroid also varies strongly with age with the larger doses being received by infants and young children. Thus, even though infants and young children make up a small fraction of the population, their contribution to the total collective dose can be proportionally much higher. Therefore, it is appropriate to consider an age correction to the collective doses for the contribution from ^{131}I. (It would be appropriate to consider such an age correction for all radionuclides; this was not done for this feasibility study for radionuclides other than ^{131}I, as the age-correction effects for other radionuclides are known to be much smaller.) The details of the age-correction calculation for ^{131}I are shown in Table 7, where data are shown for each year of age group from <1 through age 20 y and for ≥21 y. The year-by year population values are from the U.S. 1960 census; the dose coefficients (without modification to geometric means) are from ICRP (1998), and the integrated intakes represent average ratios of age-adjusted intakes from Whicker and Kirchner (1987) multiplied by the average seasonally-adjusted intakes used for this study. The results are that the age-corrected collective doses from ^{131}I would be 2.52 times higher for thyroid dose and 2.45 times higher for effective dose compared to the values calculated for adults only. The age-corrected values of collective dose and per caput dose are shown in the last column of Table 6.

As shown in Table 6, the age-corrected values of collective effective dose and per caput dose are somewhat larger for internal dose than for external dose. This follows from the fact that the effective dose is dominated by the dose to the thyroid from ^{131}I. As will be shown later, the dose to all organs except for the thyroid is much lower than the effective dose.

Table 6. Total collective effective doses and per caput doses from all tests.

Parameter	Value	Age corrected value[a]
Internal dose commitment		
Collective effective dose, person Sv	53,000 ± 5,900	110,000 ± 14,000
Per caput dose, μSv	320 ± 40	680 ± 90
External dose commitment (Beck 1999)		
Collective effective dose, person Sv	84,000	
Per caput dose, μSv	520	

[a] For the contribution from ^{131}I.

[6] The per caput dose is the collective dose divided by the number of persons in the population considered. The value of the population for this report is the estimated 1954 population of 163 million.

Table 7. Derivation of an age correction for collective dose from ^{131}I.

Age	Fraction of 1960 population	Thyroid F_g, Sv Bq^{-1}	Effective F_g, Sv Bq^{-1}	Average integrated intake, Bq Bq^{-1} m^2	Thyroid product, Sv m^2 Bq^{-1}	Effective product, Sv m^2 Bq^{-1}
<1	0.0229	$3.70 \times 10^{-}$	$1.80 \times 10^{-}$	0.0645	5.47×10^{-9}	2.66×10^{-10}
1	0.0229	$3.60 \times 10^{-}$	$1.80 \times 10^{-}$	0.0548	4.52×10^{-9}	2.26×10^{-10}
2	0.0229	$3.60 \times 10^{-}$	$1.80 \times 10^{-}$	0.0548	4.51×10^{-9}	2.25×10^{-10}
3	0.0224	$2.10 \times 10^{-}$	$1.00 \times 10^{-}$	0.0548	2.58×10^{-9}	1.23×10^{-10}
4	0.0222	$2.10 \times 10^{-}$	$1.00 \times 10^{-}$	0.0548	2.56×10^{-9}	1.22×10^{-10}
5	0.0220	$2.10 \times 10^{-}$	$1.00 \times 10^{-}$	0.0548	2.54×10^{-9}	1.21×10^{-10}
6	0.0213	$2.10 \times 10^{-}$	$1.00 \times 10^{-}$	0.0548	2.45×10^{-9}	1.17×10^{-10}
7	0.0211	$2.10 \times 10^{-}$	$1.00 \times 10^{-}$	0.0548	2.43×10^{-9}	1.16×10^{-10}
8	0.0204	$1.00 \times 10^{-}$	$5.20 \times 10^{-}$	0.0548	1.11×10^{-9}	5.80×10^{-11}
9	0.0194	$1.00 \times 10^{-}$	$5.20 \times 10^{-}$	0.0548	1.06×10^{-9}	5.53×10^{-11}
10	0.0194	$1.00 \times 10^{-}$	$5.20 \times 10^{-}$	0.0548	1.06×10^{-9}	5.53×10^{-11}
11	0.0194	$1.00 \times 10^{-}$	$5.20 \times 10^{-}$	0.0548	1.06×10^{-9}	5.52×10^{-11}
12	0.0199	$1.00 \times 10^{-}$	$5.20 \times 10^{-}$	0.0623	1.24×10^{-9}	6.46×10^{-11}
13	0.0196	$6.80 \times 10^{-}$	$3.40 \times 10^{-}$	0.0623	8.29×10^{-10}	4.14×10^{-11}
14	0.0153	$6.80 \times 10^{-}$	$3.40 \times 10^{-}$	0.0623	6.47×10^{-10}	3.24×10^{-11}
15	0.0154	$6.80 \times 10^{-}$	$3.40 \times 10^{-}$	0.0623	6.52×10^{-10}	3.26×10^{-11}
16	0.0156	$6.80 \times 10^{-}$	$3.40 \times 10^{-}$	0.0623	6.61×10^{-10}	3.31×10^{-11}
17	0.0160	$6.80 \times 10^{-}$	$3.40 \times 10^{-}$	0.0623	6.76×10^{-10}	3.38×10^{-11}
18	0.0141	$4.30 \times 10^{-}$	$2.20 \times 10^{-}$	0.0623	3.78×10^{-10}	1.93×10^{-11}
19	0.0127	$4.30 \times 10^{-}$	$2.20 \times 10^{-}$	0.0447	2.44×10^{-10}	1.25×10^{-11}
20	0.0122	$4.30 \times 10^{-}$	$2.20 \times 10^{-}$	0.0447	2.35×10^{-10}	1.20×10^{-11}
≥21	0.6030	$4.30 \times 10^{-}$	$2.20 \times 10^{-}$	0.0447	1.16×10^{-8}	5.93×10^{-10}
Weighted sum	1.00				4.85×10^{-8}	2.41×10^{-9}
Ratio of weighted sum-to-adult value					2.52	2.45

