A FEASIBILITY STUDY OF THE HEALTH CONSEQUENCES TO THE AMERICAN POPULATION FROM NUCLEAR WEAPONS TESTS CONDUCTED BY THE UNITED STATES AND OTHER NATIONS

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Charles Miller, Ph.D.
Co-Principal Investigator
Radiation Studies Branch
National Center for Environmental Health
Centers for Disease Control & Prevention

Andre Bouville, Ph.D.
Co-Principal Investigator
Radiation Effects Branch
Division of Cancer Epidemiology and Genetics
National Cancer Institute

Inquiries and requests for copies should be directed to:

Charles Miller, PhD
Radiation Studies Branch
National Center for Environmental Health
Centers for Disease Control and Prevention
Mail Stop E39
1600 Clifton Road NE
Atlanta, GA 30333

List of Contributors

Centers for Disease Control and Prevention

Paul Garbe
Charles W. Miller
Joan Morrissey
Claudia Parvanta
Judy Qualters
J. Felix Rogers
James M. Smith
Diana Swindel
Robert C. Whitcomb, Jr.
Charles M. Wood

National Cancer Institute

Andre Bouville
Clare Collins
Betsy Duane
Ethel Gilbert
Charles Land
Anne Lubenow
Nick Luckyanov
Kiyohiko Mabuchi
Elane Ron
Susan Sieber
Steven L. Simon
Bob Weinstock

Consultants

Lynn Anspaugh
Harold Beck

Abstract

For the first time, preliminary doses to representative persons in all counties of the contiguous United States have been estimated for a set of important radionuclides produced as a result of nuclear weapons testing from 1951 through 1962 by the United States and other nations. This project demonstrates that it is feasible to conduct a more detailed study of the health impact on American people as a result of exposure to radioactive fallout from the testing of nuclear weapons in the United States and abroad. However, significant resources would be required to implement this project, and careful consideration should be given to public health priorities before embarking on this path. To assist in the process of making a decision about future fallout-related work, five different options have been developed for consideration:

1. No additional fallout-related work;
2. Retrieve and archive the historic documentation related to radioactive fallout from nuclear weapons testing conducted by the United States and other nations;
3. Conduct a more detailed dose reconstruction of radioactive fallout from global nuclear weapons testing for Iodine-131, the most significant radionuclide identified in this study;
4. Conduct a more detailed dose reconstruction for multiple radionuclides in radioactive fallout from both Nevada Test Site and global nuclear weapons testing;
5. Conduct a detailed study of the health effects of nuclear weapons testing fallout including, in a single project, dose estimation, risk analysis, and communication of the results to interested parties.

Detailed estimates of the resources needed to complete each option considered have not been developed. However, the actual cost of some past projects is presented in the report for purposes of illustration only. This draft Technical Report is being peer reviewed by the National Academy of Sciences' Committee on Assessment of Centers for Disease Control and Prevention's Radiation Studies. The Department of Health and Human Services will not make any formal recommendations concerning future fallout-related work until this peer review is complete.

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Executive Summary

Introduction

In 1998, Congress requested that the Department of Health and Human Services (DHHS) conduct an initial assessment of the feasibility and public health implications of a detailed study of the health impact on the American people of radioactive fallout from the testing of nuclear weapons. In response to that request, DHHS has estimated preliminary doses and health risks from exposure to radioactive fallout from nuclear weapons tests conducted from 1951 through 1962 at the Nevada Test Site (NTS), as well as at other sites throughout the world ("global" tests).

In developing this assessment, DHHS has actively solicited input from the public and from its Advisory Committee for Energy-Related Epidemiologic Research (ACERER). Both written and oral progress reports have been given to ACERER and Congressional staff during the course of the project. Copies of written progress reports were available for public review, and all written and oral comments received on these progress reports were carefully considered in the preparation of the Technical Report.

This draft Technical Report will be peer reviewed by the National Academy of Sciences' Committee on Assessment of CDC Radiation Studies. A report from that committee is expected six to nine months after initiation of the committee's deliberations. In addition, this draft Technical Report is available for public review on the Internet at http://www.cdc.gov/nceh/radiation/default.htm. A printed copy of the draft is also available from the Radiation Studies Branch, Division of Environmental Hazards and Health Effects, National Center for Environmental Health, Centers for Disease Control and Prevention (CDC), Mail Stop E39, 1600 Clifton Road NE, Atlanta, Georgia 30333.

All comments received will be carefully considered in the preparation of the final version of the Technical Report. No formal recommendations concerning future fallout-related work will be provided until peer review of the draft Technical Report for this feasibility project is complete.

Preliminary Results

Radiation Dose Estimates. In this project, for the first time, preliminary dose estimates for representative persons in all counties of the contiguous United States have been estimated for the most important radionuclides produced as a result of nuclear weapons testing from 1951 through 1962 by the United States and other nations. Any person living in the contiguous United States since 1951 was exposed to radioactive fallout, and all organs and tissues of the body received some radiation exposure. Doses were estimated separately for the tests conducted at the NTS and for the tests conducted at other sites throughout the world (global testing).

Lifetime dose estimates were calculated separately for external and for internal irradiation. External irradiation results from exposure to radiation emitted outside of the body, for example by radionuclides present on the ground; the corresponding doses are similar in most body organs. In this feasibility study, two approximations were made: 1) the external doses to the red bone marrow and the thyroid gland are equal, and 2) the external dose does not depend on age. On the other hand, internal irradiation results from the decay of radionuclides incorporated into the body by inhalation or ingestion, with levels of exposure varying according to the distribution of radionuclides in the organs and tissues of the body; for example, radioiodines concentrate in the thyroid gland, whereas radiostrontium is mainly found in bone tissues.

Because the purpose of the project was only to determine feasibility, there was no intention in the required timeframe to develop new tools or to gather all data needed to complete an extensive study of doses to Americans from nuclear weapons tests conducted by the United States and other nations. Instead, preliminary doses have been calculated based on a detailed review of a limited number of reports and using available dose assessment models. In some cases – particularly for the doses resulting from the intake of shorter-lived radionuclides (e.g., Iodine-131) in global fallout – the doses calculated may have considerable error. Future work would improve the precision of these calculations.

The usefulness of the doses estimated in this project is limited to rudimentary evaluations of the average impact on limited health outcomes for the population of the United States. Because of the low precision of the estimates, these doses should not be used to estimate health effects for specific individuals or for subpopulations. The goal of these calculations was to determine feasibility only, and, therefore, the magnitude of uncertainty of these doses has not always been evaluated. Although the computed county-specific deposition densities and doses are uncertain, dose maps which are presented in this report are useful to illustrate general spatial patterns of fallout exposure for average individuals across the United States.

As examples of results from this study, a summary of doses averaged over the contiguous United States is presented in Table 1. Because the thyroid and red bone marrow

Table 1. Summary of average thyroid and red bone marrow doses (milliGray [mGy]) from NTS and global fallout received as a result of exposure to the most important radionuclides. The values are for adults at the time of the tests, unless otherwise specified. Blank spaces reflect negligible values of dose.

		NTS Fallout			Global Fallout		
Radionuclide	Half-life	External Dose [a] (mGy)	Thyroid Internal Dose (mGy)	Red Bone Marrow Internal Dose (mGy)	External Dose [a] (mGy)	Thyroid Internal Dose (mGy)	Red Bone Marrow Internal Dose (mGy)
Tritium	12.3 y					0.07	0.07
Carbon-14	5730 y					0.1	0.1
Manganese-54	313 d				0.04		
Strontium-89	52 d		0.001	0.03			
Strontium-90	28.5 y			0.02		0.0009 [0.002][b]	0.2 [0.5][b]
Zirconium/Niobium-95	64 d	0.08			0.2		
Zirconium/Niobium-97	17 h	0.02					
Ruthenium-103	39 d	0.03			0.02		
Ruthenium-106	368 d		0.001	0.002	0.04		
Antimony-125	2.7 y				0.03		
Iodine-131	8 d	0.02	5 [30][b]	0.001		0.4 [2][b]	0.00009 [0.0002][b]
Tellurium/Iodine-132	3.3 d	0.1	0.06	0.001			
Iodine-133	0.9 d	0.02	0.04				
Cesium-136	13 d		0.002	0.002			
Cesium-137	30 y	0.01	0.009	0.009	0.3	0.1	0.1
Barium/Lanthanum-140	13 d	0.2		0.006	0.05		
Cerium-144	284 d				0.02		
Neptunium-239	2.4 d	0.02					
Rounded totals:							
- Adults;		0.5	5	0.1	0.7	0.7	0.6
- Child born 1 January 1951.			[30][b]			[2][b]	[0.9][b]

[a] The external dose is equal for all organs of the body.

[b] Values in brackets are for a child born 1 January 1951

are among the most radiosensitive organs and tissues of the body, their doses were selected as examples for presentation (Table 1). Thyroid cancer, noncancer thyroid disease, and leukemia, which arises from the red bone marrow, are health effects that would be studied if a more detailed evaluation is conducted.

As shown in Table 1, the estimated average total internal doses from global fallout are considerably smaller for the thyroid but greater for the red bone marrow than those from NTS fallout, whereas the doses from external irradiation are similar for NTS and for global fallout. Additionally, as illustrated in Table 1, the mixture of radionuclides contained in fallout is different for the two sources of fallout. As a result of these differences, the temporal and geographic distributions of doses from NTS and from global fallout differ substantially. For the nuclear weapons tests conducted at the NTS, fallout occurred predominantly in the western states surrounding the NTS; the short-lived radionuclides, identified by a short half-life (column 2 in Table 1), were key components of the NTS fallout and the highest doses to Americans were due to Iodine-131. In contrast, global fallout exposures were higher in areas with high precipitation rates, such as the eastern states; the long-lived radionuclides, such as Cesium-137 and Strontium-90, were in much greater abundance in global fallout than in NTS fallout.

Risk Assessment. The relation between the dose from radioactive materials and the risk of disease in a population may be described by models that express health risk as a function of dose and factors that modify risk such as age at exposure and gender. Because some of the components of these models are uncertain, estimates of risk are uncertain. Any evaluation of risk depends on the development of more refined dose estimates that take into account their uncertainty. To the extent that reliable dose estimates can be provided, it is feasible to estimate the lifetime risks of developing organ-specific cancer associated with fallout exposures for populations or population subgroups. It is also feasible, but difficult, to quantify the very large uncertainties in these risk estimates.

Some estimates of the average risk to the United States population for the categories all cancers, leukemia, and thyroid cancer have been developed using the preliminary doses estimated in this feasibility study. With the exception of thyroid cancer, the examples were developed using simple approaches, and are given for illustration only. These risks are used to illustrate the feasibility of a more detailed study, and to provide a preliminary estimate of the potential impact of fallout radiation on the American population.

The National Cancer Institute has previously conducted a detailed reconstruction of doses to the thyroid gland for Iodine-131 from tests in Nevada (NCI 1997). These doses were subsequently used to estimate that between 11,300 and 212,000 (median value = 49,000) thyroid cancers would be expected to occur among the United States population from exposure to Iodine-131 from the NTS (IOM 1999). The wide range in the number of thyroid cancers predicted (11,300 - 212,000) illustrates the large uncertainty that such estimates carry. Consideration of global fallout would likely increase these estimates by about 10%. However, the global dose estimates have a larger degree of uncertainty and, therefore, the range of the number of predicted cancers would become relatively larger. This example for thyroid cancer illustrates the possibility of estimating risks with their inherent uncertainties.

The average external dose from all radionuclides over the period 1951-2000 from both NTS and global fallout is estimated to be about 1.2 mGy (Table 1). It is estimated that about 11,000 extra cancer deaths from all cancers, including leukemia, would be predicted to occur among the population of the United States alive at any time during the years 1951-2000 as a result of external exposure to fallout. (The predicted number of incident cases [including non-fatal cases] would be about double the number of deaths or about 22,000) More information on deaths from cancer can also be estimated for persons born in different years. For example, the 3.8 million people born in the United States in 1951 will likely experience less than 1,000 extra fatal cancers as a result of fallout exposures in contrast to the approximately 760,000 fatal cancers that would be predicted in the absence of fallout. It is expected that the largest number of excess cancer deaths would occur in that group of persons born in 1951, because, on average, this group received higher doses at younger ages than groups born earlier or later. Also, radiation doses from external exposure are more uniform over geographic areas and do not substantially vary according to age or lifestyle habits. Thus, cancer risks for all cancers from external exposure are likely to vary less by geographic location, birth cohort and other factors than are risks of thyroid cancer from NTS Iodine-131 exposure. This lack of obviously high exposure areas or populations makes it more difficult to identify groups with particularly large risks.

Leukemia is perhaps of special interest because it has been strongly linked with radiation in many epidemiological studies and because bone-seeking radionuclides, such as Strontium-90, are found in fallout. About 10% or 1,100 of the 11,000 cancer deaths from external exposure may be predicted to be from leukemia. It is estimated that an additional 550 cases of leukemia may occur among the population of the United States who were alive at any time during the years 1951-2000 as a result of internal exposure to the red bone marrow from fallout radionuclides. For the approximately 3.8 million persons born in 1951, it is estimated that 17 excess cases of fallout-related leukemia will occur in this group (a risk of 1 in 220,000) from internal exposure.

Based on the preliminary estimates of dose and risk developed in this feasibility study, fallout radiation appears to have the greatest impact on risks of thyroid tumors. Risks of leukemia would be lower. Cancers of other organs or tissues could be assessed as well, but due to the smaller amount of information available about radiation-associated health effects and the lower doses for most organs, the uncertainties associated with these estimates would be extremely large.

Characterization of the cancer risk to the American people could be enhanced through improvements in methodology (for example, better quantification of uncertainties in models for expressing risks for specific cancers, identification of potentially highly exposed populations, and characterization of lifestyle and other behavioral factors that could affect the potential for exposure and for risk). However, even with these improvements, risk estimates that are developed for fallout exposures will remain highly uncertain. In addition, such estimates represent the average risk to members of a population group who share common characteristics such as age, place of residence, and dietary factors. The true risk to individuals in the United States may vary substantially from the average for many reasons, e.g., a difference in their dose from the predicted value, their lifestyle patterns, other environmental exposures, their individual susceptibility to radiation effects, and the random nature of the predicted risk. Hence, although it should be possible to give individuals an indication of whether their geographic location, age, or lifestyle during the years of nuclear testing have increased the likelihood of their developing certain radiation-related cancers, accurately determining the risk for specific individuals is not possible.

With regard to noncancer health outcomes, a quantitative risk analysis is not feasible in the near term. For most noncancer outcomes, more fundamental research is needed to quantify the relation between low, protracted radiation dose and disease and/or the uncertainty associated with the estimated risk. However, among these noncancer physical health outcomes, diseases of the thyroid gland have the greatest potential for occurrence.

Development of a Health Communication Strategy. One of the most important public health implications of performing a detailed dosimetric and risk analysis study is the need to clearly communicate the results of the study to the American public and health-care providers. The results obtained during the feasibility study are too preliminary to adequately warrant developing a plan for comprehensive nationwide education. The effort to communicate the results from the research carried out in a more detailed study would be extremely challenging. However, it is especially important to carefully explain the potential health consequences associated with exposure to numerous radionuclides in fallout, the limitations of what science can provide (in particular, the uncertainty in estimates of dose and risk), and information regarding possible implications.

Any education and public awareness plan would need to focus on communication and education for the general public and for health-care providers. It would be important to include right-to-know issues and educate the American public about estimates of fallout exposures and risk factors for diseases related to radiation, so that people could determine their probable risk category and decide what health steps are necessary on the basis of that information. It would be equally important that a component be directed toward physicians and other health-care providers so they can serve as a source of information to the public and can help with the decision-making process of the patients.

A communication plan as described would require significant resources in funding and personnel. While communication is an integral part of a more detailed study, the scope and design of any plans would need to carefully balance the desires of stakeholders with the public health priority of fallout exposures. For example, the American public could receive information on the potential health consequences from nuclear test fallout in a phased approach, drawing on the efforts under way by the National Cancer Institute for the Iodine-131/Nevada Test Site Communications Project. If that model proves effective, it could be used by Federal agencies and non-Federal groups to communicate information regarding dose estimates and health risks from other exposures from the NTS and global testing as they are developed.

Options for Future Work

The preliminary findings of this feasibility study suggest that the health risks from exposure to fallout from past nuclear weapons tests may be small, but this study also demonstrates that conducting a detailed study of the health impact on American people as a result of exposure to radioactive fallout from the testing of nuclear weapons in the United States and abroad is technically possible. However, significant resources would be required to implement this detailed study, and careful consideration should be given to public health priorities before embarking on this path.

To assist in the process of making a decision about future fallout-related work, five different options have been developed for consideration. Detailed estimates of the resources needed to complete each option considered have not been developed. However, the actual cost of some past projects is presented for purposes of illustration only.

Option 1. No additional fallout-related work.

The dose and risk estimates presented in this report are preliminary in nature. Estimates of uncertainty have not been quantified for many of these estimates, they are subject to a variety of errors, and they are incomplete. Nevertheless, the dose and risk estimates presented here may be sufficient for making decisions on appropriate public health follow up.

Option 2. Retrieve and archive the historic documentation related to radioactive fallout from nuclear weapons testing conducted by the United States and other nations.

Although a large number of summary reports related to nuclear weapons fallout have been published, many of the primary documents upon which these summary reports are based will be lost forever if they are not protected soon. Hence, documents could be collected and protected immediately. The National Center for Environmental Health of the Centers for Disease Control and Prevention (CDC) has been actively involved in document retrieval and document data base development since 1992. Document location, retrieval, and data base development have cost \$3-5 million and taken 2-4 years to complete at each of three nuclear weapons research and development sites where CDC has worked.

Option 3. Conduct a more detailed dose reconstruction of radioactive fallout from global nuclear weapons testing for Iodine-131, the most significant radionuclide identified in this study.

