A SUMMARY OF ESTIMATED DOSES TO MEMBERS OF THE PUBLIC FROM ATMOSPHERIC NUCLEAR TESTS AT THE NEVADA TEST SITE

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Abstract

This paper discusses estimates of radiation dose to representative members of the public of the United States (U.S.) from atmospheric nuclear tests conducted from 1951 through 1962 at the Nevada Test Site. The estimates provided here summarize five studies conducted over the past two decades. From those studies, an estimate of the average deposition of ^{137}Cs within each of the more than 3,000 counties across the country has been derived as well as doses to representative persons in each county and to specific subpopulations. The years of the largest contributions to the collective external dose were 1952, 1953, and 1957. Those years accounted for about 70% of the 84,000 person-Gy received by the U.S. public. Irradiation of the thyroid gland of members of the U.S. public was also a consequence of dispersion of radioiodine in the fallout. Thyroid doses varied by location and by birth year. The population weighted thyroid dose for a child born in 1951 and for an adult in 1951 were 30 and 5 mGy, respectively. Maps are provided to show the geographic distribution of ^{137}Cs as well as the average thyroid dose received in each county from the Nevada tests.

1. INTRODUCTION

The United States began conducting nuclear tests above ground at the Nevada Test Site (NTS) on January 27, 1951. Atmospheric testing continued intermittently until August 5, 1963. During that period, 119 tests were conducted, most of them aboveground. The total nuclear yield of these explosions was approximately one megaton of TNT-equivalent explosive energy.

Beginning in the early 1980s and continuing until 1997, four dose reconstruction studies related to exposure from the NTS were completed. Presently, a fifth study is in progress. The mandate for these studies has come about largely as a result of interest by the public and the U.S. Congress. These studies vary considerably in scope, design, and purpose. All five of these studies will be briefly discussed and a summary of the estimated doses received by members of the public will be presented.

The individual studies are known as: 1) the ORERP study of the U.S. Department of Energy; 2) the Utah Leukaemia Case-Control study; 3) the Utah Thyroid Cohort Study; 4) the National Cancer Institute ^{131}I fallout study; and 5) the Feasibility Study on fallout exposures from NTS and global fallout being jointly conducted by the Centres for Disease Control and Prevention (CDC) and the National Cancer Institute (NCI). The first three studies were concerned with

doses received by "local" populations (less than 800 km from the NTS), while the fourth and the fifth studies deal with the estimation of doses received by populations across the continental United States. The fourth study is limited to the estimation of thyroid doses from ^{131}I while the fifth study, now in progress, includes all other important radionuclides present in fallout and all other organs and tissues. In the first four of these studies, uncertainty estimates were attached to the calculated doses.

2. SUMMARY OF STUDIES AND ESTIMATED DOSES

Testing of nuclear weapons in Nevada resulted in the release of fission and activation products to the atmosphere that were dispersed across the U.S. in the form of gases and fallout particles. About 6 PBq of ^{137}Cs was released from NTS tests; about one-third or 2 PBq was deposited in the U.S. The years of 1952, 1953, 1955, and 1957 were years of particularly large releases and depositions. The time-dependence of the ^{137}Cs deposition in the U.S. from the NTS is shown in Figure 1 and the geographic pattern of deposition is shown in Figure 2.