As a consequence, the doses to organs except for the thyroid are substantially higher from external exposure than from internal dose.

Collective effective dose by year of testing. The collective effective dose commitments by year of testing are shown in Table 8. Age corrections have not been made in this table, as the primary goal is to indicate the contributions by year only in a relative sense. The highest contribution occurred in 1957 during the 16 explosions of Operation Plumbbob. The second and third higher contributions occurred in 1952 during the eight events of Operation Tumbler-Snapper and in 1953 during the 11 events of Operation Upshot-Knothole.

Table 8. Collective effective dose commitments from ingestion by year of testing. Values are not corrected for age.

Year of testing	Collective effective dose commitment, person Sv
1951	1,900 ± 310
1952	10,000 ± 700
1953	7,900 ± 560
1955	5,900 ± 1,600
1957	20,000 ± 1,300
1962	6,600 ± 5,400
Total	53,000 ± 5,900

A surprisingly large contribution is attributed to the two explosions that occurred in 1962 during Operation Storax; almost all of the later was due to Project Sedan, a large cratering experiment.[7] The relative ranking of contributions by year is not the same as for external dose (Beck 1999), although the largest contribution for both was from tests conducted in 1957. The reason for differences in order is primarily due to the seasonal dependence for the contribution from dose via ingestion. As shown in Figs. 3 through 19, the seasonal dependence is quite strong for many radionuclides with a peak typically occurring in June–July. The relative ranking by year is the same as noted for the dose to the thyroid from ^{131}I only as reported in NCI (1997).

Collective effective dose by event. The collective effective dose commitments for the 16 events contributing at least 1000 person Sv are indicated in Table 9 in descending order of dose. As for Table 8, these values have not been age-corrected. It was not anticipated that Project Sedan[8] would head this list, but there are several notable factors for this event. First, the uncertainty associated with the deposition for this event is very large; this and the additional uncertainties involved in the dose calculation result in a very large uncertainty for the associated dose from this event—in fact, the uncertainty is nearly as large as the estimated dose. Another important factor is that this event took place during a time of year when the integrated intake function is at a maximum. And finally, the yield for the Project Sedan was the largest of those listed in Table 1. However, the yield for this event is presumed to have been mostly fusion, although the fractional fission yield is not available; the fact that the fission yield is unavailable is a major contributor to the uncertainty in the calculated deposition values for Project Sedan. The other events listed in Table 9 are generally known to have been major contributors to off-site dose, and they typically occurred during the time of year when radioecological transfer would have been high.