As noted earlier, these preliminary dose and risk analyses indicate that fallout radiation has the greatest impact on risks of thyroid tumors. The National Cancer Institute has previously completed a detailed dose reconstruction and basic risk analysis for Iodine-131 fallout received from the Nevada Test Site (NCI 1997; IOM 1999). This project cost approximately $3 million and took many years to complete. Follow up activities include development of an Internet site where individuals may obtain an estimate of their individual dose, and implementation of a communications project to inform people in the United States about the results of this study and its potential public health implications.

Consideration of global fallout would likely increase the dose and risk estimates previously developed for Iodine-131 from NTS fallout by about 10%. Therefore, it might be desirable to perform a detailed dose reconstruction and basic risk analysis for Iodine-131 in global fallout, and incorporate that information into the existing NCI Internet site and communications plan. This effort should also include collecting and protecting primary documents related to nuclear weapons testing (Option 2).

Option 4. Conduct a more detailed dose reconstruction for multiple radionuclides in radioactive fallout from both Nevada Test Site and global nuclear weapons testing.

The work that has now been completed demonstrates that conducting a more detailed study of the health impact on American people of exposure to radioactive fallout from the testing of nuclear weapons in the United States and abroad is technically possible. There are numerous possible subject areas that can be researched for the purpose of improving the preliminary dose estimates provided in this report and to provide a more complete historical record of the nature of the releases from the weapons testing and the resulting exposures received by Americans from NTS and global fallout.

It might be desirable to expand on Option 3, above, and perform a detailed dose reconstruction and basic risk analysis not only for Iodine-131 in global fallout but also for other radionuclides found in both NTS and global fallout. The results of this dose reconstruction and risk analysis could then be incorporated into the existing NCI Internet site and communications plan. This effort should also include collecting and protecting primary documents related to nuclear weapons testing (Option 2).

The cost and staffing requirements for implementing Option 4 would depend on the level of detail desired beyond that presented in the Report. For example, CDC's National Center for Environmental Health has been involved in a comprehensive dose reconstruction for the Department of Energy's nuclear weapons production site at Hanford, Washington, since 1992. This project involves portions of the States of Washington, Oregon, and Idaho, and it includes nine Native American nations. The Hanford project has cost approximately $30 million to date. Option 4 would, of course, involve 50 States and it could include numerous population subgroups.

Option 5. Conduct a detailed study of the health effects of nuclear weapons testing fallout including, in a single project, dose estimation, risk analysis, and communication of the results to interested parties.

This option differs from Option 4 primarily in the type of communication campaign and in the level of risk characterization that would be undertaken. Option 4 proposes to utilize existing communication planning being undertaken by the National Cancer Institute (NCI). This option would expand NCI's effort to develop a nationwide communications campaign.

Costs and staffing requirements for communications efforts are dependent on the results of the dose reconstruction and the risk assessment work and what public health implications are learned through that research. However, other issues will also need to be considered. For example, even if results from the dose reconstruction and risk analysis do not provide a risk-based rationale for conducting a large-scale, nationwide communications campaign, public right-to-know and social justice issues may affect the scale and reach of the campaign. CDC and NCI's diethylstilbestrol (DES) National Education Campaign (a smaller scale national campaign specific to individuals exposed to DES in utero and their health care providers) is estimated to cost \$3 - \$5 million for the planning phase alone. Funding and resource needs for the implementation phase for the DES campaign are expected to increase exponentially during the implementation and distribution phase. In another example, in the late 1980's CDC mailed information on Acquired Immune Deficiency Syndrome (AIDS) to every household in the United States. This mailing cost over \$30 million.

Also, there are many issues that have been raised in this feasibility study that transcend the mandate of DHHS. For example, the Department of Energy is responsible for maintaining many of the environmental monitoring records that are needed for a detailed study, and the Department of Defense may need to grant access to classified records required for improving some of the dose estimates. If additional research is directed, we recommend that a trans-Federal advisory committee be established to provide advice on the conduct of future activities. Such a committee should be composed of independent scientists familiar with technical aspects of the proposed activities and representatives from appropriate Federal agencies, State public health agencies, and public stakeholder groups.

For the past 8 years, CDC's National Center for Environmental Health has been actively working with committees chartered in accordance with the Federal Advisory Committee Act, including ACERER. The annual cost of each of these advisory committees is approximately $500,000. In addition, the equivalent of two full-time professional staff and one or two support staff are required to support the activities of each advisory committee.

Conclusions

The preliminary findings of this feasibility study suggest that the health risks from exposure to fallout from past nuclear weapons tests may be small, but this study also demonstrates that conducting a detailed study of the health impact on American people as a result of exposure to radioactive fallout from the testing of nuclear weapons in the United States and abroad is technically possible. This draft Technical Report is being peer reviewed by the National Academy of Sciences' Committee on Assessment of CDC Radiation Studies. All comments received will be carefully considered in the preparation of the final version of the Technical Report. No formal recommendations concerning future fallout-related work will be provided until peer review of the draft Technical Report for this feasibility project is complete.

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Chapter 1

Introduction

Contents: *This chapter provides an introduction to the full report. It includes a discussion of why this project was undertaken, what is included in the project, and what is beyond the scope of this effort. The organization of this report is briefly described.*

1.1 Background

In 1998, Congress provided funding for the Department of Health and Human Services (DHHS) to study the health impact on American peoples of radioactive fallout. More specifically, the Committee on Appropriations of the United States Senate reported the following (U.S. Senate 1998):

> "The Committee has allocated $1,850,000 with the emergency fund for a study of the health consequences to the American population of nuclear weapons tests conducted by the United States and other nations. The Committee expects the Centers for Disease Control and Prevention to be the lead agency on the study, with the support of the National Cancer Institute. The Department should conduct an initial assessment of the feasibility and public health implications of such a study. The assessment ought to address major issues such as: radiation dose estimation and risk assessment, appropriate epidemiologic investigations, and health communication strategies for promoting better understanding of the research by the general public. In developing the assessment, design, and conduct of the study, the Department is expected to include input from the public and the Advisory Committee on Energy-Related Epidemiologic Research. In conducting the study, the Department ought to give high priority to examining the health consequences of exposure among both the general and high-risk populations to the full range of radionuclides produced by a nuclear weapons test. The Committee expects to be informed of the study's progress on a regular basis and expects to receive a final report by July 1, 2000."

This action by Congress followed the release of the National Cancer Institute's (NCI) report *Estimated Exposures and Thyroid Doses Received by the American People from Iodine-131 in Fallout Following Nevada Atmospheric Nuclear Bomb Tests* (NCI 1997). This report provided county-level estimates of the potential radiation doses to the thyroid for American citizens resulting from atmospheric nuclear weapons testing at the Nevada Test Site (NTS) in the 1950s and 1960s. A summary of the NCI report is presented in Appendix A. DHHS' Advisory Committee for Energy-Related Epidemiologic Research (ACERER) subsequently recommended that DHHS "(c)omplete a comprehensive dose reconstruction project for NTS fallout" (ACERER 1998). In a review of the NCI report performed at the request of DHHS, the Institute of Medicine (IOM) concluded that additional research to estimate the total radiation exposure resulting from the deposition of all radionuclides released as a result of nuclear weapons testing would be of limited public health value (IOM 1999). The IOM acknowledged, however, that the public might desire such an effort to obtain a more complete accounting of the potential health impact of nuclear weapons testing on American populations.

This report presents the technical results of an initial assessment of the feasibility and public health implications of a detailed study of the health consequences of nuclear weapons testing. In developing all aspects of the study, the Centers for Disease Control and Prevention (CDC) and NCI have actively solicited input from the public and from ACERER. Both written and oral progress reports were made to ACERER and Congressional staff members during the course of the project. Copies of the written progress reports were available for public review, and written and oral comments were received. Appendix B includes a summary of some of these activities.

1.2 Scope of work

1.2.1 Feasibility study

CDC and NCI were not asked to complete an extensive study of the health consequences to American peoples of nuclear weapons tests conducted by the United States and other nations but rather to assess feasibility only. Hence, instead of developing new tools or gathering all possible data and information that is necessary to perform an extensive, detailed study of this type, a review of previous studies supplemented with extensive, but preliminary, calculations was used to evaluate the feasibility of a detailed study. The information that is readily available on the doses from radioactive fallout from nuclear weapons tests includes: (1) the NCI (1997) report related to the thyroid doses from ^{131}I produced by atmospheric nuclear weapons tests conducted at the NTS; (2) several publications related to the estimation of doses received by the populations who lived in proximity of the NTS (e.g., Church et al. 1990); and (3) miscellaneous pieces of information related to global fallout due mainly to atmospheric nuclear weapons tests conducted on islands in the Pacific Ocean and in the former Union of Soviet Socialist Republics (U.S.S.R.). The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) has analyzed some of this information in order to derive average doses over the northern and southern hemispheres (e.g., UNSCEAR 2000).

In this feasibility report, preliminary estimates are provided of the radiation doses received by American peoples in the contiguous 48 States as a result of the atmospheric nuclear weapons tests conducted by the United States, the former U.S.S.R., and the United Kingdom (U.K.). Only above ground nuclear weapons tests conducted from 1951 through 1962 are considered in this report. Atmospheric nuclear explosions conducted by France, and China, as well as underground nuclear explosions from any nation, are not considered in this feasibility report, as it is generally acknowledged that the most important contributions to the radiation exposures arose from atmospheric nuclear tests conducted by the United States, U.K., and the former U.S.S.R during the pre-1962 time period. For example, the tests considered in this report that were conducted at the NTS account for over 95% of the total ^{131}I produced during the entire testing period at the NTS (NCI 1997).

Doses due to external exposure from radionuclides deposited on the ground and internal exposures from ingestion of contaminated foods are estimated for each county of the contiguous States for the most sensitive organs and tissues. These dose estimates are based on an initial review of the open literature, and they are not derived from sophisticated computer programs that could be designed for that purpose. They are, however, a significant extension of previously reported dose estimates, especially for fallout from non-NTS 'global' sources. Ingestion dose estimates are provided for 19 different radionuclides for fallout from NTS. Based upon the screening calculations performed for previous fallout studies, these radionuclides account for at least 95% of the dose through ingestion of contaminated foods to each organ (Ng et al. 1990). Two additional radionuclides, ^{3}H and ^{14}C, are considered for global fallout. Doses due to inhalation of radionuclides were not considered in this initial feasibility report, but they have generally been found to be much smaller than those due to ingestion.

The preliminary doses that are presented for NTS and global fallout are significantly different with regard to their precision and reliability. Doses from NTS are based on a large database and a significant amount of previous work in the area of dose estimation. Preliminary estimates of the uncertainty associated with these dose estimates are provided.

Estimates of doses from global fallout, however, are based on a much more limited database and on previous dose estimates that have been averaged over large geographic areas. The dose estimates presented here for any particular county are probably quite imprecise, and the exposure rate probably varied significantly from place to place within a county. Not enough data were available to allow for the quantification of the uncertainty associated with the doses from global fallout.

In addition to providing preliminary estimates of dose, this report also addresses the feasibility of utilizing these doses and other information in a risk analysis to characterize the effects of global fallout on the health of people in the United States. As a preliminary example to demonstrate the feasibility of estimating lifetime cancer risk due to exposure to radioactive fallout, estimates of the average lifetime risk of developing all cancers, leukemia, and thyroid cancer are presented for the United States population. This report also presents a brief review of ongoing epidemiologic studies being conducted in the United States and elsewhere. Finally, the report provides the outline of the strategy and issues that could be considered if a health communication plan is developed for promoting maximum understanding of the research by affected citizens if a detailed study is ever undertaken.

1.2.2 Public health implications

An important aspect of this project is consideration of the public health implications of a detailed study. CDC and NCI acknowledge that some people desire that the most detailed dose and risk assessment possible be done so they will know more about their radiation exposure from nuclear weapons fallout. Also, additional studies may contribute to our scientific knowledge of the health effects of ionizing radiation. The question that should also be addressed is whether or not an appropriate public health intervention will result from performing such studies. The answer to that question is complex and must be evaluated in terms of public interest, the Government's commitment to closure of 'fallout' related issues, and the severity of the risk from fallout compared to other hazards in today's environment which might be remedied by use of the same funding.

Also, CDC and NCI generally understands public health as "(t)he science and art of preventing disease, prolonging life, and promoting health through organized efforts of society" (Acheson Report 1988). Dose and risk analyses can help in the identification of the likelihood of diseases that in turn can potentially be treated or prevented. The very preliminary results presented in this report suggest that science is unlikely to provide a public health impetus for conducting more detailed fallout-related studies. However, given the history of secrecy associated with the development and testing of nuclear weapons and documented and intentional radioactive releases as well as human radiation experiments, the Federal Government must be sensitive to the views of some Americans about the United States, global weapons programs, and the Government's responsibilities. This legacy of mistrust has developed over the past half-century, and it presents a formidable social and political context within which to perform studies and communicate results. Resolution of these issues will require assistance from agencies other than CDC and NCI.

1.3 Issues outside the scope of this report

One issue related to examining the health consequences resulting from nuclear weapons tests is that of medical screening of individuals for potential radiogenic diseases. In their review of the NCI report on NTS thyroid doses, the IOM recommended against a program to systematically screen either the American population in general or any population subgroup for thyroid cancer (IOM 1999). However, ACERER has recommended that DHHS "(f)urther evaluate screening opportunities for thyroid cancer…[and] to evaluate the advisability and feasibility of screening for other (noncancerous) thyroid and parathyroid diseases, with a priority to evaluate this service for those at highest risk due to their exposures" (ACERER 1998). CDC and NCI are continuing dialogue with stakeholders on the issue of thyroid screening. As a result of any future work related to studying the potential public health impact on American populations of nuclear weapons testing, there may be other potentially radiogenic diseases where discussion of screening is appropriate.

American people living around nuclear weapons development and production sites may have been exposed to radionuclides released from these sites as well as to radionuclides in weapons testing fallout. Extensive dose reconstruction and risk assessment activities have been completed for some of these sites, e.g. the former Feed Materials Production Center near Fernald, Ohio, and similar activities are underway at other sites, e.g. the Savannah River Site near Aiken, South Carolina. There are still other sites where no such activities are underway or planned for the future, e.g. the Gaseous Diffusion Plant at Portsmouth, Ohio. Another group for which attempts have been made to reconstruct doses is military personnel exposed during nuclear weapons tests (NRC 1985). Some stakeholders have suggested that a method should be developed to add up doses from these multiple exposures for affected individuals. A discussion of the technical and communication issues associated with such a program of adding doses is beyond the scope of this report.

The doses estimated in this report that arise from the ingestion of contaminated food depend greatly on the values chosen for the amount of different foods that are eaten by people. The values of food intake used in this preliminary feasibility report are based on averages developed for a previous assessment of NTS doses (Breshears et al. 1989). These values may not be appropriate for all people in the United States, including members of Native American tribes. A more detailed breakdown of food consumption, however, is beyond the scope of this project.

1.4 Organization of this report

This feasibility report continues with discussion of how, when, and where radionuclide fallout was created during the testing of nuclear weapons in the atmosphere (Chapter 2). Preliminary county-level dose estimates are provided for people living in the 48 contiguous States for a number of radionuclides of potential biologic significance from both NTS and global fallout (Chapter 3). Next, a brief literature overview of the potential effects of radiation on the health of people is presented, including a discussion of epidemiologic investigations (Chapter 4). In this same chapter, preliminary dose estimates are used to perform a preliminary estimate of the average risk to the American population of developing all cancers, leukemia, and thyroid cancer from fallout to demonstrate the feasibility of estimating risk for selected health outcomes. Next, a discussion of the issues that must be addressed if a plan is to be developed to communicate the results of a detailed study to the American public is presented (Chapter 5). Finally, the overall results of this study are summarized and options that might be considered for further activities are presented (Chapter 6). Many technical terms are used in the body of this report. These terms are defined when they are first used. To assist the reader further, a Glossary of terms (italicized throughout this report) is provided following Chapter 6. A number of appendices provide additional technical details for some of the material presented in the main body of the report.

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Chapter 2

Fallout from Nuclear Weapons

***Contents:** This chapter provides an overview of fallout production mechanisms and a brief review of the history of worldwide nuclear weapons tests.*

2.1 Fallout Production Mechanisms

The explosion of a nuclear weapon releases energy by two processes -- fission and fusion. Fission releases energy by splitting uranium or plutonium atoms into two or more smaller atoms. In fusion a fission bomb forces the combination of tritium or deuterium atoms into larger atoms, producing a more powerful explosion. The explosive energy is expressed in kilotons (kt) or Megatons (Mt) of TNT equivalent. The explosion creates three types of radioactive debris (fallout): fission products, activation products, and fissionable material used in the construction of the bomb that did not fission during the explosion process.

2.1.1 Fission Products

The fission of 52 grams of plutonium will split 10^{23} plutonium atoms and release one kiloton of energy. Every fission creates an average of two radioactive fission fragments and the radionuclide identity of each of these fission fragments varies. This fission process that takes place when a nuclear weapon is designated creates a mix of over 900 different fission products (England and Rider 1994). The mix of fission products is very well known, as are the half-lives of all the radioactive fission products. If the energy from fission (fission yield) of an explosion is known, known fission product yields (England and Rider 1994) can be used to calculate the quantity of each fission product at a specified time after the burst.

Of the fission products created, 77 are stable and have no public health implications. Only 165 radioactive fission products have half-lives longer than one hour. Some fission products are not actually created by the initial explosion, but are created later from the decay of other fission products. If the fission yield and the time since the weapon exploded are known, the quantity of fission products present at that time can be calculated (Whicker and Schultz 1982).

In a fusion weapon, total yield and the fission yield (the fraction of energy released caused by fission) are both required to calculate the amount of fission products created by the weapon's detonation. This information remains classified today. Without it, we can only estimate the amounts of fission products created in weapons tests.

2.1.2 Activation Products

The detonation of a nuclear weapon, fission or fusion, releases a massive shower of neutrons. These neutrons strike and are absorbed by surrounding materials – the structural materials of the bomb itself or the soil or water over which the bomb is detonated. Atoms of these materials that absorb neutrons and become radioactive are called activation products. The radionuclides that actually result from the activation process depend on the materials used to make the bomb, the surface over which the test is conducted, and the height of the explosion.