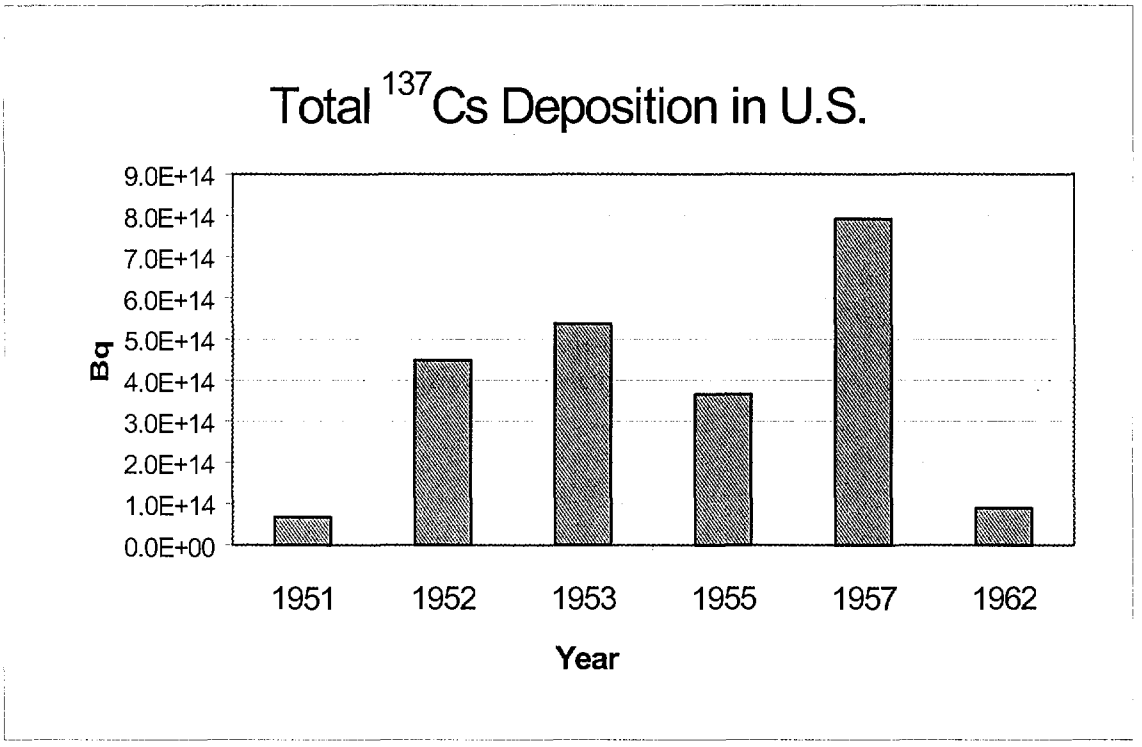

FIG 1. Total ^{137}Cs (Bq) deposited in the U.S. from NTS tests as a function of year of testing.

Information released by the U.S. Government about the release of ^{137}Cs, ^{131}I and other radionuclides has engendered public and Congressional interest in the effects of fallout on the health of Americans. The various efforts at dose reconstruction in the U.S. related to Nevada weapons testing have taken place, in part, as a result of such interest, though the studies described here fulfilled several different objectives. The five studies varied primarily according to the degree of methodological development and dose estimation for representative persons versus attention to estimating doses to real individuals in the population.