[7] See the following footnote concerning Sedan.

[8] This illogical prominence of the estimated dose from Sedan prompted a re-evaluation of the deposition values by Beck (personal communication 2000) for this event. The conclusion is that the original ^{131}I-deposition values taken from the NCI data base used for NCI (1997) are seriously in error for Sedan: The calculated total deposition across the U.S. is thirty times higher than the amount of ^{131}I stated to have been released by this event. The error is apparently associated with the meteorological model used to calculate deposition for Sedan. As this model was also used for Ranger Baker, Ranger Baker-2, and Storax Small Boy, similar errors may have occurred for these three events. This major discrepancy for Sedan and questions about the other events must be resolved, if this dose-reconstruction project evolves beyond the current feasibility phase.

Table 9. Collective effective dose commitments from ingestion for the 16 nuclear explosions that are estimated to have resulted in more than 1000 person Sv. Values are not corrected for age.

Event	Date	Collective effective dose commitment, person-Sv
Storax Sedan	6 July 1962	6200 ± 5400
Tumbler-Snapper George	1 June 1952	4400 ± 540
Plumbbob Diablo	15 July 1957	4100 ±850
Upshot-Knothole Harry	19 May 1953	2800 ±280
Plumbbob Kepler}Owens	24–25 July 1957	2600 ± 380
Plumbbob Hood	5 July 1957	2600 ±340
Tumbler-Snapper How	5 June 1952	2100 ±240
Tumbler-Snapper Simon	25 April 1953	1900 ±280
Plumbbob Priscilla	24 June 1957	1900 ± 460
Teapot Zucchini	15 May 1955	1700 ± 510
Plumbbob Galileo	2 September 1957	1600 ± 250
Teapot Apple 2	5 May 1955	1600 ± 180
Tumbler-Snapper Fox	25 May 1952	1500 ± 250
Plumbbob Doppler	23 August 1957	1400 ± 480
Plumbbob Wilson	18 June 1957	1300 ± 150
Buster Charlie	30 October 1951	1100 ± 180
Sum of the above		39,000 ± 5,600

Together, these 16 events account for 73% of the total non-age-corrected estimated dose.

Collective effective dose by radionuclide. The collective effective dose commitments (not corrected for age) for all tests according to the ten radionuclides contributing more than 98% of the estimated dose are shown in Table 10 arranged in descending order of dose. Iodine-131 alone accounts for 76% of the non-age-corrected collective effective dose. Of the ten more important radionuclides only ^{90}Sr and ^{137}Cs are long lived. Plutonium radionuclides accounted for only 0.4% of the estimated total dose. As noted above, the potentially important radionuclide ^{239}Np has not been included in this feasibility study.

Collective dose by organ. As indicated above, doses were also calculated for each radionuclide for any organ that had a dose coefficient more than twice that of the dose coefficient for effective dose. Total collective organ doses were then calculated by summing the dose by organ, but if a dose had not been calculated separately for that organ for a radionuclide, then the effective dose for that radionuclide was added to the sum. This procedure is only approximate, but was used for this feasibility study in order to derive some estimate of the organs receiving the more significant doses. The results for the organs listed

in Table 4 are given in the middle column of Table 11 and indicate that the bone surface and colon are of potential interest.

Table 10. Collective effective dose commitments for all tests according to radionuclide. The ten radionuclides in the table account for more than 98% of the total dose from ingestion calculated for all 20 radionuclides. Doses from ^{239}Np were not considered in this feasibility study.

Radionuclide	Collective effective dose commitment, person-Sv
^{131}I	40,000 ± 5,700[a]
^{89}Sr	2800 ± 150
^{140}Ba	1900 ± 180
^{137}Cs	1700 ± 120
^{132}Te	1300 ± 160
^{106}Ru	1200 ± 250
^{144}Ce	860 ± 69
^{103}Ru	620 ± 87
^{90}Sr	600 ± 37
^{136}Cs	580 ± 210
Sum of above	52,000 ± 5,900

[a] The age-corrected value is 99,000±14,000.