All nuclear weapons detonations create large quantities of carbon-14 (^{14}C) from neutron interactions with nitrogen in the atmosphere. A detonation also releases large quantities of tritium (^{3}H). The location of the test will determine what other activation products to expect. For example, tests over water create activated sodium, Pacific Island tests create activated calcium, and tests over rocky inland soil create activated silicon. If the location, the height of the burst, the total yield, and the fission yield of the test are known, it is possible to calculate a reasonable estimate of the activation products present (UNSCEAR 1993).

2.1.3 Dispersal of Un-fissioned Material

All nuclear weapons use some combination of uranium-235 (^{235}U), uranium-238 (^{238}U), and plutonium-239 (^{239}Pu) as the source of fission energy. Even in the most efficient modern weapons, some of the fissionable material in the bomb does not fission. A typical nuclear weapon will use both plutonium and uranium as the source of fission energy, so every nuclear weapon detonation scatters large quantities of uranium, and most of them also scatter plutonium. The quantity and type of fissionable material used in a weapon and the efficiency of the weapon are also classified so we can only estimate the amount of plutonium and uranium scattered by weapons tests.

2.1.4 Physical Characteristics of the Radioactive Debris

A nuclear explosion creates a large fireball. Everything inside the initial fireball, earth or water, is vaporized. The fireball rises rapidly and expands as it cools. As the fireball rises it incorporates soil or water. Eventually, the fireball loses buoyancy and stops rising. The kinetic energy of the incorporated soil or water will cause those particles to start spreading horizontally, increasing the size of the cloud created by the fireball at the top. This process gives the cloud its characteristic mushroom shape (Glasstone 1957). The top of a cloud from a large yield weapon may be as high as 140,000 feet, and the cloud may be 50 miles in diameter.

The vaporized material in the cloud condenses as it cools, creating a mix of fission or activation products and condensed material. The fission product decay chains contain gases and solids, some with very short half-lives (Glasstone 1957). Gases tend to stay in the atmosphere, while solids mix more readily with the condensate. Fireballs from large tests cool more slowly than fireballs from small tests, while the decay of the fission products always proceeds at the same rate. For this reason, the fission product mix in the fallout after a large explosion will be different from that after a small explosion. This alteration of the fission product mix is called fractionation. Because of fractionation, actual measurement of the fission product mix made after each individual test is required to determine the exact nature of the fallout from that test.

2.1.5 Deposition of Radioactive Debris

Large particles of fallout tend to settle locally, while small particles and gases may travel around the world. Rainfall washes out fallout in the troposphere (approximately the first 10 km of the atmosphere), causing localized high concentrations many miles from the test site. Large atmospheric explosions will inject radioactive material into the stratosphere (the layer of the atmosphere immediately above the troposphere) where it will remain for years. Even today, small quantities of fallout created during the atmospheric testing period are still being deposited on the surface of the earth. Deposited material is typically measured in Becquerels (radioactivity with units of one disintegration per second) per square meter (Bq m^{-2}).

2.2 Brief Review of Nuclear Weapons Tests

2.2.1 Atmospheric Tests

The first test of a nuclear weapon was in the atmosphere on 16 July 1945, in southeastern New Mexico. Following this test, nuclear bombs were dropped on Hiroshima and Nagasaki, Japan, in August 1945. These bombs leveled both cities and ended World War II in the Pacific. Subsequent testing of nuclear weapons in the atmosphere continued until 1980, with periods of intensive testing in the years 1952-1954, 1957-1958 and 1961-1962. A limited nuclear test ban treaty (Treaty Banning Nuclear Weapons Tests in the Atmosphere, in Outer Space and Under the Water) was signed in August 1963, and much less frequent testing in the atmosphere occurred subsequently. Over 500 atmospheric nuclear explosions have occurred at a number of locations. Five countries have acknowledged atmospheric nuclear weapons tests: the United States, the former Union of Soviet Socialist Republics (U.S.S.R.), the United Kingdom, France, and China. Test weapons were placed on barges in the ocean, suspended from balloons, placed on wood or steel towers, exploded in outer space, placed on the ground surface, dropped from airplanes, and used to create large craters in the earth as described in Section 2.2.3.

The United States and the former U.S.S.R. also tested nuclear rocket engines in the atmosphere. These tests were radiologically equivalent to low yield atmospheric weapons tests, in that they injected fission products into the troposphere. However, these are generally not included in compilations of atmospheric nuclear testing.

2.2.2 Underground Tests

In addition to the atmospheric tests, about 1,400 nuclear test explosions have been carried out beneath the earth's surface, including some by India and Pakistan. After 1963, when the limited nuclear test ban treaty banning atmospheric tests was negotiated, underground testing became more frequent. A well-contained underground nuclear explosion delivers extremely low doses to any group of people. Even though there have been occasions when radioactive materials leaked from underground tests, the environmental and health impacts of these explosions are lower than those from the atmospheric tests.

2.2.3 Cratering Tests

In addition to the atmospheric and underground tests, the United States conducted a series of cratering tests to assess the feasibility of using nuclear weapons as excavation tools. Glasstone (1957) provides details of crater size and tons of earth removed as a function of yield and depth. The fallout from these tests tends to be much more of a local phenomenon, and, again, these tests are generally not included in compilations of atmospheric weapons tests.

2.3 List of Nuclear Weapons Tests

There are several published databases and printed books listing all nuclear weapons tests in the world. There are some significant differences in the number of tests and yields of the test between these sources. There are several reasons for these differences.

Sources are not always consistent in what they count as a test. Sometimes the testers used conventional explosives to blow up a warhead, testing its safety from inadvertent detonation or transportation accidents. These tests scattered plutonium locally, but created no fission or activation products. These were called safety experiments.

Sometimes warheads were used in physics experiments that may or may not have created fission products. These experiments, called by different names, may or may not be included in a country's list of reported nuclear weapons tests.

Some sources consider all nuclear weapons tests conducted on the same day in the same place as one test. Others count weapons at the same time only if they are in different holes at the test site. A series of tests may be conducted on the same day in the same location at different times. (DOE 1992; 1994)

Some sources used seismic data, so they may list as a test a conventional explosion at a nuclear test site (Lawson 1998; Australia 2000) or even an earthquake near a nuclear test site (Sykes 1997).

Locations introduce another source of confusion. Some documents list different test sites for tests (Mikhailov 1999; Kirchman and Warner 2000). Test sites in the former U.S.S. R. are listed in some publications by test site name (Lawson 1998) while others may list the administrative district (Mikhailov 1999). Some list only the general latitude and longitude (PIDC) while others give the specific locations (Mikhailov 1999; DOE 1992; Lawson 1998).

Figure 2.1 shows the locations where nuclear weapons tests totaling greater than one megaton in yield were conducted prior to 1963 (PIDC). Table 2.1 presents a summary developed by developed by the United Nations Scientific Committee on the Effects of Atomic Radiation of the number and yield of atmospheric nuclear weapons tests

(UNSCEAR 2000). Safety tests, underground tests, and cratering tests are not included in this list. As noted earlier, the number of megatons, not the number of tests, determines how much radioactive material is created during a detonation. Table 2.1 shows that UNSCEAR estimates that the total yield of all nuclear weapons tested in the atmosphere is approximately 440 Mt. If one uses the highest estimates that have been published for the yield of individual tests, the total is approximately 604 Mt. This uncertainty will likely not be resolved until more information on nuclear weapons testing is declassified.

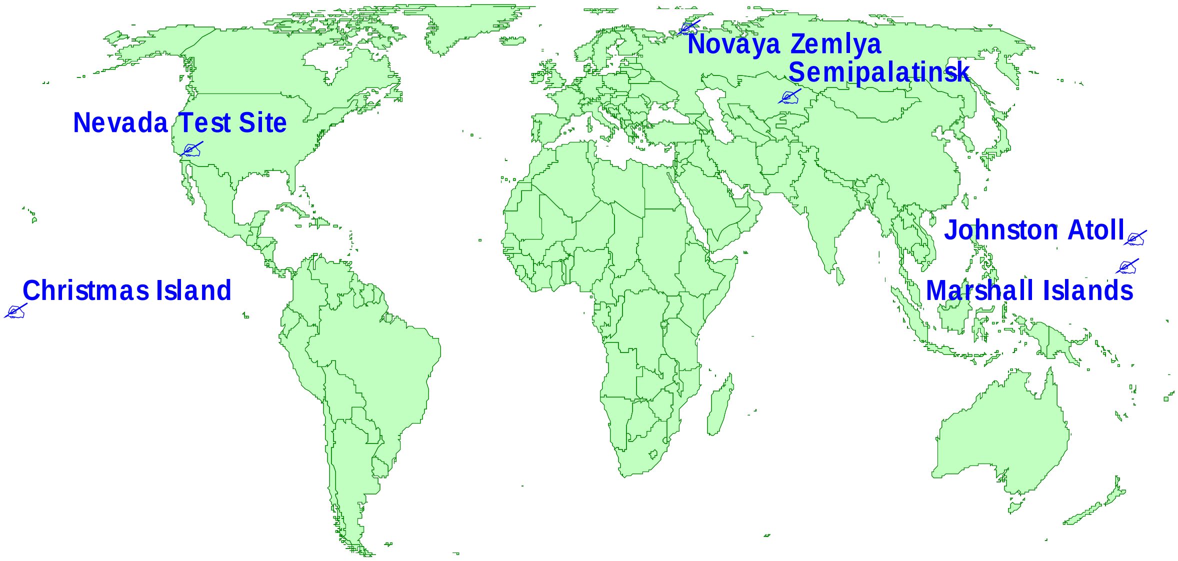

Figure 2.1. Locations of sites having greater than one megaton total tests conducted prior to 1963.

Table 2.1. A summary of atmospheric nuclear tests by major site and country (UNSCEAR 2000)

Country	Test Site (see Figure 2.1)	Number of Tests Conducted	Yield (megatons)	Total Yield (megatons)
China	All	22	21	21
France	All	45	10	10
United Kingdom	Christmas Island	6	7	8
	Others	15	1	
United States	Nevada	86	1	154
	Marshall Islands	69	109	
	Christmas Island	24	23	
	Johnston Atoll	12	21	
	Others	6	0.1	
Former U.S.S.R.	Novaya Zemlya	91	239	247
	Semipalatinsk	116	7	
	Others	12	1	
Totals		543		440

2.4 Conclusions

The detonation of a nuclear weapon in the atmosphere releases three types of radioactive debris into the environment. Depending on the size and type of weapon detonated, some of this fallout may travel great distances before depositing on the earth and exposing people to radiation. The next two chapters evaluate the dose and risk and to the American people as a result of exposure to fallout from nuclear weapons testing. Appendix C discusses the need to preserve documents that would be useful to resolve some of the issues raised in this Chapter, as well as other questions related to historic fallout exposures, should additional fallout-related work ever be mandated.

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Chapter 3

Estimation of Doses from Fallout

Contents: This chapter addresses external and internal radiation exposure from fallout originating at the Nevada Test Site and at other sites worldwide. The methods used to estimate doses and the principal findings are presented.

3.1 Introduction

This chapter of this report presents dosimetric methods and results of calculations to estimate radiation doses that could have been received by Americans living in the contiguous United States as result of exposure to radioactive fallout originating at the Nevada Test Site and at other nuclear testing sites worldwide. It should be noted that these methods are based on the data collected over more than four decades but primarily on the experience acquired in dose reconstruction during the past decade and a half. Crude methods of estimating doses have been used for this feasibility study. In some cases – particularly for the case of shorter-lived radionuclides (e.g., ^{131}I) in global fallout – the doses presented may be in error by as much as an order of magnitude. Future work could likely improve the precision of these calculations, however.

Because of the low precision of some of the dose estimates presented, the doses should not be used to make a claim of individual health effects or increases in health effects among subpopulations. The goal of these calculations was to show feasibility only, and in many cases the possible degree of error of the doses has not been evaluated. Thus, the usefulness of the doses presented here is limited only to very approximate evaluations of overall (that is, national) health detriment. Even though county-specific deposition densities and doses were computed and presented in a series of maps, those county-specific estimates are uncertain, and individual county values should not be used for definitive risk assessments until further refinements are made and the degree of possible error is evaluated in detail. The maps are provided only to show general spatial patterns of fallout and resulting exposure patterns across the United States.

The dose estimates in this report are: (1) based primarily on a review of the readily available open literature and supplemented with calculations of moderate complexity rather than on sophisticated computer models, (2) calculated on a county-by county basis as well as averaged over the contiguous United States, (3) calculated separately for the most important radionuclides produced in nuclear weapons tests, (4) provided in terms of effective dose and absorbed dose to the thyroid gland and to the red bone marrow, and (5) calculated for tests conducted in individual years as well as summed over all years. The dose estimates and the methodology used for calculating them are summarized in this chapter. The details of the calculations and methodology are given in detailed consultant reports that are included in this report in Appendices D through G.

In this chapter, preliminary estimates of radiation doses from fallout are presented for two groups of people that were assumed to have resided in the same county during their entire lives: (1) those who were adults in 1951, that is, at the time when substantial amounts of fallout from nuclear weapons tests began to occur in the United States and (2) those who were born on 1 January 1951, and are expected to be among the population group that received the highest doses from fallout. Thyroid and bone marrow absorbed doses accumulated through the year 2000 are presented for the two population groups. Exposure of the thyroid to ionizing radiation can, in some cases, give rise to the induction of thyroid cancer, especially among those exposed as very young children, while exposure of the red bone marrow can, in some cases, contribute to the induction of leukemia in the population. In addition, absorbed doses are presented for selected other organs and tissues, and effective doses will be used to compare exposures from various radionuclides, types of nuclear tests, or exposure pathways, when appropriate.

Radiation doses are presented separately for the nuclear weapons tests conducted at the Nevada Test Site (NTS) and for those carried out at other sites outside of the United States. The main reason for this division is that the nuclear tests conducted in the United States and elsewhere resulted in different geographic deposition patterns of the fallout. In addition, the mixture of radionuclides deposited depended on the origin of the nuclear debris (fallout). Some of the primary considerations in making these estimates were:

- The tests conducted at the NTS had low yields, so that the radioactive clouds originating from the atmospheric explosions remained in the lower layers of the atmosphere and fallout deposition occurred within days. The level of fallout generally decreased with distance from the NTS, and consisted predominantly of short-lived radionuclides, like ^{131}I. The environmental measurements made after each test usually made it possible to relate the radioactive contamination to specific tests and thus to assess the radiation impact of each of those tests;
- In contrast, the radioactive contamination due to tests conducted far away from the United States was due primarily to high-yield tests, which resulted in radioactive clouds that reached high layers of the atmosphere. It took months to years for radionuclides to deposit on the ground from those altitudes. Within that time, relatively homogeneous mixing of the activity occurred in the high layers of the

> atmosphere within latitudinal bands all around the world, while the activity that gradually descended to lower atmospheric layers was preferentially removed from the atmosphere via precipitation. Consequently, the levels of global fallout were relatively constant throughout the United States, the differences being due to differences in precipitation levels. Fallout from those tests consisted predominantly of long-lived radionuclides, like Cesium-137 (^{137}Cs), as most of the short-lived radionuclides decayed before they deposited on the ground. Thus, environmental measurements made at that time did not make it possible to relate the contamination to a specific test.

Following releases of radionuclides into the environment, human populations can be exposed to external or internal irradiation. In this report, the estimated radiation doses from external and from internal irradiation are presented separately.

Exposures via external irradiation occur when the radionuclides are outside the body (in the air, on the ground, building materials, vegetation, etc.). External irradiation usually arises from: (1) submersion in air contaminated with gamma-emitting radionuclides; and/or (2) the decay of gamma-emitting radionuclides deposited on the ground. In the case of radiation exposures from nuclear weapons tests, external irradiation from submersion in contaminated air plays a very minor role and will not be considered explicitly. Exposures via internal irradiation occur when radionuclides enter into the body, generally by inhalation or ingestion. Doses from internal irradiation may result from (1) the inhalation of radionuclide-contaminated air, and (2) the ingestion of radionuclides in water and foodstuffs. The estimation of doses from internal irradiation will focus on those from ingestion, as the doses from inhalation are usually much smaller than those from ingestion. Therefore, the doses that are presented in this report are those arising from the decay of gamma-emitting radionuclides deposited on the ground (external irradiation) and those incurred via the ingestion of radionuclides in water and foodstuffs (internal irradiation). Both types of dose are derived from the estimation of the amounts of radionuclides deposited per unit area of ground (often called ‘deposition densities’ in this report).

3.2 NTS Fallout

There were 100 officially reported nuclear events conducted in the atmosphere at the NTS (DOE 1994). These tests ranged in yield from extremely small explosions (<1 t equivalent TNT) to a maximum size of 74 kt (Shot Hood on 5 July 1957). In addition, there were “cratering” events that released significant amounts of radioactive 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; only the most significant events in terms of their releases to the offsite environment are considered. Deposition densities have been estimated for a total of 61 events: eight in 1951 (Ranger and Buster-Jangle series), eight in 1952 (Tumbler-Snapper series), 11 in 1953 (Upshot-Knothole series), 13 in 1955 (Teapot series), 19 in 1957 (Plumbbob series), and two in 1962 (Storax series). 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. The 61 tests that were included in this assessment accounted for over 95% of the total ^{131}I produced (NCI 1997); hence, they were the most important in terms of the exposure delivered to the American people. A complete list of these events with dates and yields is given in Table 3.1.