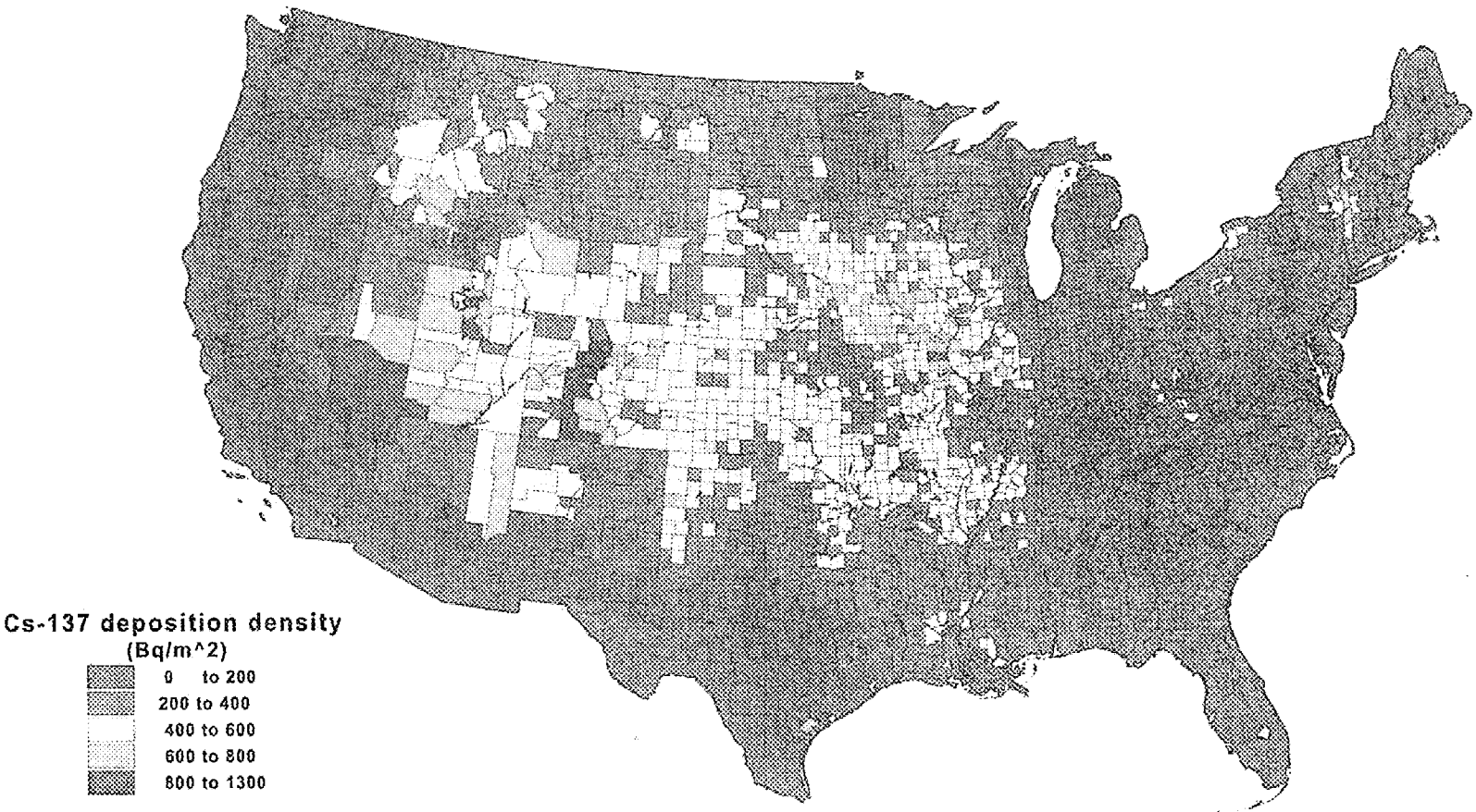

FIG. 2. Map of county estimates of ^{137}Cs deposition density (Bq/m^2) from all tests conducted at the Nevada Test Site.

3. THE ORERP STUDY

The Off-Site Radiation Exposure Review Project (ORERP) sponsored by the U.S. Department of Energy was the first major study to address the necessary methodology needed to estimate credible doses to the U.S. public from NTS fallout at a variety of locations. The project, established in the late 1970s, utilized expertise of scientists from a variety of organizations including government laboratories, government agencies, universities, etc. Considerable new methodology developed by the ORERP later contributed to the success of the other studies to be described. In particular, the ORERP developed tables of factors to convert exposure rates following deposition of fallout to relative amounts of all important fission and activation products (Hicks 1981). These detailed tables were calculated for each individual nuclear test.

In addition, the ORERP developed computer models to estimate both external and internal dose (Henderson and Smale 1990; Whicker and Kirchner 1987). The latter modelling effort was particularly innovative in that it described different lifestyle scenarios, different pathways of exposure, and incorporated parameter values for lifestyles, age-dependence, etc. The ORERP also developed databases of deposition densities at many locations in the western United States (Beck 1984).The ORERP computed a variety of different dose estimates, pertaining mainly to collective dose and for representative persons in the western states. The reader is referred to Anspaugh et al. (1986, 1990), Whicker et al. (1996), and to Bouville (1996). ORERP estimates of dose following test event HARRY are provided in Table 1 below. The location, St. George, UT, is downwind (east) of the NTS.

TABLE 1. ORERP STUDY: ESTIMATES OF INTERNAL AND EXTERNAL DOSES IN ST.GEORGE, UT FROM TEST EVENT HARRY (19 May 1953)

Organ/tissue	Infant dose (mGy)	Adult dose (mGy)
	Internal irradiation	
Thyroid	840	51
Lower large intestine	25	5.0
Upper large intestine	8.8	2.0
Bone surfaces	7.6	1.1
Total Body	1.1	0.48
	External irradiation	
Total Body	~10	~10

4. THE UNIVERSITY OF UTAH LEUKAEMIA CASE-CONTROL STUDY

The two studies, conducted by the University of Utah and funded by the U.S. National Cancer Institute, were also in response to public and Congressional interest. The Utah studies differed considerably from that of the ORERP, however, in that they were epidemiological investigations whose purposes were to test hypotheses posed by earlier investigators concerning possible health effects among residents of Utah.