Table 11. Collective dose commitments for all tests according to organ.
If an organ dose had not been calculated separately for a given radionuclide, the effective dose for that radionuclide was added to the organ total; this resulted in a substantial overestimate. The last column is corrected to remove the overestimate due to ^{131}I effective dose. Doses are based on calculations for adults.

Organ	Collective organ dose commitment, person-Sv	Corrected[a] collective organ dose commitment, person-Sv
Effective	53,000 ± 5,900	110,000 ± 14,000
Bone surface	71,000 ± 7,000	31,000 ± 4,000
Colon	96,000 ± 10,000	56,000 ± 8,400
Kidneys	53,000 ± 5,900	13,000 ± 1,600
Liver	54,000 ± 5,900	14,000 ± 1,600
Red marrow	56,000 ± 5,900	16,000 ± 1,600
Thyroid	820,000 ± 110,000	2,000,000 ± 280,000

[a] Excess contribution from ^{131}I effective dose eliminated and age corrections made for effective and thyroid dose.

However, as the doses to the bone surface and colon were not calculated specifically for ^{131}I, it is also clear from the results in Table 10 that the effective dose from ^{131}I accounts for most of the estimated dose to the bone surface and colon shown in the middle column of Table

11. The ICRP (1998) dose coefficients for the organs considered here and for effective dose are reproduced in Table 12. The thyroid has a very high dose coefficient compared to the other organs, and, even though its tissue weighting factor is only 0.05, it accounts for essentially all of the effective dose coefficient; the dose coefficients for the other organs are at least 100 times smaller than that for the effective dose. Therefore, the collective organ doses shown in the middle column of Table 11 were corrected by subtracting the effective dose from ^{131}I and adding back the dose for that organ. Operationally, this was done by the following calculation:

$$S_{\text{Organ,corrected}} = S_{\text{Organ}} - S_{\text{Effective,131}} \cdot \left(1 - \frac{DC_{\text{Organ,131}}}{DC_{\text{Effective,131}}} \right), \quad (4)$$

where S is collective dose and DC is dose coefficient. The estimates of effective dose and thyroid dose are also age corrected, as explained above and according to the values derived in Table 7. The results of these estimates of corrected collective organ dose commitments are shown in the last column of Table 11. Practically, the net result was the subtraction of 40,000 person Sv from the collective dose for all organs, except thyroid. Compared to the corrected collective doses for most other organs (thyroid being a notable exception), the collective doses to the bone surface and colon are significantly higher.

About two thirds of the corrected collective dose commitment to the bone surface is contributed by three radionuclides: ^{90}Sr, $^{239+240}$Pu, and ^{89}Sr in that order. For the colon, three-fourths of the corrected dose is contributed by four radionuclides: ^{89}Sr, ^{140}Ba, ^{106}Ru, and ^{144}Ce in that order (^{239}Np was not considered during this feasibility study). It is also useful to note that these collective organ doses are less than the collective dose received from external radiation, as inferred from Table 6. (The collective dose to the bone surface from external exposure would be larger than the collective effective dose from external exposure.) Thus, the only organ that has received a substantially higher collective dose from the ingestion of contaminated foods as compared to the dose from external exposure

Table 12. ICRP (1998) dose coefficients for ^{131}I for effective dose and for the organs considered in this study.

Organ	Dose coefficient, Sv Bq^{-1}
Effective	2.2×10^{-8}
Bone surface	1.3×10^{-10}
Colon	1.2×10^{-10}
Kidneys	4.6×10^{-11}
Liver	4.9×10^{-11}
Red marrow	1.0×10^{-10}
Thyroid	4.3×10^{-7}

is the thyroid, which is estimated to have received a collective dose about 24 times higher than that due to external exposure.

Comparison to dose estimates from global fallout

One of the requirements for this project was to compare the doses calculated above to the latitudinal average doses published by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR 1993). The latter doses are for "global fallout" from the large explosions conducted by the U.S. in the Pacific Region and by Russia near the Arctic Circle, whereas the doses calculated here are for local and regional fallout from the relatively small tests at the NTS. The nature of the UNSCEAR calculations is basically the same as that conducted for this study: Calculated doses are per caput doses for adults and focus on effective dose commitments with the only age correction having been made for doses from ^{131}I. A comparison of dose commitments arising from the ingestion of contaminated foods is shown in Table 13. The UNSCEAR values listed here are for averages over the 40°–50° latitude band of the north temperate zone, which would cover much, but not all, of the contiguous United States.