Table 3.1. Nuclear weapons tests conducted at NTS that are considered in the feasibility study

Operation (Series)	Test	Placement	Date	Yield (kt)
Ranger	BAKER	airdrop	28-Jan-51	8
	BAKER-2	airdrop	2-Feb-51	8
Buster	BAKER	airdrop	28-Oct-51	3.5
	CHARLIE	airdrop	30-Oct-51	14
	DOG	airdrop	1-Nov-51	21
	EASY	airdrop	5-Nov-51	31
Jangle	SUGAR	surface	19-Nov-51	1.2
	UNCLE	crater	29-Nov-51	1.2
Tumbler-Snapper	ABLE	airdrop	1-Apr-52	1
	BAKER	airdrop	15-Apr-52	1
	CHARLIE	airdrop	22-Apr-52	31
	DOG	airdrop	1-May-52	19
	EASY	tower	7-May-52	12
	FOX	tower	25-May-52	11
	GEORGE	tower	1-Jun-52	15
	HOW	tower	5-Jun-52	14
Upshot-Knothole	ANNIE	tower	17-Mar-53	16
	NANCY	tower	24-Mar-53	24
	RUTH	tower	31-Mar-53	0.2
	DIXIE	airdrop	6-Apr-53	11
	RAY	tower	11-Apr-53	0.2
	BADGER	tower	18-Apr-53	23
	SIMON	tower	25-Apr-53	43
	ENCORE	airdrop	8-May-53	27
	HARRY	tower	19-May-53	32
	GRABLE	airburst	25-May-53	15
	CLIMAX	airdrop	4-Jun-53	61
Teapot	WASP	airdrop	18-Feb-55	1
	MOTH	tower	22-Feb-55	2
	TESLA	tower	1-Mar-55	7
	TURK	tower	7-Mar-55	43
	HORNET	tower	12-Mar-55	4
	BEE/ESS			
	BEE	tower	22-Mar-55	8
	ESS	crater	23-Mar-55	1
	APPLE/WASP			
	APPLE-1	tower	29-Mar-55	14

Operation (Series)	Test	Placement	Date	Yield (kt)
	WASP	airdrop	29-Mar-55	3
	POST	tower	9-Apr-55	2
	MET	tower	15-Apr-55	22
	APPLE-2	tower	5-May-55	29
	ZUCCHINI	tower	15-May-55	28
Plumbbob	BOLTZMANN	tower	28-May-57	12
	WILSON	balloon	18-Jun-57	10
	PRISCILLA	balloon	24-Jun-57	37
	HOOD	balloon	5-Jul-57	74
	DIABLO	tower	15-Jul-57	17
	KEPLER/OWENS			
	KEPLER	tower	24-Jul-57	10
	OWENS	balloon	25-Jul-57	9.7
	SHASTA	tower	18-Aug-57	17
	DOPPLER	balloon	23-Aug-57	11
	SMOKY	tower	31-Aug-57	44
	GALILEO	tower	2-Sep-57	11
	WCL			
	WHEELER	balloon	6-Sep-57	0.197
	COULOMB-B	surface	6-Sep-57	0.3
	LAPLACE	balloon	8-Sep-57	1
	FIZEAU	tower	14-Sep-57	11
	NEWTON	balloon	16-Sep-57	12
	WHITNEY	tower	23-Sep-57	19
	CHARLESTON	balloon	28-Sep-57	12
	MORGAN	balloon	7-Oct-57	8
Storax	SEDAN	crater	6-Jul-62	104
	SMALL BOY	tower	14-Jul-62	Low

For the purposes of the feasibility study, three types of estimates were made: (1) deposition densities of a selected set of 43 radionuclides on the ground on a county-by-county basis for each test (see Table 3.2), (2) doses from external irradiation for the most important radionuclides as determined by Hicks (1981, 1982), and (3) doses from internal irradiation for the most important radionuclides contributing to internal dose. The group of

Table 3.2. Radionuclides in NTS fallout for which deposition densities (Bq m^{-2}) were explicitly calculated on a county-by-county basis.

Radionuclide	Half-Life	Used in External Dose Calculations	Used in Internal Dose Calculations
^{89}Sr	52 days		x
^{90}Sr (^{90}Y*)	28.5 years		x
^{91}Sr	0.4 days	x	x
^{91m}Y	*	x	
^{91}Y	59 days	x	
^{93}Y	0.4 days	x	
^{97}Zr (^{97}Nb*)	0.7 days	x	x
^{95}Zr (^{95}Nb*)	64 days	x	
^{97m}Nb	*	x	
^{99}Mo	2.8 days	x	x
^{99m}Tc	*	x	
^{99}Tc	213,700 years		
^{103}Ru (^{103m}Rh*)	39 days	x	
^{105}Ru (^{105m}Rh*)	0.2 days	x	
^{105}Rh	1.5 days	x	x
^{106}Ru (^{106}Rh*)	368 days	x	x
^{131}I (from NCI 1997)	8 days	x	x
^{132}Te*	3.3 days	x	x
^{132}I	*	x	
^{133}I	0.9 days	x	x
^{136}Cs	13 days		x
^{137}Cs (^{137m}Ba)	30 years	x	x
^{140}Ba (^{140}La*)	13 days	x	x
^{140}La	1.7 days	x	
^{141}Ce	32.5 days	x	
^{143}Ce	1.4 days	x	x
^{143}Pr	14 days		
^{144}Ce (^{144}Pr*)	284 days	x	x
^{147}Nd	11 days	x	x
^{147}Pm	2.6 years		
^{239}Np	2.36 days	x	
$^{239+240}$Pu	24131 / 6569 years		x
^{241}Pu	14.4 years		x
^{241}Am	430 years	x	

[*] Calculations for the progeny (in parentheses) are based on data for the precursor nuclide.

radionuclides selected for the internal dose calculations account for about 90% of the internal dose (see Table 3.2). If further work is conducted, it should include ^{239}Np in the internal dose calculations.

3.2.1 Deposition Densities

Fallout deposition density is the amount of each radionuclide per square meter that is accumulated on the ground as a result of settling of particles from clouds containing nuclear debris. The amount of each radionuclide deposited on the ground is important information for calculating both external and internal doses. Deposition of fallout can take place under both dry and wet weather conditions; however, when rainfall coincides with the passage of a cloud containing nuclear debris, the deposition of fallout is considerably increased.

The daily deposition density of each radionuclide listed in Table 3.2 was estimated from the daily ^{131}I deposition density estimates reported in the National Cancer Institute Study on ^{131}I exposure of the American people (NCI 1997). All calculations for this report were carried out separately for each county (and sub-county as defined in NCI (1997), Appendix 2), and then summed to provide estimates on a test-by-test, annual and cumulative basis. The deposition densities of nuclides other than ^{131}I were calculated from the NTS ^{131}I deposition density values by using the relationships calculated by Hicks (1981) for each NTS test. Further detail on these methods is provided in Appendix D.

Plutonium isotopes were also contained in the fallout from Nevada weapons tests. Because plutonium isotopes primarily emit alpha particles, they do not contribute to external dose and contribute only a small amount to ingestion (internal) dose. The primary hazard from plutonium comes about when it is inhaled. However, even inhalation has been shown not to be a significant contributor to population exposure from NTS testing (Church et al. 1990). Plutonium is primarily discussed here because of the high degree of interest by the public in plutonium contamination of man and the environment. Only crude estimates of plutonium deposition density can be made for individual tests partly because certain data – in particular, the ratios of plutonium to ^{137}Cs, ^{90}Sr, etc. – are still classified by the United States Government.

A reasonable set of assumptions has been made, however, from which rough estimates of plutonium deposition density, which while possibly significantly in error for any specific given test, provides a reasonable total deposition value when summed over all tests. Using these methods, $^{239+240}$Pu and ^{241}Pu depositions in fallout were estimated for each test and test series. It should be noted that only about one-half the plutonium from tower and surface tests would be deposited outside the immediate vicinity of the NTS because it is associated with large particles that are deposited close-by to the detonation site. Accurate estimates of plutonium deposition from particular tests will only be possible if additional information on the cesium to plutonium ratios for particular tests is declassified. Thus, the plutonium results presented in this report should be treated as only preliminary crude estimates.

For the radionuclides considered in this report, deposition density estimates were developed for each of the approximately 3,000 counties within the contiguous United States. Nearby the NTS, where some of the larger counties experienced considerable gradations in deposition, counties were broken into subparts. In all, estimates were computed for 3094 geographic units (counties or subparts of counties). These estimates of radioactivity deposition density are based on the ^{131}I deposition densities reported in NCI (1997) (see

Appendix D) which in turn were based primarily on measurements made at the time of fallout and reported from the gummed-film network operated by the Department of Energy (DOE) Environmental Measurements Laboratory, which was then known as the Atomic Energy Commission (AEC) Health and Safety Laboratory. Because the measurement sites were few compared to the large number of counties, and because the deposition in each county is so highly influenced by the occurrence of rainfall, the measurements were extended to other nearby locations through the use of mathematical interpolation procedures (NCI 1997). Extrapolating data to locations without measurements is one of the inherent and unavoidable limitations of these calculations.

The total deposition of ^{137}Cs from all NTS tests considered in this report through 1962 is shown in Figure 3.1. As can be seen, the years of greatest deposition were 1957, 1953, and 1952. The geographic pattern of deposition of ^{137}Cs as shown in Figure 3.2 is similar to that for ^{131}I (see NCI 1997), although, due to the long half-life (30 years) of ^{137}Cs, the decrease in activity in the eastern United States is less than that for ^{131}I. The county estimates range from well below 200 Bq m^{-2} to about 1300 Bq m^{-2}. The regional and local variations of deposition density are primarily due to variations in precipitation. The well-known elevated area in northern New York State was due to heavy thunderstorm activity during passage of the cloud from test SIMON in April 1953 (NCI 1997; Beck et al. 1990).

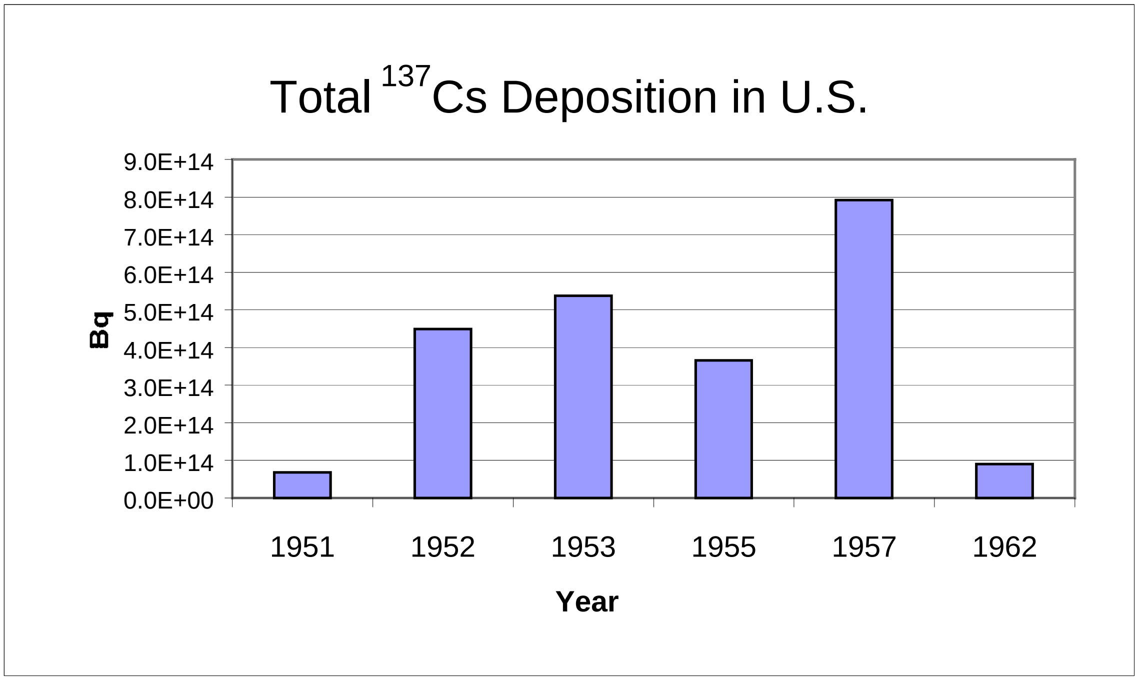

Figure 3.1. Total ^{137}Cs (Bq) deposited in the United States from NTS tests as a function of year of tests

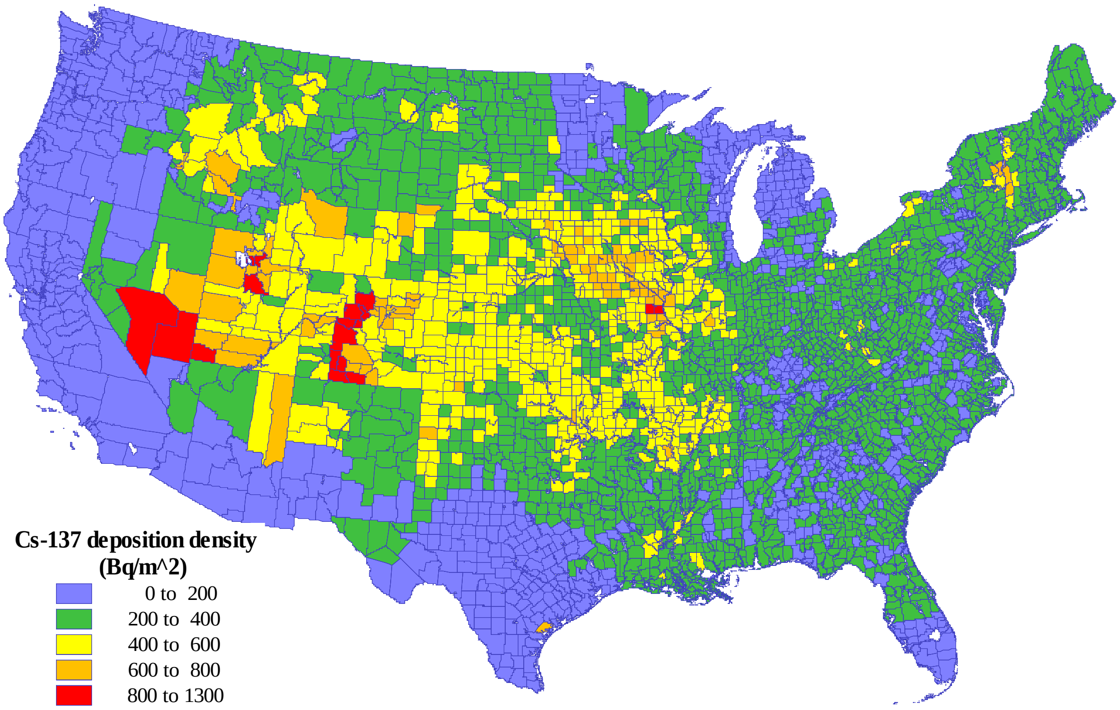

Figure 3.2. Cesium-137 deposition density due to all NTS tests.

The geographic patterns of deposition density for certain fallout radionuclides like ^{90}Sr (Figure 3.3) and $^{239+240}$Pu (Figure 3.4) vary somewhat from those for ^{137}Cs and ^{131}I primarily due to the differences in the nuclear fuel used in different tests and the directions of travel of the clouds of debris from each test. The deposition of ^{90}Sr was very similar to that of ^{137}Cs. The highest plutonium deposition density, not surprisingly, was in counties near the NTS, though other moderately high deposition densities can be seen in a few Midwest counties. For most of the country, the amount of cesium was 10 to 20 times the amount of plutonium deposited. As discussed previously, the plutonium estimates in this report for any particular county are very uncertain, and the data provided should be viewed only as illustrative of the variations across the country due to the varying paths of fallout clouds.

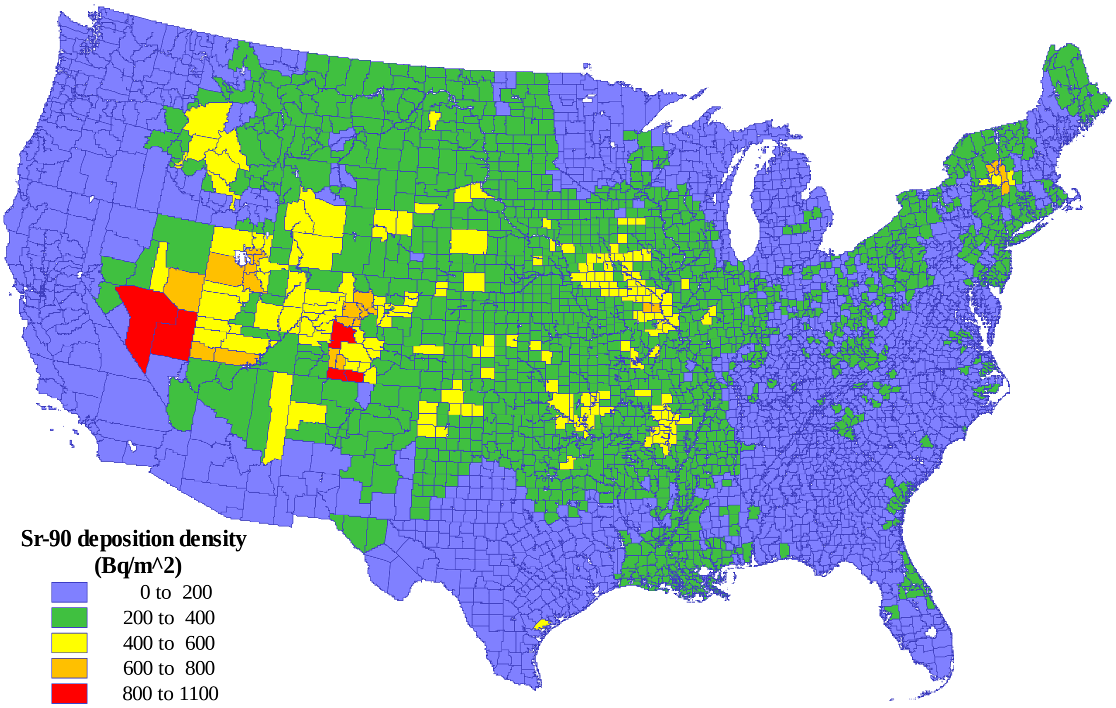

Figure 3.3. Strontium-90 deposition density due to all NTS tests.