The study of leukaemia among Utah residents used methods and data from the ORERP study as well as personal residence histories of all persons dying in Utah with leukaemia after 1 November 1958 and matched control subjects. Residence histories were obtained from records of the Church of Jesus Christ of Latter-day Saints and other sources. Because the tissue of interest was the active bone marrow, external irradiation by fallout was the primary contributor to the radiation exposure of the subjects. Previous investigations show that internal dose from fallout was only a small contribution. Methodology for the leukaemia study and estimated doses were discussed by Simon et al. (1995) and by Lloyd et al. (1990), and are summarized in Table 2 below. Results of the epidemiological analysis were reported in Stevens et al. (1990).

TABLE 2. UTAH CASE-CONTROL STUDY; SUMMARY OF ACTIVE BONE MARROW DOSES (MGY) FOR 6,507 SUBJECTS (Simon et al. 1995)

	CASES	**CONTROLS**	**OVERALL**
Mean	2.9	2.7	2.8
Median	3.2	3.1	3.2
Minimum	0	0	0
Maximum	26	29	29

5. THE UNIVERSITY OF UTAH THYROID COHORT STUDY

The Utah study of thyroid disease also used data and methodology for estimating deposition from the ORERP. However, independent methods for estimating individual doses and uncertainty were developed specifically for this study by the Utah investigators (see Simon et al. 1990). Doses were estimated for 3,545 subjects of which 3,122 were re-examined for evidence of thyroid disease, both benign and cancerous.

The dosimetry methodology accounted for all major pathways of exposure including external and internal irradiation (ingestion and inhalation). The primary source of ^{131}I to the study subjects was consumption of milk though fresh leafy vegetables were also included in the calculations. The source of milk (i.e., commercial or backyard cow) was important because of differences in feeding habits and in time delays between production and consumption. In addition, whether or not the subjects drank goat's milk was important because of the higher transfer factors from ground deposition to milk contamination for goats. Milk consumption rates for each study subject during the years of fallout deposition were determined from interviews with the parents of each subject.

Individual doses ranged from near zero to 4600 mGy. Average thyroid doses in the three counties where subjects lived at the time of exposure were 72 mGy (Washington County, Utah), 3.6 mGy (Graham County, Arizona) and 28 mGy (Lincoln County, Nevada) (see Table 3).

Doses to milk drinkers greatly exceeded those to subjects that did not drink milk. Similarly, consumers of goat's milk had higher predicted doses than those to subjects drinking only cow's milk (see Table 4).

A summary of the dosimetry findings for the Utah thyroid cohort study is presented in Till et al. (1995) and findings of the epidemiological analysis of the Utah thyroid cohort study are presented in Kerber et al.(1993) and in Stevens et al. (1992).

TABLE 3. UTAH THYROID COHORT STUDY: SUMMARY OF THYROID DOSES (mGy) FROM UTAH THYROID COHORT STUDY (Till et al. 1995)

	Washington County, Utah	Graham County, Arizona	Lincoln County, Nevada	Overall
Number of subjects	1896	1369	280	3545
Mean dose	170	13	50	98
Median dose	72	3.6	28	25
Minimum dose	0	0	0	0
Maximum dose	4600	450	840	4600
Mean GSD[a]	2.7	3.0	2.7	2.8

[a]Geometric Standard Deviation.