As discussed above, the small nuclear tests conducted in the atmosphere at the NTS would not have created significant amounts of ^{3}H and ^{14}C in comparison to the large amounts that were produced by the much larger tests of fusion devices in the atmosphere conducted by the U.S. in the Pacific Region and by Russia near the Arctic Circle. Thus, these two radionuclides have not been included in the current assessment of doses from the NTS, but the two radionuclides are noted to be significant contributors to dose from global fallout.

The method used by the UNSCEAR (1993) to calculate dose commitment from ^{14}C also deserves some comment. The value in UNSCEAR (1993) for the effective dose commitment from ^{14}C is 2600 μSv, but this commitment extends over infinite time for a radionuclide with a half life of 5730 years and which remains widely distributed in the atmosphere and hydrosphere over very long times. Thus, the per caput dose commitment calculated by the UNSCEAR is intergenerational. According to UNSCEAR (1993) 5% of this dose would be delivered during the first 100 years; therefore, in order to compare more reasonably with the dose commitments from the NTS the value of 2600 μSv has been reduced by multiplying by 0.03; this modified result is given in Table 13.

In general, the effective dose commitment from the NTS is dominated by short-lived radionuclides, such as ^{131}I, ^{89}Sr, and ^{140}Ba. In contrast, the estimates of dose commitment from global fallout are dominated by long-lived radionuclides, such as ^{137}Cs and ^{90}Sr. This is consistent with the mechanisms that produced the deposition of fallout from the two sources.

Another feature of global fallout was that the debris was injected into the upper troposphere and stratosphere and circulated around the globe with relatively little mixing across latitude bands; debris was removed from these regions of the upper atmosphere with a half life of about one year. Thus, if rainfall had been equal at all locations within a latitude band, then the deposition of radionuclides from global fallout should have been essentially constant within latitude bands. Of course, rainfall was not equal at all locations, and the amount of yearly rainfall correlates strongly with the amount of fallout deposition.

Table 13. Comparison of fallout dose commitments from NTS and from global sources.

Radionuclide	Per caput effective dose commitment, μSv	
	This project Nevada Test Site (NTS)	UNSCEAR (1993) Global fallout
^{3}H	-	48
^{14}C	-	78[a]
^{55}Fe		14
^{89}Sr	17	2.3
^{90}Sr	3.7	170
^{91}Sr	0.0065	
^{97}Zr	0.15	
^{99}Mo	1.0	
^{103}Ru	3.8	
^{106}Ru	7.2	
^{105}Rh	0.086	
^{132}Te	7.8	
^{131}I	610[b]	79
^{133}I	1.9	
^{136}Cs	3.6	
^{137}Cs	10	280
^{140}Ba	12	0.42
^{143}Ce	0.40	
^{144}Ce	5.3	
^{147}Nd	1.1	
^{238}Pu		0.0009
$^{239+240}Pu$	1.2	0.50
^{241}Pu	0.087	0.004
^{241}Am		1.5
Sum	680[b]	670[a]

[a] The UNSCEAR (1993) value of 2600 μSv was multiplied by a factor of 0.03, the portion estimated to be delivered in 50 y.

[b] Age corrected.

Debris from the NTS originated from relatively small explosions, and much of the debris remained within the lower regions of the atmosphere. Thus, a much greater fraction of NTS debris was deposited within the U.S. during the first few days following the explosions. Rainfall was also an important determining feature of the amount of NTS fallout deposited at a given location, but also important was the distance from the NTS. Thus, the variation in the amount of NTS fallout deposition is expected to be larger than for global fallout. As mentioned earlier, the maximum amount (averaged over a county-size area) of non-age-corrected dose commitment from NTS fallout summed over all years was 3000 μSv and the minimum was 11 μSv—a ratio of nearly 300. Although the per caput dose commitments shown in Table 13 indicate that dose from global fallout was about the same as the value from NTS fallout, at any specific location the true ratio can vary substantially. The timing of deposition also varied for NTS versus global fallout. While

most of the NTS fallout occurred in the 1950's, most of the global fallout occurred in 1963–1965 (UNSCEAR 1993).