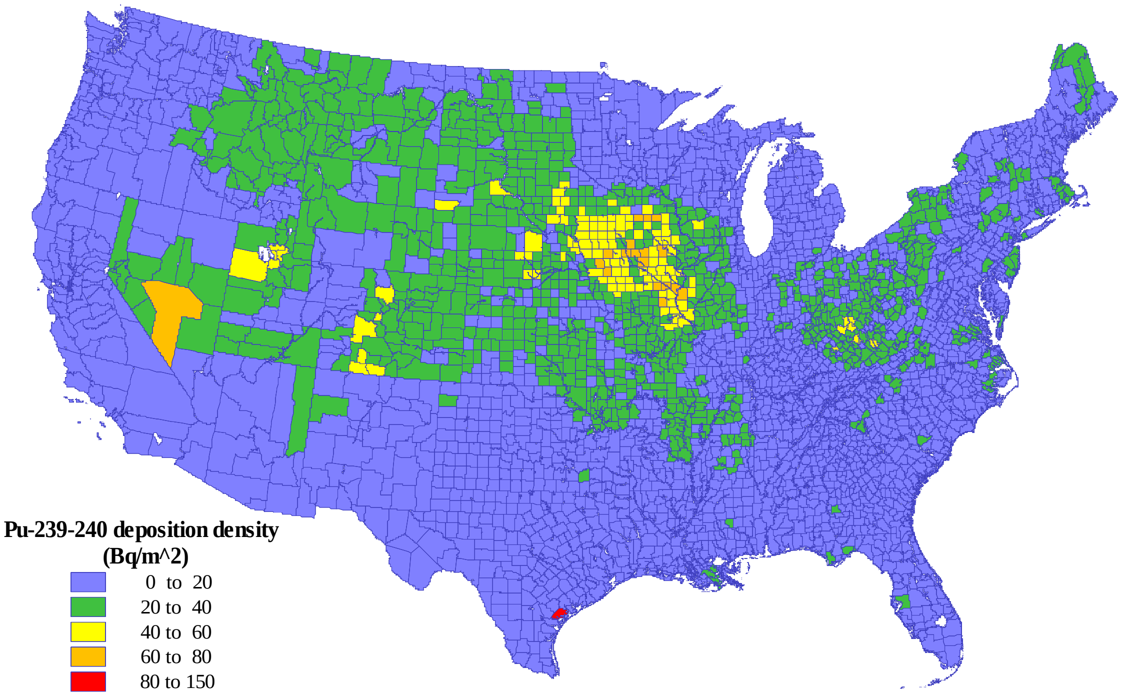

Figure 3.4. Plutonium (239+240) deposition density due to all NTS tests.

The six test series deposited different amounts of fallout within the United States. For example, the 1957 Plumbbob series deposited 35% of the total cesium followed by the 1953 Upshot-Knothole series that contributed 23%. These proportions are shown in Figure 3.5.

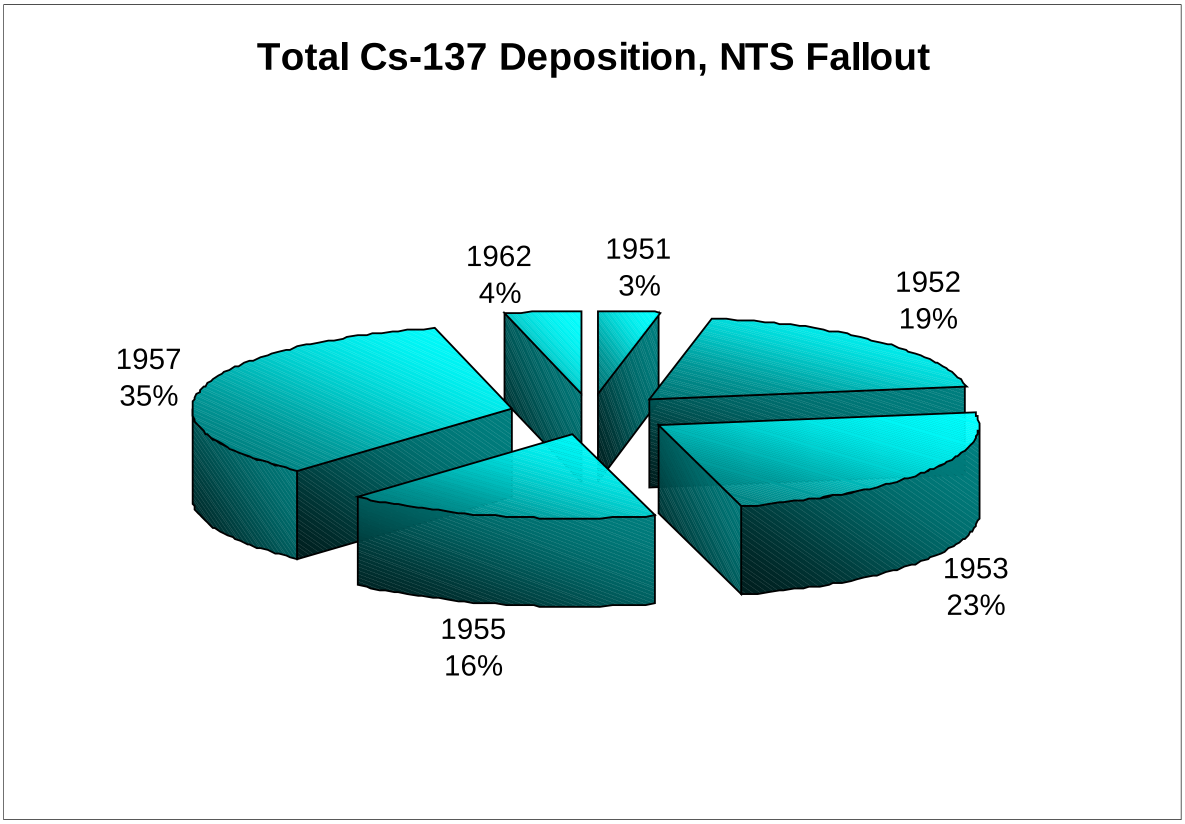

Figure 3.5. Fraction of total ^{137}Cs deposited in the United States from NTS by year of test.

The total amount of ^{137}Cs deposited in the contiguous United States from all tests was 2.3 PBq. The total deposition for a number of other selected radionuclides is shown in Table 3.3. The population-weighted deposition densities, calculated on the basis of the information available for each county, are also presented in Table 3.3. Because of the sharp gradations in deposition density from west to east, and the higher populations in the eastern United States, the population-weighted deposition densities are only slightly less than the actual deposition densities. However, the population-weighted values give a better indication of the relative health impacts that might be expected. From all NTS tests, 34% of the ^{137}Cs produced was deposited in the contiguous United States, the remainder was deposited elsewhere; presumably, a large fraction was deposited in the oceans.

Table 3.3. Total deposition and population-weighted mean deposition density for selected radionuclides for NTS fallout.

Nuclide	Total Deposition (PBq)*	Population weighted deposition density (Bq m^{-2})
^{137}Cs	2.3	260
^{90}Sr	1.8	200
^{95}Zr	220	2.5×10^4
^{103}Ru	430	4.6×10^4
^{140}Ba	1400	1.4×10^5
^{141}Ce	500	5.4×10^4
^{144}Ce	40	4.6×10^3
^{106}Ru	24	2.6×10^3
^{89}Sr	330	3.6×10^4
^{131}I	1500	1.9×10^5
$^{239+240}$Pu	0.13	~16
^{241}Pu	0.54	~59

*PBq = 10^{15} Bq

3.2.2 NTS External Exposure and Dose

Radiation received externally to the body from fallout is primarily a result of the gamma radiation emitted by radionuclides deposited on the ground. External exposure generally results in a radiation dose to the entire body and is usually considered to be uniform over the body, particularly when fallout is widespread in the environment. The calculation of radiation dose is often made through intermediate calculations of the amount of ionization of a volume of air (formally called exposure and measured in Roentgens (R)). The absorbed dose in specific organs or tissues of the body is expressed in units of Gray (Gy). The effective dose, expressed in Sievert (Sv), is a weighted whole-body dose, in which the differences in damage caused by different types of radiation and radiosensitivity of the different tissues or organs of the body are taken into account. The calculation steps from deposition density (Bq m^{-2}) to exposure (R) to absorbed dose in tissues or organs (Gy), and to 'effective dose' (Sv) are described in Appendix D.

The doses presented in this report are primarily based on measurements or estimates of radionuclide deposition densities, isotopic ratios calculated for each test by Hicks (1981), and various conversion factors. Very few actual measurements of exposure were made outside the immediate vicinity of the NTS. However, the external dose resulting from emitted gamma rays from individual radionuclides in surface soil is well understood. Hence, theory and available data can be used to predict the exposure or the dose that the public might have received across the United States. It should be understood, however, that in those cases where little data are available, particularly concerning the lifestyles of individuals and the rate of penetration of radionuclides into the soil at any particular location, doses can only be estimated with very limited precision.

For states immediately downwind from the NTS, available data, including actual exposure rate measurements where available, were used to estimate deposition densities (Beck and Anspaugh 1991; Beck 1996). NCI (1997) used these data and data from gummed-film measurements to estimate ^{131}I deposition densities for each county of the contiguous United States. The NTS deposition densities in this report are based directly on the estimates of ^{131}I deposition density reported in NCI (1997). The conversion factors relating deposition density to exposure rate in air have been validated in many studies and are believed to be accurate to within 5% (NCRP 1999).

A large number of fission products are produced in a nuclear explosion. However, only a few account for most of the external exposure. Different radionuclides contribute significantly to the exposure rate at different times and thus the relative importance of the various radionuclides with respect to total exposure varies according to the length of time for the fallout to arrive at the location where exposure took place. At early arrival times after each test (within a few hours), the short-lived iodine isotopes contribute substantially to the exposure while after a few days, ^{132}I, ^{140}Ba, ^{95}Zr-^{95}Nb and ^{103}Ru are more important.

The externally delivered dose is often expressed by what is called effective dose (ICRP 1991), a quantity that is likely to correlate well with the occurrence of cancer (total of all types) arising as a result of the exposure of the whole body. Specifically, the effective dose is the sum of organ doses weighted by two factors, one to account for the quality and type of radiation and one to account for the relative radiosensitivity of specific organs such that:

$$E_R = \sum_R w_R \sum_T w_T D_{T,R} \qquad \text{Equation 3.1}$$

where:

E_R = effective dose from radionuclide R,

w_R = weighting factor for radionuclide R,

w_T = weighting factor for body tissue T, and

$D_{T,R}$ = absorbed dose in tissue T from radionuclide R.

Values of the radiation weighting factor are 1.0 for electrons, x-rays and gamma rays, between 5 and 20 for neutrons of various energies, and 20 for alpha particles. The radiation weighting factor adjusts the absorbed dose (simply the energy absorbed per mass of tissue) to better reflect the probability of damage by the type of radiation exposing the body. The fission products emit electrons, x-rays, and gamma rays, so that their radiation weighting factors are equal to 1.0. However, the plutonium isotopes emit alpha particles and therefore, their radiation-weighting factors are equal to 20.

The tissue weighting factors reflect the radiosensitivity of different organs, and are chosen so that a uniform dose over the whole body gives an effective dose numerically equal to the uniform whole-body dose. The International Commission on Radiological Protection has determined values of the radiation- and tissue-weighting factors (ICRP 1991). The conversion from exposure to effective dose is about 0.66 rem per Roentgen (0.0066 Sv R^{-1}) for the range of gamma energies usually encountered in fallout and for adults. Calculations using computer models of the human body indicated that the effective dose to young children is about 10-30% higher (NCRP 1999) than for adults. In order to simplify the feasibility calculations, two assumptions were made in the estimates presented here: (1) the external dose to organs like the thyroid and bone marrow were taken to be numerically equal to the effective dose, and (2) external doses were assumed to be age-independent. The first of these assumptions results from the fact that the external doses to most tissues and organs are about the same, primarily because the gamma ray energies emitted from many radionuclides are energetic enough to completely penetrate the body. Hence, it is justified to make an approximation that the effective dose (Sv) is numerically equal to the absorbed dose for most organs.

Radionuclides deposited on the ground penetrate into the soil with passing time; that process is usually accelerated by rainfall. Hence, after a few months, measurements have shown that external exposure decreases because of the radionuclide’s penetration into the ground as well as the fact that radionuclides decay with the passage of time, leaving less and less activity to expose people.

The dose received by individuals depends on the time they spent outdoors while the fallout was on the ground. Because most people spend most of their time indoors, their exposure is reduced greatly due to the inability of the radiation to effectively penetrate building materials. The amount of shielding provided by a building depends on the materials and design of the building. In general, heavily constructed buildings made of brick or concrete will allow only about 20% of the radiation to penetrate, while lightly constructed buildings will allow 40% or more. Assuming that most persons spend about 80% of their time indoors (UNSCEAR 1993; NCRP 1999) in a building that transmits about 30% of the radiation from the outside, their effective dose would be about 44% (0.8 x 0.3 + 0.2 = 0.44) of that that would be received outdoors. Using similar assumptions, the dose to persons of various occupations and lifestyles can be estimated.

The actual dose to a person who lived in the United States during the years of fallout would generally lie within a range from about one-fourth as large as the estimates provided here to about four times larger than these estimates. In some cases, the range of possible doses at a single location might even be larger. This wide range is a result of the variations in the amount of time people spent outdoors and the types of structures individuals lived and worked in.

A number of maps provided show the geographic distribution of external dose. Figure 3.6 shows the external dose from all NTS tests, and applies equally to red bone marrow and the thyroid gland, both in adults and children. The most exposed individuals likely lived in states immediately downwind from the NTS. However, smaller areas of higher and lower exposures occurred throughout the United States as a result of the uneven deposition of fallout over the United States and the variation in directions taken by the clouds containing the radioactive fallout. Residents of some counties near the NTS received doses in excess of 3 mSv (300 mrem) while residents of the extreme western and northwestern states and some midwestern counties received average doses less than 0.25 mSv (25 mrem).

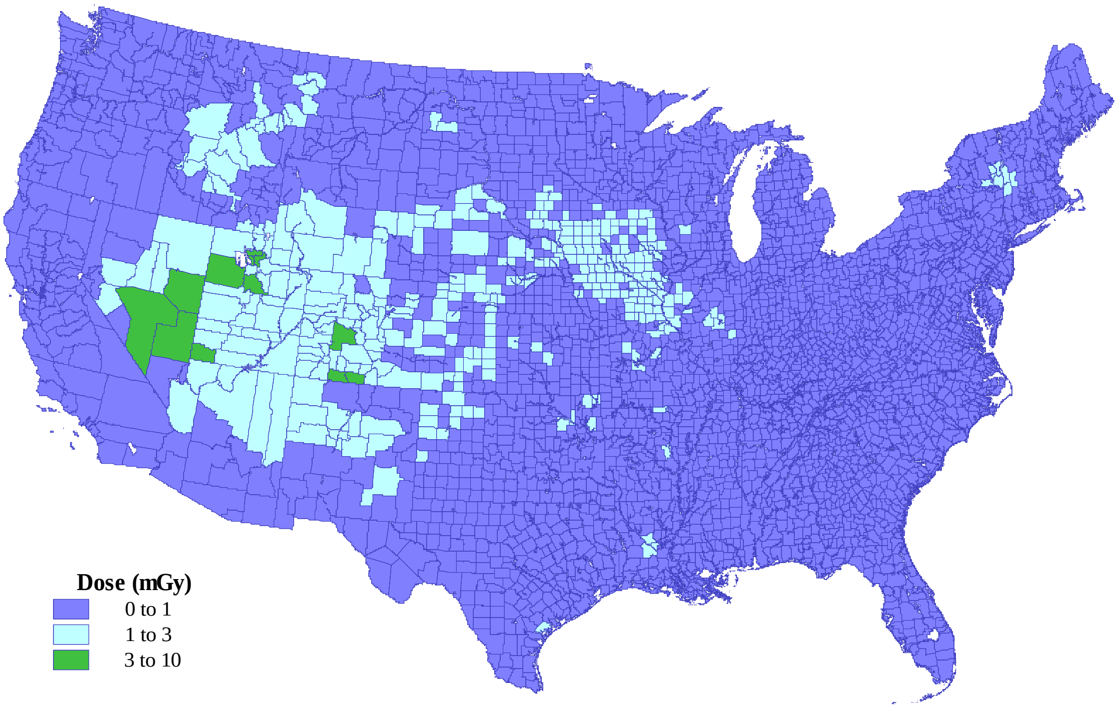

Figure 3.6. External dose to the red bone marrow and the thyroid gland for both children and adults resulting from all NTS tests.

It should be understood that the numerical values of dose provided in Figure 3.6 and in the remainder of this chapter are estimates for a hypothetical individual living in the specified county. How close the doses provided here are to the actual dose received by a person living there depends on many factors, primarily, how similar the assumptions in the calculations are to an individual's lifestyle over the time the exposure was received. There are many factors about each individual member of the public – such as age, diet, lifestyle, etc. – that might result in their exposure being different than the estimates provided in this report. Though there are statistical and mathematical methods available that can be used to estimate the range of doses in each county, to apply these methods requires a great deal of literature review, expert judgment, and mathematical calculations. Assessment of the range of possible doses that might have been received in each county and/or the assessment of the precision of dose estimates for representative individuals are subject areas that will require additional work in future assessments of fallout-related doses.

The calculation of the collective doses from external irradiation resulting from each year when test series were conducted allows for an estimate of the relative contribution of each year of testing to the total dose. Results are presented in Table 3.4. Because most of the external dose is due to short-lived radionuclides, the external dose from each year of testing at the NTS was essentially received during the same year. The most important years of testing were 1957 (Plumbbob series) and 1953 (Upshot-Knothole series). The population-weighted exposure corresponds to an average effective dose of about 0.48 mSv (48 mrem), during the years of testing, about what an average person would receive from natural radiation emitted from the minerals in the soil in 1-2 years time depending on the area of the country where they lived.