TABLE 4. COMPARISON OF THYROID DOSES (mGy) BETWEEN MILK DRINKERS AND NON-MILK DRINKERS (Till et al. 1995)

	Non-milk drinkers	Cow's and/or Goat's milk drinkers	Goat's milk drinkers
Number of subjects	120	3337	155
Mean dose	12	100	300
Median dose	0.5	30	39
Maximum dose	25	4600	4600

6. THE NATIONAL CANCER INSTITUTE ^{131}I FALLOUT STUDY

The study of the National Cancer Institute (NCI 1997) was the first study to estimate thyroid doses from NTS fallout to representative persons in all 3,000+ counties of the United States. The NCI study also used certain methodologies developed by the ORERP though the NCI study relied heavily on extensive review of deposition data and interpolation strategies of deposition information derived from the gummed film monitoring network of the Atomic Energy Commission's Health and Safety Laboratory in New York City (Beck et al. 1990). All major pathways of exposure were considered as well as a set of consumption and age-dependent scenarios (Bouville et al. 1990).

The collective thyroid dose to the population of the contiguous United States from all atmospheric bomb tests detonated at the Nevada Test Site was estimated to be about 4 x 10^6 person Gy, corresponding to a per capita thyroid dose of about 20 mGy. The greatest contributions to the collective thyroid dose are estimated to have been due to the Plumbbob test series in 1957, the Tumbler-Snapper test series in 1952, and the Upshot-Knothole test series in 1953. Thyroid doses to representative individuals were found to vary mainly according to age, origin and consumption rate of milk, as well as to place of residence at the time of the tests.