Dose from inhalation

For this feasibility study, dose has not been estimated for inhalation. The primary reason is that estimates of integrated air concentration were not available. When the gummed-film network was being operated, substantial numbers of measurements were made of concentrations of radionuclides in air. If these measurements should be used in the future for calculations of dose from inhalation, it would be necessary to go through a similar process of kriging with consideration of rainfall to produce estimates on a county-by-county basis. In the case of air concentration, rainfall should be inversely correlated with integrated air concentration, whereas the reverse is true for deposition.

Past experience (Ng et al. 1990; UNSCEAR 1993) indicates that dose from inhalation is much less important than the dose received from external exposure or the ingestion of contaminated foods. In general, dose via inhalation only becomes of some importance for those radionuclides that have an extremely low rate of absorption across the gut wall, but remain in the lung for a long time when inhaled. Such a radionuclide is $^{239+240}$Pu.

Another approach to providing crude estimates of dose from inhalation is to base the calculation upon a deposition density and to assume that there is a relationship between deposition density, *P*, and integrated air concentration, *IAC*, that is given by a deposition velocity, v_g. This approach is only approximate, as this relationship is influenced very strongly by rainfall amount; and rainfall is an important vector producing deposition of fallout. Such an approach has been used by the UNSCEAR (1993) and is based upon long-term observations of the relationship between *IAC* and *P* at New York City. According to the UNSCEAR, an average value of v_g is 1.76 cm s^{-1}. Thus, given *P*, the dose from inhalation can be calculated by

$$D_h = \mathrm{K} \times R \times P \times \frac{1}{v_g} \times B \times F_h \ , \tag{5}$$

where K is a units-conversion factor, *R* is a reduction factor associated with indoor occupancy, *B* is breathing rate, and F_h is the dose coefficient for intake via inhalation. According to NCI (1997) a reasonable derivation of *R* is to assume that adults spend 80% of their time indoors where the concentration of radionuclides in air is 0.3 of that in outdoor air. A commonly used value by the ICRP for *B* is 22 m^3 day^{-1}; values of F_h are available for all organs in ICRP (1998).

For the purpose here it is more convenient to calculate the ratio of dose from inhalation to the dose from ingestion for a particular radionuclide for a particular event:

$$\frac{D_h}{D_g} = \frac{\mathrm{K'} \times R \times B \times F_h}{v_g \times I \times F_g} \ . \tag{6}$$

For illustrative purposes, the event (Project Sedan) estimated to have produced the largest dose is used and values have been calculated for the ten radionuclides of greater impact (Table 10) plus $^{239+240}$Pu. The results are presented in Table 14. For these conditions the only radionuclide whose dose via inhalation would have exceeded the dose via ingestion is $^{239+24}$Pu. However, $^{239+240}$Pu did not account for a significant amount of the total dose from the tests. For the other radionuclides, the estimated ratio is generally a third or much less. These values are biased toward the low side by the date of Project Sedan, which occurred when radioecological transfer was high. The values are biased toward the high side due to the fact that most of the deposition occurred during rainstorms. Better estimates could be made in the future of doses via inhalation, but kriged or otherwise derived values of integrated air concentration would be necessary.

Comparison of results with those from NCI (1997)

NCI (1997) presents the results of a very detailed, multi-year study of the dose to residents of the U.S. The study considers only ^{131}I and the dose to the thyroid. The bottom line result from NCI (1997) is a collective thyroid dose of 4,000,000 person Sv, whereas a comparable number estimated from this work (Table 11) is 2,000,000 Sv. Further, the distribution of individual dose on a county-by-county basis appears to be somewhat different with the NCI (1997) values appearing to be higher in Idaho, Montana, and the Midwest.

Table 14. Calculated ratios of dose from inhalation-to-dose from ingestion for the conditions of Project Sedan.