Table 3.4. 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

*From previous years' fallout.

3.2.3 NTS Internal Dose

The method of calculation for internal dose 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 area consisted of several counties in Nevada and one county in Utah that were known to have received higher deposition densities. 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, and nearby areas of California (including Los Angeles)].

The general ORERP method is described here because it was used for these feasibility calculations. Further detail on these methods is provided in Appendix E. That method includes:

- 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 dose at each age that would be received by a member of the public from the ingestion of a single unit of activity of a particular radionuclide.

The formulation developed by the ORERP project, in simple form, can be expressed by the following equation:

$$D = P \times I \times F_g \qquad \text{Equation 3.2}$$

where

D = Absorbed dose, Gy, or 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 density, Bq per Bq m^{-2}; and

F_g = Ingestion dose coefficient for the radionuclide, Gy Bq^{-1} or Sv Bq^{-1}.

Doses from internal irradiation resulting from ingestion of contaminated foodstuffs were derived from the deposition density estimates obtained for 61 tests, 43 radionuclides, and within each county of the contiguous United States (see Table 3.2). In a first step of the feasibility calculations, the radionuclide concentrations in important foodstuffs (milk, meat, leafy vegetables, root vegetables, and grain products) were estimated by means of mathematically based environmental transfer models. Age-dependent consumption rates of foodstuffs (see Table 3.5) were used with estimates of the average value of the fraction of foods produced locally (see Figures 3.7 and 3.8) to estimate the radionuclide activities ingested with the contaminated foodstuffs. Finally, mathematical models simulating the behavior of radionuclides in the gastrointestinal tract, uptake of radionuclides by the gastrointestinal tract and the subsequent absorption and retention of radionuclides in the various organs and tissues of the body were used to estimate the thyroid and bone marrow doses received by persons who were adults in 1951 and for persons who were born in 1951.

Table 3.5. Food-consumption rates used in the PATHWAY code (Whicker and Kirchner 1987). Estimates are based primarily on data summarized by Rupp (1980) for rural families.

Food Type	Food Consumption Rates By Age Group, Fresh kg day^{-1}			
	<1 y	1–11 y	12–18 y	>19 y
Milk	0.800	0.623	0.635	0.360
Milk products	0.144	0.074	0.143	0.062
Beef	0.044	0.113	0.210	0.277
Poultry	0.003	0.017	0.028	0.030
Eggs	0.017	0.026	0.036	0.053
Leafy vegetables	0.002	0.021	0.036	0.062
Stored fruits and vegetables	0.207	0.266	0.356	0.360
Grains	0.025	0.025	0.151	0.137

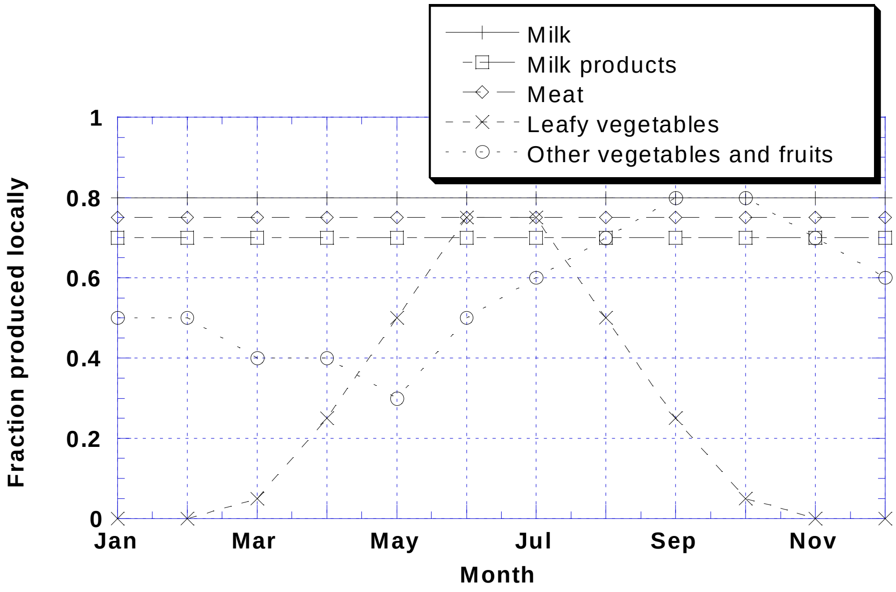

Figure 3.7. Fraction of food that is assumed to be locally produced for several different food categories. Values for eggs are the same as those for milk. From Whicker and Kirchner (1987).

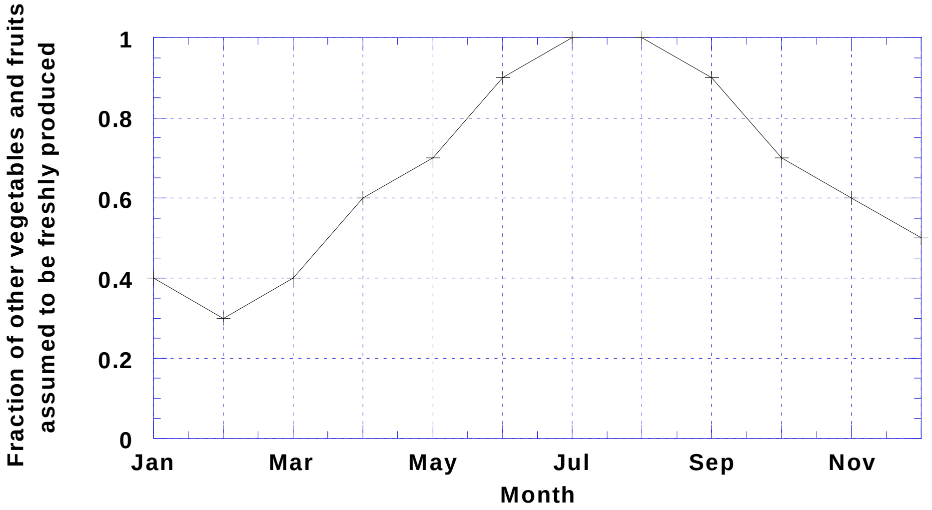

Figure 3.8. Consumed fraction of non-leafy vegetables and fruits assumed to be freshly produced. From Whicker and Kirchner (1987).

Radionuclides of Interest. Ingestion doses were calculated from nineteen of the most important radionuclides contributing to internal dose: ^{89}Sr, ^{90}Sr, ^{91}S, ^{97}Zr, ^{99}Mo, ^{103}Ru, ^{105}Ru, ^{106}Ru, ^{131}I, ^{132}Te, ^{133}I, ^{136}Cs, ^{137}Cs, ^{140}Ba, ^{143}Ce, ^{144}Ce, ^{147}Nd, $^{239+240}$Pu, and ^{241}Pu (see Table 3.2). The ORERP findings indicated that this group of radionuclides accounts for over 90% of the internal dose in the vicinity of the NTS as a result of ingestion of contaminated foods.

In addition to the list of parent radionuclides listed above, doses from decay products were also included in the calculation to the extent that the decay-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. Other 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).

Age Groups Considered. The detailed calculations of dose were performed for adults only in this feasibility study. This choice was necessitated by the limited time resources available for this study and because adults constitute by far the largest segment of the population. Doses to children born in 1951 were roughly estimated on the basis of the computed doses for adults. In the case of thyroid doses (such as from exposure to ^{131}I), age differences result in dramatically different doses with children receiving larger doses. This age-dependence has been treated extensively by the NCI (1997).

Estimates of Cumulative Intake. For the radionuclides listed above, seasonally dependent values of the intake of each radionuclide were estimated from output of the computer code, PATHWAY, developed as part of the ORERP project. That program mathematically accounts for the ecological behavior of radionuclides by considering the initial retention of fallout by vegetation, the loss of radionuclides from vegetation, dilution of radionuclide concentration in fresh vegetation by plant growth, uptake of radionuclides through the soil-root system, and recontamination of plant surfaces by resuspension and redeposition, and by rain splash. As expected, the intake of many radionuclides by the public would have occurred in the early summer months when garden and farm food production would have been highest. In Figures 3.9 to 3.11, the annual pattern of intake over the course of a year is shown for three radionuclides (^{90}Sr, ^{131}I, and ^{137}Cs) and four age categories (<1 y, 1-11y, 12-18y, and adults).

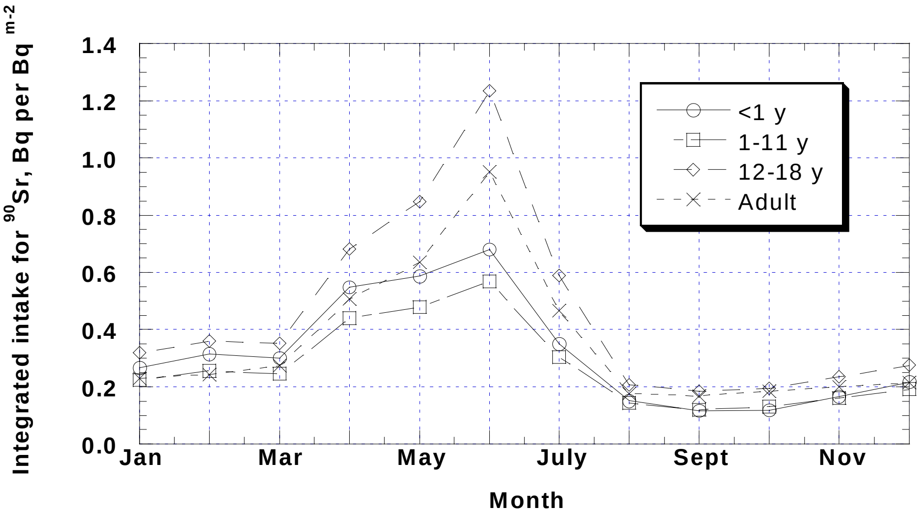

Figure 3.9. Monthly values of integrated intake for four age groups for ^{90}Sr. Data were derived from Whicker and Kirchner (1987).

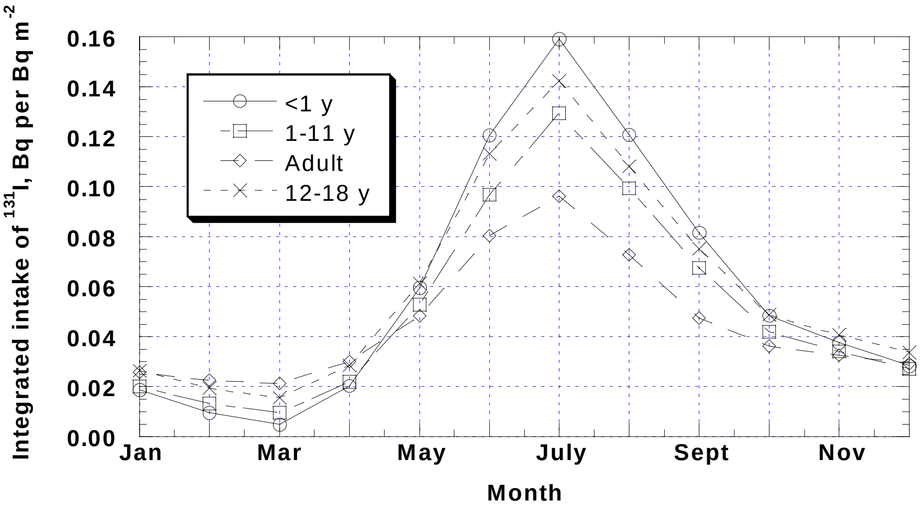

Figure 3.10. Monthly values of integrated intake for four age groups for ^{131}I. Data were derived from Whicker and Kirchner (1987).

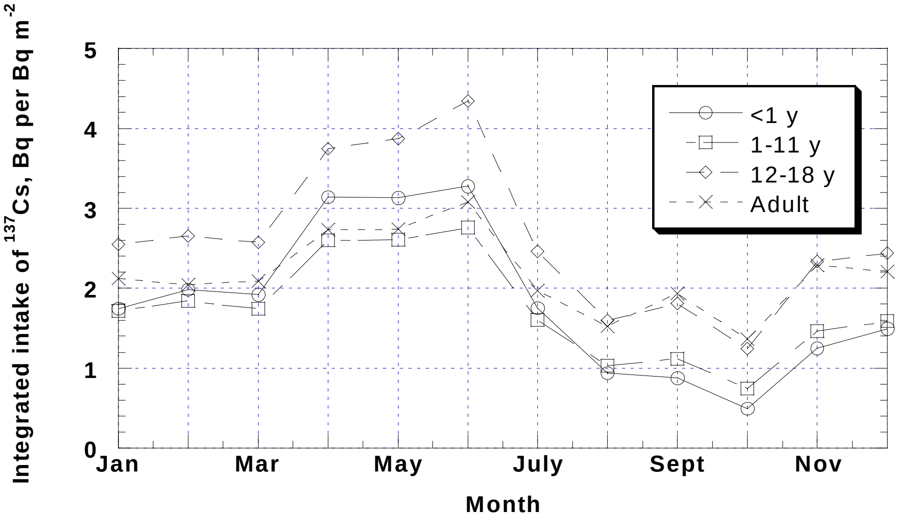

Figure 3.11. Monthly values of integrated intake for four age groups for ^{137}Cs. Data were derived from Whicker and Kirchner (1987).

It should be noted that the model PATHWAY used to derive the integrated intakes (Figures 3.9 through 3.11) was developed to simulate the transfer of radionuclides to foodstuffs in areas close to the Nevada Test Site. The model was used in this feasibility report primarily for illustrative purposes as it is recognized that parameter values used by the program are not strictly applicable to other regions of the United States where precipitation patterns and agricultural practices differ substantially from those encountered in areas close to the NTS.

One of the critical factors that is known to vary substantially at different locations is the initial retention of fallout by fresh vegetation, particularly when deposition occurs with precipitation. Some increase in the precision of predicted doses might be achieved if county-by-county estimates of rainfall for each day following each shot were retrieved from National Weather Service records and used to adjust the calculated retention of fallout on plants, as was done in NCI (1997) for the dose from ^{131}I. That effort was beyond the scope of the present feasibility study, though could be a part of any future work.

Dose Coefficients. The ICRP-tabulated values are the source of dose coefficients used for these dose calculations. Recently, the ICRP (1998) has made available a system that allows the calculation of absorbed and effective doses for all organs for the six age groups considered by the ICRP (<3 months, 1 year, 5 year, 10 year, 15 year, adult). The dose coefficients 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. In this feasibility report, doses are calculated through the year 2000, corresponding roughly to the period 50 years following the intake. The ICRP dose coefficients are applicable to that situation with very little approximation because the doses from most radionuclides taken into the body are delivered within the first year after the intake.

Organs of Interest. In principle, doses can be calculated for the 22 organs considered by the ICRP and for which dose coefficients are available (ICRP 1998).

However, experience from ORERP (Ng et al. 1990) is that only the thyroid gland would likely receive a higher dose from the ingestion of NTS fallout compared to the dose received from external exposure to the same fallout. Hence, doses (and risks described in a later chapter) to two organs are emphasized: (1) red bone marrow, because of its role as a blood forming organ in which leukemia can arise, and (2) the thyroid, in which thyroid cancer and other diseases can be induced.

Periods of Exposure. For each county (or part of a county) and for each radionuclide, the cumulative dose was calculated through the year 2000 for the depositions resulting from tests that took place in the years of 1951, 1952, 1953, 1955, 1957, or 1962.

NTS Internal Dose. In addition to absorbed doses to thyroid and red bone marrow, effective doses have also been calculated. The calculated internal doses from the 19 radionuclides considered are summarized for each county by year of test (1951, 1952, 1953, 1955, 1957, and 1962) and for all NTS tests together. Multiplying the average dose for each county by the estimated 1954 population and summing over all counties in the country calculated estimates of collective dose to the entire contiguous United States. Some internal dose was estimated to have been received in every county considered.

The highest estimate of cumulative internal effective dose from NTS fallout (1.8 mSv) was for Nye County, Nevada, and the lowest (0.010 mSv) in Wahkiakum County, Washington. The counties receiving greatest internal dose from NTS fallout were in general in Nevada and in Utah due to their close proximity to the NTS and because they were generally downwind from the test site, while the counties receiving the lowest internal dose were in the Pacific Northwest, primarily Washington and Oregon. Though the 3,000+

counties could be ranked according to the magnitude of the estimated dose, the precision of the feasibility calculations is not great enough to make quantitative distinctions about differences in dose among counties. The maps provided are only an indicator of the general geographic distribution of dose over the United States. Figure 3.12 presents estimated internal dose to red bone marrow for children born 1 January 1951 while Figure 3.13 presents estimated internal dose to the thyroid for children born 1 January 1951. County-specific dose estimates for children (born 1 January 1951) range from <0.1 mGy in less than 10 counties to as high as 300 mGy over 550 counties. Those estimates assume average milk consumption. In general, thyroid doses for adults are a factor of 10 times lower.