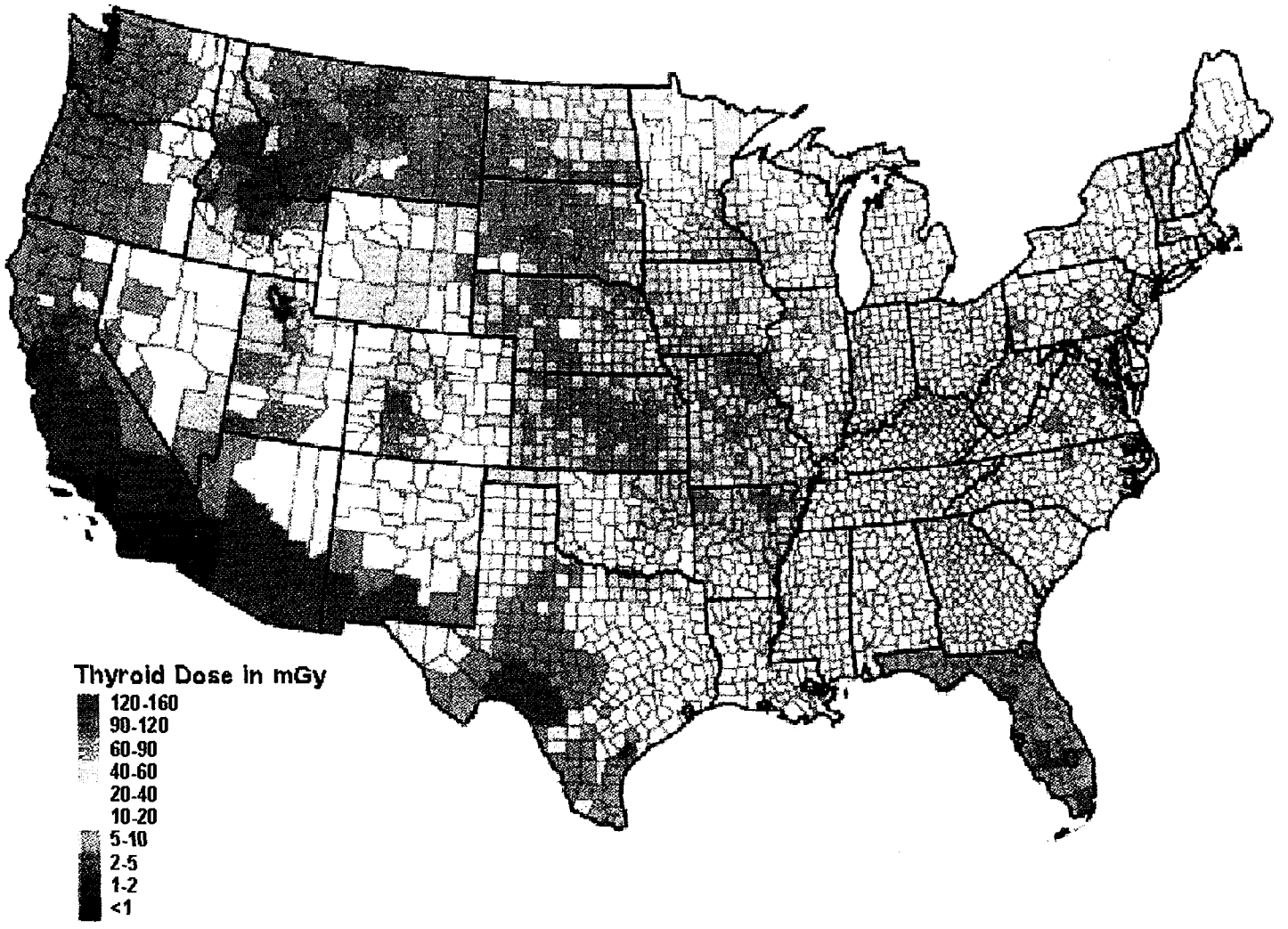

FIG. 3. Map of county estimates of thyroid dose (mGy) from ^{131}I released from all tests conducted at the Nevada Test Site, averaged over all age groups.

Interested readers are referred to the website of the National Cancer Institute (http://rex.nci.nih.gov/, see "About Radiation Fallout") for the entire report and a series of colour coded maps giving the results of the extensive calculations. Figure 3 presents a map showing the estimated thyroid dose received in each county averaged over all groups.

Because the risk of thyroid cancer following exposure to ^{131}I is not known with certainty, the expected number of excess cases had to be predicted based on what is known about childhood exposure to external radiation. The predicted number of lifetime excess thyroid cancer cases associated with the exposure from testing is dependent on the relative biological effectiveness of ^{131}I, the effects of gender and age at exposure on radiation risk, the risk coefficient, and the statistical model used. The 95% confidence limits on the predicted number of excess thyroid cancer cases resulting from NTS exposures have been estimated to be 11,300 and 212,000 (IOM and NRC 1999). It is estimated that over one-third of the predicted cases have already been diagnosed.

7. THE CDC/NCI FEASIBILITY STUDY ON ESTIMATING TOTAL DOSES FROM NTS FALLOUT

In October 1998, the United States Congress directed the Department of Health and Human Services to conduct a study of health consequences to the American people from radioactive fallout resulting from nuclear weapons tests conducted by the United States and other nations. Following this mandate, the Centres for Disease Control and Prevention (CDC) and the NCI collaborated to determine feasibility and to produce preliminary dose estimates.

The CDC/NCI feasibility study, now being completed, has crudely estimated doses resulting from the tests conducted at the NTS and considered, at least in a preliminary fashion, all important radionuclides and radiation exposures resulting from external irradiation and from consumption of contaminated foodstuffs. In this framework, preliminary doses to representative persons in all counties of the continental United States have been estimated for the first time for a set of the most important radionuclides produced as a result of nuclear weapons testing between 1951 and 1963 by the U.S. and other nations. Only preliminary doses resulting from NTS fallout are discussed here. They are provided for illustration purposes of the type of results obtained in the study, as the extensive report prepared by CDC and NCI is currently under scientific review. It is stressed that the numerical values of the dose estimates may change before the publication of the report.

Doses were calculated for 61 of the most significant events that occurred at the NTS during 1951, 1952, 1953, 1955, 1957, and 1957. Most of the radiation exposure from external irradiation was from gamma rays emitted by fission products deposited on the ground; the external dose was mainly due to short-lived radionuclides and occurred within the first 3 weeks after each test. On an annual basis, the time dependence of doses to the U.S. population followed the same basic time-pattern as the deposition of ^{137}Cs (see Figure 1 and Table 5). The total collective external dose was about 84,000 person-Gy corresponding to an average external dose from all NTS tests of about 0.5 mGy, equivalent to about one year of external radiation exposure from natural background. Residents in the states immediately downwind from the NTS received much higher exposures than the average while people in the western and north-western U.S. and some areas of the Midwest and of the Southeast received much less than the average. The actual dose received by any individual depended on the fraction of time he/she spent outdoors during the first few weeks after fallout 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.