Radionuclide	$\frac{D_h}{D_g}$
^{131}I	0.022
^{89}Sr	0.079
^{140}Ba	0.33
^{137}Cs	0.00087
^{132}Te	0.38
^{106}Ru	0.053
^{144}Ce	0.13
^{103}Ru	0.17
^{90}Sr	0.011
^{136}Cs	0.014
$^{239+240}$Pu	2.6

Differences most likely result from the different treatments for the critical factor of the amount of fallout retained by vegetation. For this study a constant value was used, whereas NCI (1997) used a value that varied depending upon the amount of rainfall. A similar treatment (which would require the input data on the daily amounts of rainfall for each county) could be used, if the assessment of dose from other radionuclides is to move beyond this feasibility phase. However, there is still large uncertainty in the rainfall-rate dependent values of this parameter, and it might be useful to undertake once again a review of the data

that can be used to derive such factors and the uncertainties in such values. For lower amounts of rainfall and high standing biomasses the NCI (1997) procedure results in estimates of the retention of fallout by vegetation of essentially 100%, which is not consistent with several experimental observations [Hoffman et al. (1989) and as reviewed by Anspaugh (1987)].

CONCLUSIONS

The main objective of this work was to determine whether it is feasible to reconstruct the doses from radionuclides other than ^{131}I to the population of the United States that resulted from the tests of nuclear weapons at the Nevada Test Site. The results provided here establish that such a reconstruction is feasible, provided that estimates of deposition density for a particular radionuclide are available. As it was demonstrated many years ago for the ORERP project that there is a definable relationship for the ratio of one radionuclide to another for all radionuclides of interest (Hicks 1982, 1990), this conclusion is not surprising.

What is more of a surprise is the extent to which the dose from ^{131}I dominates the dose received by the American public from tests at the NTS. Other than the doses from ^{131}I to the thyroid (and how this effects the effective dose), doses to other organs are much smaller and are less than the dose that was estimated by Beck (1999) to have resulted from external exposure.

The effective dose received by the U.S. population from releases from the NTS is about the same as the dose received from global fallout. However, large deviations from the average are expected, and the two sources resulted in doses delivered during two different time periods.

This study and the deposition values calculated by Beck for 20 different radionuclides are based upon the NCI (1997) data base of county-by-county ^{131}I-deposition values for each test. A review of these values for Project Sedan has revealed a major discrepancy of a factor of 30 between the total calculated deposition within the U.S. and the amount stated to have been produced by the Sedan event. This error is believed to have resulted from the meteorological model used for Sedan and a few other events. Correction of these values was beyond the scope of the current feasibility study, but should be an item of importance for any follow-on study.

Deposition values of ^{239}Np were not provided as input data for this study. Any follow-on study should include this important radionuclide, as it can contribute a substantial fraction of dose to the colon.

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Radiation Dose to the Population of the Continental United States from the Ingestion of Food Contaminated with Radionuclides from Nuclear Tests at the Nevada Test Site

Part II. Reference and Subsidiary Information Pertaining to Exposure and Doses to the American Publics from Nuclear-Weapons Related Tests Conducted at the Nevada Test Site (NTS)

Lynn R. Anspaugh
Lynn R. Anspaugh, Consulting
Salt Lake City, UT

Report to the National Cancer Institute
Purchase Order No. 263-MQ-912901

LIST OF DOCUMENTS

Trinity Event

Before the Trinity event took place, Fermi and others had performed calculations and were aware that fallout might be a problem (Hoddeson et al. 1993). Thus, monitors were ready to evacuate people, if necessary, and did follow the cloud across New Mexico and into Colorado (Hoffman 1947). It is reported that residents of one farm received exposures of up to 60 R (Hacker 1987). A source term (Hicks 1985) for Trinity was calculated and a fallout pattern (Quinn 1987) was reconstructed on behalf of the ORERP. However, doses from this event have not been reconstructed, due primarily to scarcity of data. It is known that photographic film was fogged due to packing in strawboard that was contaminated by Trinity debris that was deposited in Indiana (Webb 1949).

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Congressional Hearings

Over the years Congress has held several hearing on fallout, and the records of the major hearings listed below are major sources of information on fallout. Most of the material is concerned with global fallout, but significant amounts of information pertaining to the Nevada Test Site are also included, particularly in the 1957, 1959, and 1963 hearings.