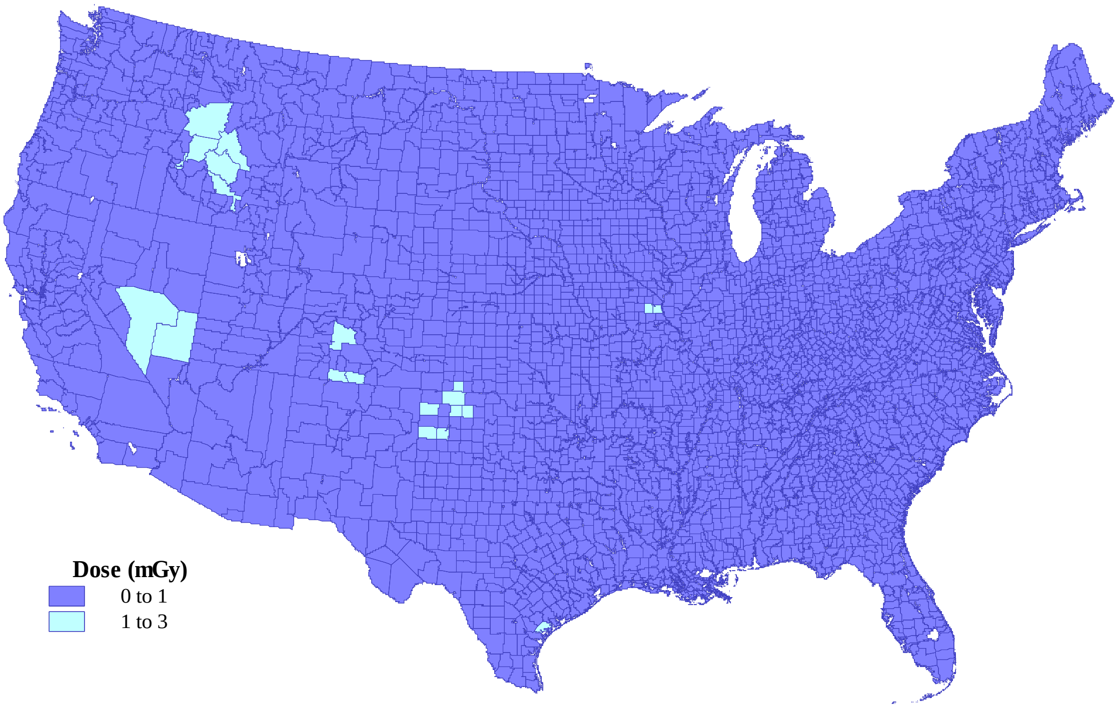

Figure 3.12. Internal dose to red bone marrow of a child born 1 January 1951 from all NTS tests.

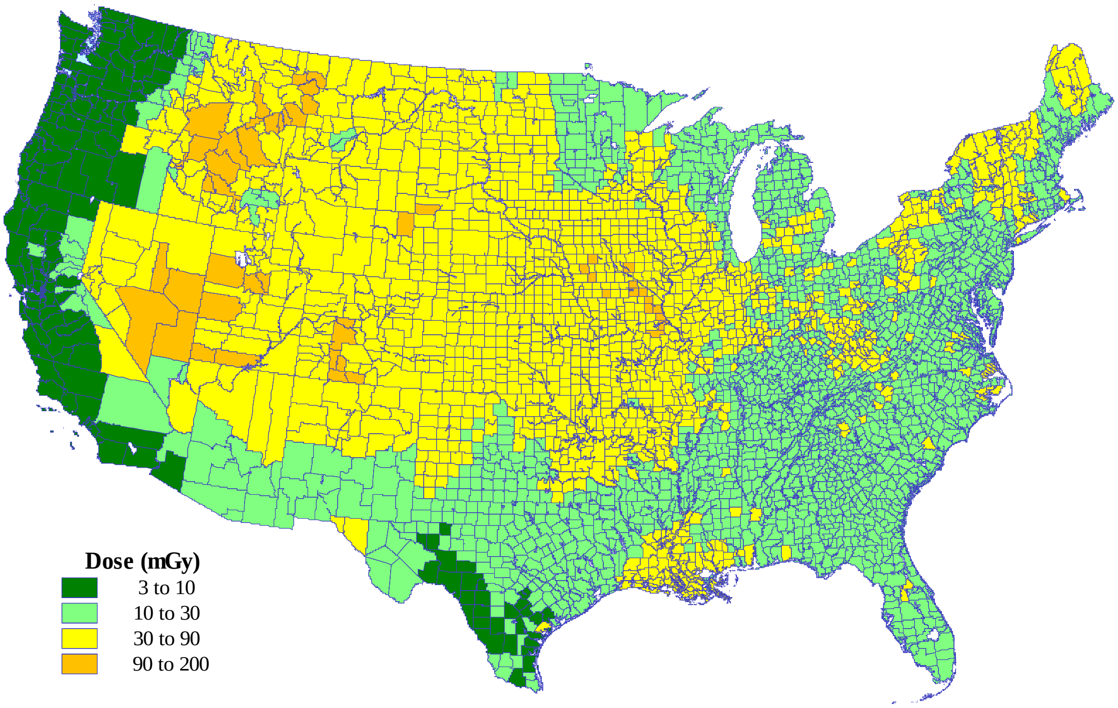

Figure 3.13. Internal dose to the thyroid of a child born 1 January 1951 from all NTS tests.

The population weighted bone marrow and thyroid doses from all NTS tests are summarized in Table 3.6. It should be noted that the values of thyroid dose in Table 3.6 are dominated by the dose from ^{131}I.

Table 3.6. 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

Population-Weighted Effective Dose by Year of Testing. The population-weighted (adult) internal effective doses by year of testing are shown in Table 3.7. The highest contribution occurred in 1957 from the 16 explosions of Operation Plumbbob. The second and third larger yearly contributions were 1952 as a result of the eight events of Operation Tumbler-Snapper and 1953 as a result of the 11 events of Operation Upshot-Knothole. A surprisingly large contribution is attributed to the two explosions that occurred in 1962 during Operation Storax; almost all of the latter was due to Project SEDAN, a large cratering experiment. As noted earlier, the intake of radionuclides through foodstuffs varies by time of year (see Figures 3.9 through 3.11). Because a large number of tests in 1957 took place in high food production months June through August (see Table 3.1), that year contributed more than twice the ingestion dose of any other year.

Table 3.7. Population-weighted (adult) effective dose from ingestion, calculated through year 2000, specified by year of testing.

Year of Testing	Effective Dose from Ingestion (mSv)
1951	0.012
1952	0.063
1953	0.049
1955	0.037
1957	0.13
1962	0.041
Total	0.33

Population-Weighted Effective Dose by Nuclear Test. The population-weighted (adult) effective doses (through the year 2000) for the 10 tests contributing the largest doses are presented in Table 3.8. Project SEDAN surprisingly heads this list. However, it should be noted that the precision on the doses from Project SEDAN is low and the values could be overestimated by one or more orders of magnitude. A careful re-evaluation of the data used by NCI (1997) to estimate the fallout from this test will be necessary in any follow-up study. The unknown fission yield is one reason for the low precision though the use of the meteorological model also added considerable uncertainty to the dose estimates. The reason that this test appears to be such a large contributor to the collective effective dose is that this event took place during a time of year when the intake function was at a maximum. The other events listed in Table 3.8 are generally known to have been major contributors to off-site dose, and they also occurred primarily during the time of year when environmental transfer would have been high. Together, these 16 events account for 73% of the effective dose (to adults at time of exposure).

Table 3.8. Population-weighted (adult) effective dose from ingestion for the 16 nuclear explosions giving largest predicted doses.

Event (series, test)	Date	Effective Dose (mSv)
Storax SEDAN	6 July 1962	0.038*
Tumbler-Snapper GEORGE	1 June 1952	0.027
Plumbbob DIABLO	15 July 1957	0.025
Upshot-Knothole HARRY	19 May 1953	0.017
Plumbbob KEPLER-OWENS	24–25 July 1957	0.016
Plumbbob HOOD	5 July 1957	0.016
Tumbler-Snapper HOW	5 June 1952	0.013
Upshot-Knothole SIMON	25 April 1953	0.012
Plumbbob PRISCILLA	24 June 1957	0.012
Teapot ZUCCHINI	15 May 1955	0.010
Plumbbob GALILEO	2 September 1957	0.010
Teapot APPLE 2	5 May 1955	0.010
Tumbler-Snapper FOX	25 May 1952	0.0086
Plumbbob DOPPLER	23 August 1957	0.0086
Plumbbob WILSON	18 June 1957	0.0080
Buster CHARLIE	30 October 1951	0.0067

*Values for SEDAN have very low precision and should be re-evaluated in future work.

Population-Weighted (Adult) Effective Dose by Radionuclide. External and internal absorbed doses calculated in this report are listed in Table 3.9. The fifteen radionuclides listed in this table contributed more than 98% of the estimated effective dose. Iodine-131 alone accounts for 76% of the population-weighted (adult) effective dose. Of the ten most important radionuclides, only ^{90}Sr and ^{137}Cs are long-lived. Plutonium radionuclides, though long-lived, accounted for only 0.4% of the estimated total effective dose.

Table 3.9. Comparison of population-weighted (adult) external dose, internal red bone marrow and thyroid dose from all tests at the NTS according to radionuclide, calculated through the year 2000.

Radionuclide*	Half-Life	External Dose (mGy)*	Internal Dose to Thyroid (mGy)	Internal Dose to Red Bone Marrow (mGy)
^{89}Sr	50.5 d	-	0.001	0.03
^{90}Sr	28.8 y	-	-	0.02
^{95}Zr-^{95}Nb	64.0 d	0.08	-	-
^{97}Zr-^{97}Nb	16.7 h	0.02	-	-
^{103}Ru	39.3 d	0.03	-	-
^{106}Ru	374 d	<<0.005	0.001	0.002
^{132}Te-^{132}I	3.2 d	0.1	0.06	0.001
^{131}I	8.02 d	0.02	5	0.001
^{133}I	0.9 d	0.02	0.04	-
^{135}I	20.8 h	<0.01	-	-
^{136}Cs	13.2 d	-	0.002	0.002
^{137}Cs	30.1 y	0.01	0.009	0.009
^{140}Ba-La	12.8 d	0.2	-	0.006
^{144}Ce	285 d	<0.005	-	-
^{239}Np	2.36 d	0.02	-	-
Sum (rounded)		~0.5	5	~0.1

*These fifteen radionuclides account for more than 98% of the total dose from ingestion and external exposure.

Population-Weighted (Adult) Dose by Organ. Population-weighted (adult) doses from each radionuclide were calculated for each organ that had a dose coefficient more than twice that of the dose coefficient for effective dose. The population-weighted organ doses were calculated by using the organ doses whenever they were available; otherwise 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.

Table 3.10 gives the population-weighted (adult) doses by organ and indicates that many organs, except for thyroid, had doses of similar magnitude. In terms of population health risk, those organs listed in Table 3.10 would be of greatest potential interest and concern.

Table 3.10. Estimates of population-weighted (adult) organ dose and effective dose from ingestion through the year 2000 from all NTS tests.

Organ	Organ Dose (mGy)	Fractional Contribution to Effective Dose
Liver	0.086	0.01
Red marrow	0.1	0.04
Bone surface	0.19	0.01
Colon	0.34	0.12
Thyroid	5.0	0.76
Remainder of soft tissues	0.032	0.06
Effective (mSv)	0.33	

About two thirds of the population-weighted cumulative dose to the bone surface was contributed by three radionuclides: ^{90}Sr, $^{239+240}$Pu, and ^{89}Sr in that order. For the colon, about three fourths of the dose was contributed by four radionuclides: ^{89}Sr, ^{140}Ba, ^{106}Ru, and

^{144}Ce in that order. It is also useful to note that these population-weighted organ doses have about the same magnitude as the dose received from external radiation, as inferred from Table 3.4.

The only organ that has received a substantially higher population-weighted dose from NTS fallout due to the ingestion of contaminated foods as compared to the dose from external exposure is the thyroid, which is estimated to have received a county-average dose about 10 times higher than that due to external exposure from NTS fallout.

Dose From Inhalation. For this feasibility study, doses from inhalation of radioactive particles and gases have not been estimated. The primary difficulty in making such estimates is that one needs values of integrated air concentrations and such data are not presently available. When the gummed-film network was being operated in the late 1950s and 1960s, 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 interpolating the data between measurement stations, as well as considering rainfall, to produce estimates on a county-by-county basis.

Past experience 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 due to 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, e.g., $^{239+240}$Pu.

Equations and theory exist to calculate inhalation dose, however, little data are available. Hence, inhalation doses will always remain imprecise.

Comparison of Results with Those From NCI (1997). The National Cancer Institute report on exposure of the American people to ^{131}I (NCI 1997) presents the results of a very detailed, multi-year study of the dose to the thyroid for residents of the United States from ^{131}I. A primary finding from that study was that the collective thyroid dose was 4,000,000 person-Gy, whereas this report estimated 2,000,000 person-Gy. These differences are primarily due to differences in modeling assumptions; nevertheless, such a level of agreement is considered to be good for retrospective dose estimates.

The doses estimated by NCI (1997) appear to be higher in Idaho, Montana, and the Midwest than from this feasibility study. Those differences most likely result from the different assumptions for the important factor describing the amount of fallout retained by vegetation. For this study a constant value was used, where NCI (1997) used a value that varied depending upon the amount of rainfall. This and related issues should be examined in more detail in any future assessment.

Sum of External and Internal Dose From NTS Fallout. The sum of the external and internal dose components is shown in a series of maps. Figures 3.14 and 3.15 show the sum of external and internal dose to the red bone marrow for adults and children, respectively. The geographic distribution of doses received is very similar for the two age categories. Figures 3.16 and 3.17 shows the sum of external and internal dose to the thyroid for adults and children, respectively. A comparison of these two maps shows that, in general, thyroid doses were much greater for children than for adults. Geographic areas where the highest thyroid doses were received included the counties near to the NTS, a group in the northern Rocky Mountains, and a few isolated counties in Colorado and the Midwest. For both red bone marrow and thyroid, populations living in the vicinity of the NTS received the highest doses from NTS fallout, while populations living along the western and eastern coasts received the lowest doses.

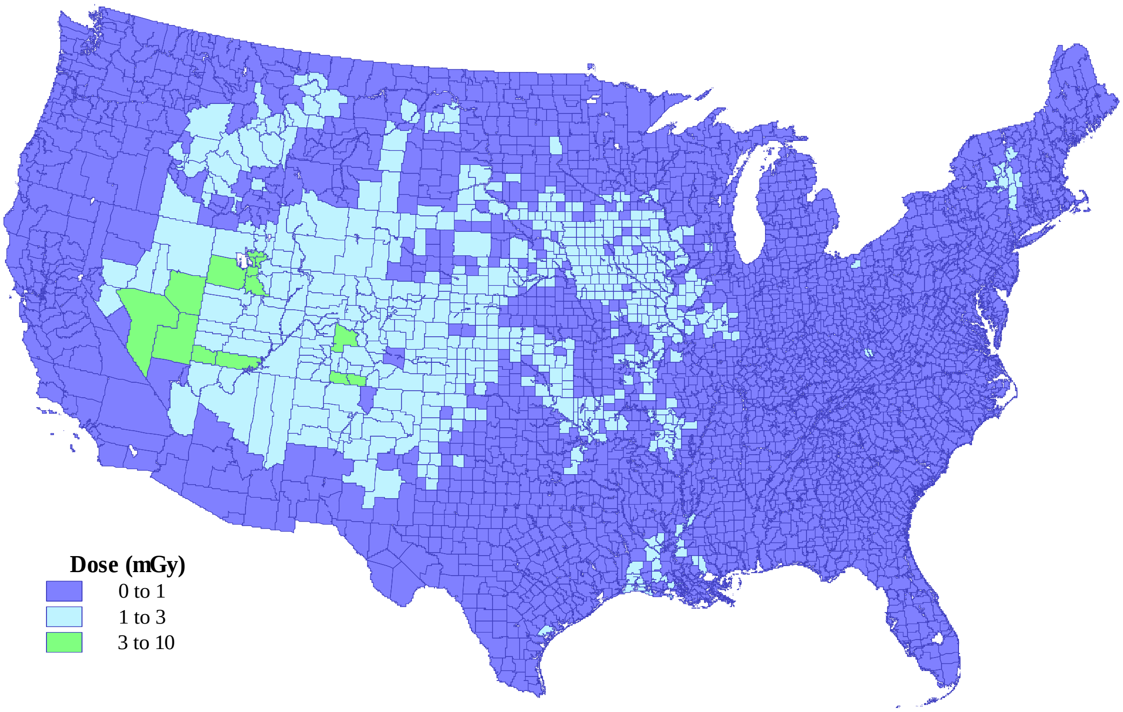

Figure 3.14. Total (external + internal) dose to the red bone marrow of an adult from all NTS tests.

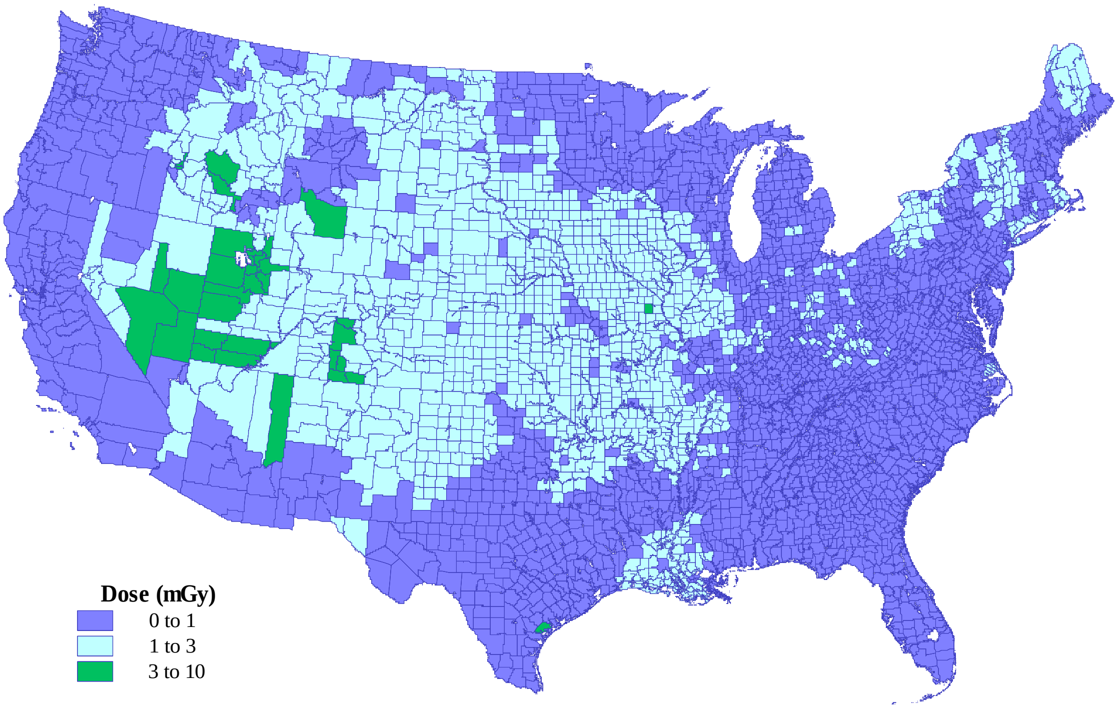

Figure 3.15. Total (external + internal) dose to the red bone marrow of a child born on 1 January 1951 from all NTS tests.