Doses from internal irradiation were calculated to a variety of organs and tissues, in particular, red bone marrow and the thyroid. Table 6 summarizes the population-weighted dose to these tissues for those citizens who were adults at the time of fallout and for those were born 1 January, 1951, that is, just before the first tests that were conducted at the NTS.

Internal radiation doses were dominated by the thyroid dose, the most important contributor being ^{131}I. Other than the doses from ^{131}I to the thyroid, doses to other organs are much smaller and are less than the dose that was estimated to have resulted from external exposure to NTS fallout. This included liver, red bone marrow, colon, etc. The more important contributors to internal dose from NTS fallout, other than ^{131}I , were the short-lived radionuclides ^{89}Sr, and ^{140}Ba. The population weighted effective dose received by the U.S. population from ingestion was estimated to be about 0.3 mSv.

TABLE 5. COLLECTIVE EXTERNAL DOSE AND COUNTRY-AVERAGE DOSE FROM NTS FALLOUT AS A FUNCTION OF YEAR OF TESTING

YEAR	Test Series	Cumulative Collective Dose (10^3 Person-Gy)	Country-Average Dose (mGy)
1951	Ranger and Buster-Jangle	6.8	0.039
1952	Tumbler-Snapper	16	0.093
1953	Upshot-Knothole	20	0.12
1955	Teapot	13	0.072
1957	Plumbbob	23	0.12
1962	Storax	5.0	0.029
Total NTS		84	~0.5

TABLE 6. POPULATION-WEIGHTED RED MARROW AND THYROID DOSES FROM ALL NTS TESTS (MGY).

Population Subgroup	Organ Dose (mGy)	
	Red marrow	Thyroid
Child born in 1951	0.12	30
Adult in 1951	0.1	5

The preliminary results provided here establish that a reconstruction of external and internal (i.e., ingestion) doses from all important radionuclides NTS fallout is feasible.

CONCLUDING REMARKS

The five dose reconstruction studies described here have added considerable knowledge about the doses received by the U.S. public as a consequence of nuclear testing in Nevada. These dose estimates have enabled the health impacts to be estimated (e.g., for thyroid cancer) to a limited degree. There are, however, still gaps in knowledge with respect to estimating doses to the U.S. population from NTS fallout. These include lack of knowledge about fission neutron energy spectra and $^{137}Cs/Pu$ ratios as well as information about individual's habits and lifestyle. In addition, estimated doses could be improved by acquiring additional data to validate dose estimates. Validation data could take the form of deposition densities, concentrations of radionuclides (in particular ^{131}I) in food products or in thyroid glands. A higher resolution grid of historical precipitation data could be used to further improve the interpolations. Finally, dose estimates are yet to be completed for Hawaii and Alaska and for the territories. Correcting these various deficiencies in availability of data and completing the identified refinements in models remain as challenges within the immediate future.

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DISCUSSION AFTER THE PRESENTATION OF S.L. SIMON

E.D. STUKIN (Russian Federation): The Nevada test site and the Semipalatinsk test site are of roughly the same size, and there were other similarities (for example, the height of the towers at the top of which the nuclear-weapon-related devices were installed was about the same). However, the individual and collective doses due to the tests carried out at the Semipalatinsk test site are 20-25 times higher than those due to the tests carried out in Nevada, and those high doses have given rise to great concern among people living in the Altay region. To what do you attribute the higher doses resulting from the tests carried out at the Semipalatinsk test site?

S.L. SIMON (USA): The only explanation I can offer for the higher individual and collective doses is differences in living habits; people in the Altay region probably consume more locally produced food and milk than people living near the Nevada test site. However, I understood that there is some controversy about how high the individual and collective doses are near the Semipalatinsk test site, and in my view it is important to resolve that issue.

B.I. OGORODNIKOV (Russian Federation): When did the United States start taking meteorological conditions into account in order to reduce the doses from nuclear weapon test fallout?

S.L. SIMON (USA): I don't know whether there were ever any major efforts to reduce such doses. With the great importance attached to nuclear weapons development at the time, our Government did not acknowledge the resulting contamination-and restrictions on radiation measurements meant that it was a long time before the general public became aware of the contamination levels.