U.S. Congress. The nature of radioactive fallout and its effects on man. Washington: U.S. Government Printing Office; Hearings before the Special Subcommittee on Radiation, Joint Committee on Atomic Energy; 85th Congress; 1957.

U.S. Congress. Fallout from nuclear weapons tests. Washington: U.S. Government Printing Office; Hearings before the Special Subcommittee on Radiation, Joint Committee on Atomic Energy; 86th Congress; 1959.

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U.S. Congress. Fallout, radiation standards, and countermeasures. Washington: U.S. Government Printing Office; Hearings before the Subcommittee on Research, Development, and Radiation, Joint Committee on Atomic Energy; 88th Congress; 1963.

U.S. Congress. Low-level radiation effects on health. Washington: U.S. Government Printing Office; Hearings before the Subcommittee on Oversight and Investigations, Committee on Interstate and Foreign Commerce, House of Representatives; 96th Congress; 1979.

Reports of organized off-site monitoring activities (Military, National Laboratory, Public Health Service, Environmental Protection Agency, Atomic Energy Commission, University of California at Los Angeles, U.S. Weather Service)

Based upon the experience with the Trinity test and the test series conducted in the Pacific during 1946 and 1948, the potential exposure of workers and the public to fallout were known and appreciated. Beginning with the first test in Nevada monitoring of the nearby region was performed by members of the military, the Los Alamos National Laboratory, and the on-site contractor. In addition, the then Atomic Energy Commission undertook monitoring across the United States through its then Health and Safety Laboratory in New York. On-site radioecological studies were also conducted by a team from the University of California at Los Angeles.

Over the years these monitoring activities became increasingly sophisticated. For the 1955 test series at the NTS responsibility for the monitoring of the nearby off-site area was assumed by the U.S. Public Health Service, and a laboratory for this purpose was established in Las Vegas. The name of this laboratory has changed several times over the years, but their responsibility for off-site monitoring continued until the end of testing.

The U.S. Public Health Service also undertook the creation and management of nationwide networks to monitor activity in air, milk, and water. The earliest measurements on a nationwide basis occurred in 1954; the importance of milk as a vector for ^{131}I had been postulated but was not known clearly until 1962. Prior to 1962 there was more interest in milk as a vector for the transmission of ^{90}Sr and ^{137}Cs from global fallout. Early results of the nationwide networks are reviewed by Terrill (1963); the nationwide monitoring networks that existed in 1961 are summarized in the first issue of *Radiological Health Data and Reports*.

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CLASSIFIED REPORTS

One of the tasks for this work was "To identify classified reports that could be declassified for the purposes of this study, including those that would greatly facilitate the estimation of doses from internal irradiation that are due to the plutonium isotopes."

For many years it has been the policy of the U.S. Government not to identify in unclassified documents the titles of classified reports, and the author presumes that is still the case. However, it can be noted that there is a classified version of the Hicks and Barr (1984) report [see above reference] that would be extremely useful in allowing for a more accurate and consistent calculation of doses from the plutonium radionuclides.

Also, there is a specific problem in dealing with the Sedan event that is caused by the fact that the fission yield of the Sedan event is still classified. The present author cannot identify a specific report in which this fission yield is listed, but such a report obviously exists.

Other than the reports noted above that would be useful in defining the releases of plutonium in general and the fission yield of a few events [beyond the feasibility study, the fission yields of other events, such as Schooner, Buggy, Palanquin, etc., might be needed in order to perform a complete assessment], the author does not know of any reports that would be useful in general in defining the dose from the consumption of contaminated foods. Some isolated classified reports on this subject might exist, but it is doubtful that classified information of a generally useful nature exists.

HIGH-RISK POPULATIONS

Another task was to identify how high-risk populations might be identified. On a geographic basis the areas with the higher estimated doses are shown in Figs. 20–26, and the 80 county or sub-county areas with the higher doses for adults are listed in Table 5. As the most important radionuclide is ^{131}I, young children are also at higher risk (see Table 7). In addition, it is known that children drinking goats' milk would receive doses that are approximately ten times higher than those drinking cows' milk. Thus, the higher risk populations would be young children living in the 80 county or sub-county areas shown in Table 5. The highest risk population would be young children drinking goats' milk in the 80 county or sub-county areas.