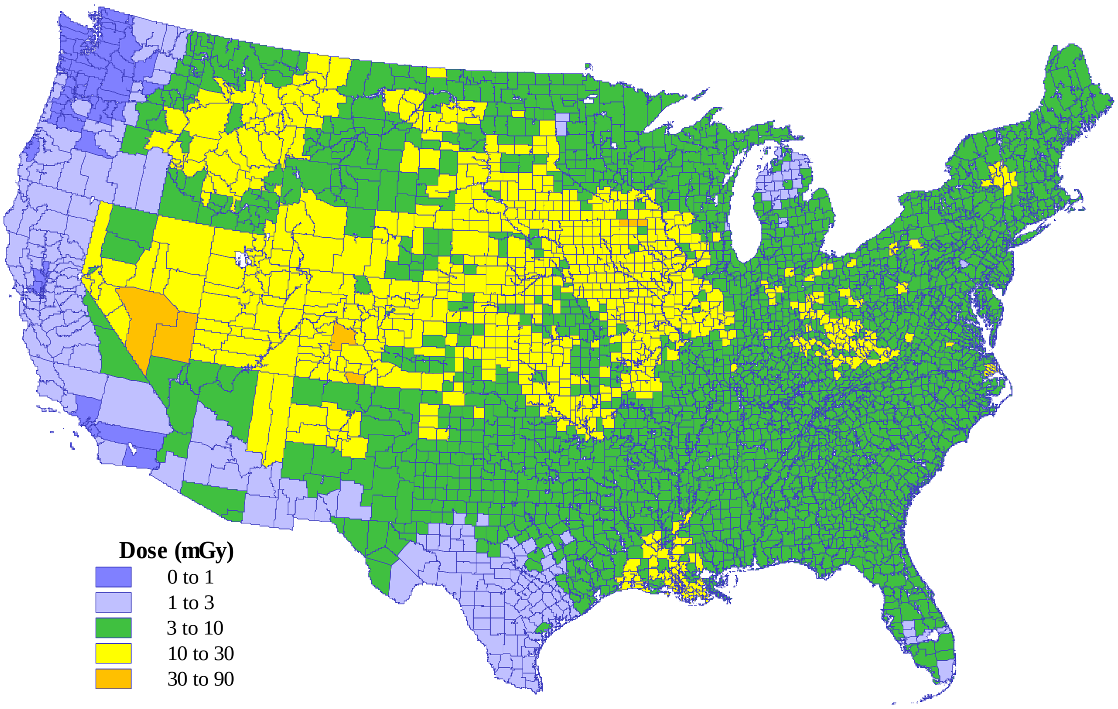

Figure 3.16. Total (external + internal) dose to the thyroid of an adult from all NTS tests.

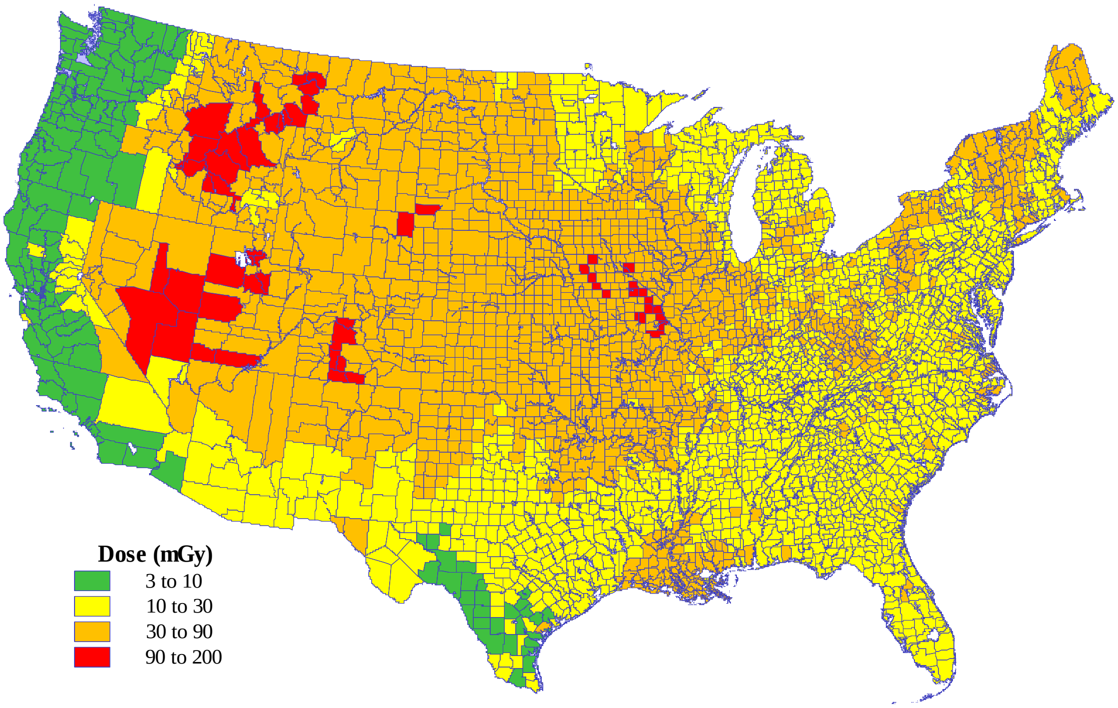

Figure 3.17. Total (external + internal) dose to the thyroid of a child born on 1 January 1951 from all NTS tests.

3.3 Global Fallout

In the previous section, calculations of the external and internal dose to the population of the contiguous United States from Nevada Test Site weapons tests were described. Other tests were conducted at a number of locations throughout the world and are referred to in this report as global nuclear tests and they produced global fallout. As noted earlier, the mostly low yield (<100 kT) weapons tests conducted at the NTS injected almost all of their debris into the lower atmosphere (troposphere) where it was deposited mostly within the contiguous United States. In contrast, the mostly high yield (i.e., thermonuclear tests with yields greater than 1 Mt accounted for over 90% of the fission products produced) tests carried out by the United States, U.K. and U.S.S.R. in the Pacific and at various sites in the U.S.S.R. injected most of their debris into the stratosphere

(UNSCEAR 1982, 1993). The total fission yield (see table 3.11) of these tests was about 170 Mt of which only about 1 Mt was from NTS tests. However, because of the long residence times for the transfer of air between the stratosphere and troposphere (on the order of 1 year), the fallout from these high yield tests was relatively depleted of short-lived radionuclides. Thus the total deposition in the contiguous United States of short-lived radionuclides such as ^{131}I was considerably lower than that from NTS tests.

The fusion yields estimated to have occurred in the northern hemisphere as a function of time are indicated in Table 3.11. These values were derived from total yield values reported in UNSCEAR (1993), DOE (1994), and Mikhailov et al. (1996). Explosions very close to the equator are conservatively considered to have taken place in the northern hemisphere.

Table 3.11. Estimates of Fission and Fusion Yields (Mt) by Year

Year	Fission Yield* (Mt)	Fusion Yield (Mt)
1952	6	5
1953	0.04	0.36
1954	31.1	17
1955	1	0.88
1956	9.6	13
1957	4.9	3.9
1958	27	31
1959	0	0
1960	0	0
1961	18	69
1962	72	99
Total	170	240

*Fission yields are estimated because some data remain classified. Assumptions are: tests smaller than 0.1 Mt total yield were assumed as 100% fission, tests in the range 0.5-5 Mt, fission were assumed to be 50% fission, tests in the range 0.1-0.5 Mt were assumed to be 67% fission.

The debris from the large tests conducted in the Pacific and in Russia was dispersed throughout the atmosphere resulting in global fallout. This fallout was deposited in a relatively uniform pattern across the United States. The amounts of the longer-lived radionuclides, such as ^{137}Cs and ^{90}Sr were about 10-15 times that from NTS fallout. However, in this preliminary study, it was not feasible to estimate the deposition density of ^{131}I from global fallout in individual counties with a high degree of confidence.

While much of the fallout from NTS tests, particularly in areas close to the NTS, fell to the ground without any accompanying rainfall, most of the debris from global fallout was deposited by precipitation which tended to effectively wash the debris from the lower altitudes after the material fell from high altitudes where it was originally transferred by the explosion. Thus, the deposition density of fallout in each county was closely related to the frequency and intensity of rain, particularly during the months when fission products were at their peak concentration in the lower atmosphere.

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

3.3.1 Global Fallout Deposition Density

Global fallout, in general, originated from weapons that derive much of their yield from fusion reactions. These explosions, conducted by the United States and the U.S.S.R., but entirely outside the contiguous United States, produced large amounts of ^{3}H and the intense neutron flux also produced large amounts of ^{14}C through the irradiation of nitrogen in the atmosphere with high-energy neutrons. Though these two radionuclides are created and/or released mainly by fusion explosions, they are also created in the atmosphere by some naturally occurring processes. Because ^{3}H and ^{14}C enter their respective environmental pools, and cycle in the environment according to their own chemical properties, they do not deposit in the same manner as do radionuclides associated with more insoluble fallout particles. Hence, the usual methods of calculating deposition density are not appropriate. In order to calculate the dose from ^{3}H and ^{14}C, it is necessary to estimate the amount of activity created per unit of fusion energy and to estimate the fusion yields as a function of time. Based on the combination of naturally occurring rates and measurements of the concentrations in components of the environment (including man), it has been possible to estimate the dose per unit release of ^{3}H or ^{14}C using the specific activity approach (UNSCEAR 1993).

When considering the transport of the radioactive debris around the world, it is known that there is little movement of radionuclides across the hemispherical boundary, so the fusion yield (see Table 3.11) in the northern hemisphere is of primary importance for this assessment. Most of the fusion tests took place in the northern hemisphere, but with a substantial number near the equator. The assumption is made here that the radioactivity created by northern hemisphere fusion tests remained in the northern hemisphere, though that assumption is somewhat conservative.

For global fallout, the mix of radionuclides of concern differs from that of NTS fallout for several reasons. The main reason is that global fallout by definition consists of radioactive debris that is globally dispersed due to its injection into the high atmosphere by the force of large explosions. Due to its high-altitude dispersion, over half of the global fallout typically does not return to earth for one or more years. During this time the short-lived fission products decay to very low levels and, except for unusual occurrences, the short-lived radionuclides of concern for NTS fallout are not of concern in the case of global fallout. Two radionuclides, ^{90}Sr and ^{137}Cs, however, have long half-lives (about 30 y each) and do not decay appreciably before they return to earth. These two radionuclides were studied extensively due to their widespread presence in global fallout.

On the basis of data provided by UNSCEAR (1993) on relative doses from individual radionuclides produced in the large nuclear devices, a set of radionuclides was selected for external and internal dose calculations in this study (see Table 3.12). The inclusion of ^{131}I on the list for internal dose may be surprising, as its half-life is only eight days. The appearance of ^{131}I in global fallout has tended to be sporadic, but contamination of milk in the United States from global fallout has been observed on a number of occasions (e.g., Dahl et al. 1963; Terrill et al. 1963). Possible mechanisms for these sporadic occurrences have been suggested by Machta (1963) and include the subsidence of large air masses contaminated with debris from U.S.S.R. tests at its Novaya Zemlya site near the Arctic Circle, and the penetration of large thunderstorms into the upper troposphere and stratosphere that resulted in the scavenging of debris from the United States tests in the Pacific. Deposition density estimates were made for each nuclide contributing significantly to the external exposure and dose from global fallout during the years 1953-72 (see Table 3.12). The monthly results for individual nuclides deposited from global fallout were summed to provide annual and cumulative estimates of deposition density for each county as well as used to derive population-weighted estimates for the contiguous United States.

Monthly deposition densities were estimated for the radionuclides listed in Table 3.12. Plutonium deposition was only crudely estimated and relied on the fact that it is generally proportional to ^{90}Sr deposition (UNSCEAR 1993). The methods used to estimate the deposition density of the fallout radionuclides from global fallout used records of the average precipitation for each month in each county of the contiguous United States as well as available radionuclide deposition density data and results of soil analyses. Monthly precipitation has been measured at over 8000 National Weather Service cooperative monitoring sites and data are available for most sites beginning in about 1900. For this preliminary feasibility study, a single estimate of monthly precipitation was obtained for each county for each month from 1953-1972 by averaging the available reported monthly data for that county. There are many possible errors in estimating a monthly precipitation value, including whether the average data at the monitoring stations are representative of the entire county or where most of the people resided.

Table 3.12. Radionuclides deposited in global fallout for which deposition densities and doses were calculated.

Radionuclide	Half-Life	Used in External Global Fallout Dose Calculations	Used in Internal Global Fallout Dose Calculations
^{3}H	12.3 y		x
^{14}C	5700 y		x
^{54}Mn	312 d	x	
^{90}Sr, ^{90}Y[a]	28.8 y	x	x
^{95}Zr	64.0 d	x	
^{95}Nb	35.0 d	x	
^{103}Ru, ^{103m}Rh[a]	39.3 d	x	
^{106}Ru, ^{106}Rh[a]	374 d	x	
^{125}Sb	2.76 y	x	
^{131}I	8.02 d	x	x[b]
^{137}Cs	30.1 y	x	x
^{140}Ba, ^{140}La[a]	12.8 d	x	
^{141}Ce	32.5 d	x	
^{144}Ce, ^{144}Pr[a]	285 d	x	
$^{239+240}$Pu	24,100y/ 6560 y		

[a] In equilibrium with parent radionuclide
[b] Population weighted dose only (not county-specific)

The most important radionuclide deposition density data that are available for global fallout are the monthly ^{90}Sr deposition density measurements reported by the HASL for about 30 sites across the United States (HASL 1958-72, USERDA 1977). The number of monitoring sites varied from year to year with the maximum number in operation during

1962-1965. Little or no data exist for years prior to 1958. In a separate program, the HASL monitored total deposition of beta-emitters at about 50 sites from 1952 through 1960 using gummed film (see Beck 1999, Beck et al. 1990). However, only the data for limited periods of time following the NTS tests have been reevaluated, and thus the data useful for estimating global fallout were unavailable for use in this analysis.

In order to estimate the deposition density of ^{90}Sr in each county of the contiguous United States on a monthly basis, it was assumed that the deposition density in any particular county was proportional to the precipitation that occurred in that county during that month. Since the deposition density per cm of precipitation has been shown to vary significantly with latitude and longitude (see Appendix F), it was necessary to develop a model describing this variation.

It should be noted that this crude model for deposition density of global fallout does not account for deposition under dry weather conditions. This is generally not a large error as the fallout under such conditions was probably less than 10% of the total deposition. The impact of not accounting for dry deposition is most significant for the more arid regions of the United States. This model as well as other details could be improved in future efforts. Although the model used to estimate the ^{90}Sr deposition density is fairly crude, a comparison with the available data for a number of sites where sufficient data are available indicates that the agreement is fairly good (see Appendix F).

As for NTS fallout, all calculations for global fallout were carried out separately for each county in the contiguous United States, though estimates have not been made for the states of Hawaii and Alaska. Specifics of those two states, e.g., geography, location relative to test sites, limited measurement data, etc., put calculations for them beyond the limits of the feasibility study, though doses for these states could be addressed in future work.

Only two radionuclides were monitored fairly continuously for global fallout, ^{90}Sr, and for fewer sites and times, ^{89}Sr. The reason for this was that ^{90}Sr at that time was considered to be the most significant health hazard from global fallout due to its incorporation in bone following ingestion of contaminated foodstuffs and because of its long physical and biological half-life. Thus, other radionuclides were monitored infrequently and only at a few sites in the United States. Because short-lived nuclides such as ^{95}Zr-^{95}Nb and others listed in Table 3.12 contributed significantly to external exposure rates, it is necessary to estimate the deposition density of these nuclides as well in order to estimate the exposure of the United States population to external gamma radiation.

Because of the sparseness of available environmental measurement data on deposition of global fallout, a mathematical model which describes the global circulation patterns that control the dispersion of fallout was used to estimate the activity ratios of various nuclides to ^{90}Sr deposition for periods when no data were available (Bennett 1978). The model predicts quite well the variation of ^{90}Sr deposition over time (UNSCEAR 1982). However, the estimates of the deposition density of the shorter-lived nuclides such as ^{131}I are much less precise because of the very small number of environmental measurement data that could be used to calibrate the model. The deposition density of each of the radionuclides listed in Table 3.12 was estimated for each county and month by multiplying the estimated ^{90}Sr deposition density for that county and month by the ratios of isotopes estimated for each month. The estimates for the more important contributors to external dose, ^{95}Zr-^{95}Nb and ^{137}Cs are probably quite reasonable since (1) ^{95}Zr was measured in precipitation or air at several sites in 1958 and 1961-62 and ^{89}Sr was measured at a relatively large number of sites (HASL 1958-72), and (2) the activity ratio of ^{137}Cs to ^{90}Sr in fallout is relatively constant.

The total deposition of ^{137}Cs from global fallout during the years 1953 through 1972 is shown in Figure 3.18. In general, the lowest values of deposition density occur in the western, more arid United States. The area of the country from just east of the Mississippi River to the eastern seaboard was relatively uniform in the amount of ^{137}Cs deposited by global fallout. Table 3.13 gives the calculated total deposition of each radionuclide and the population-weighted deposition density from global fallout (1953-1972), and compares these with the estimates for NTS fallout and estimates for the Northern Hemisphere from UNSCEAR (1993).

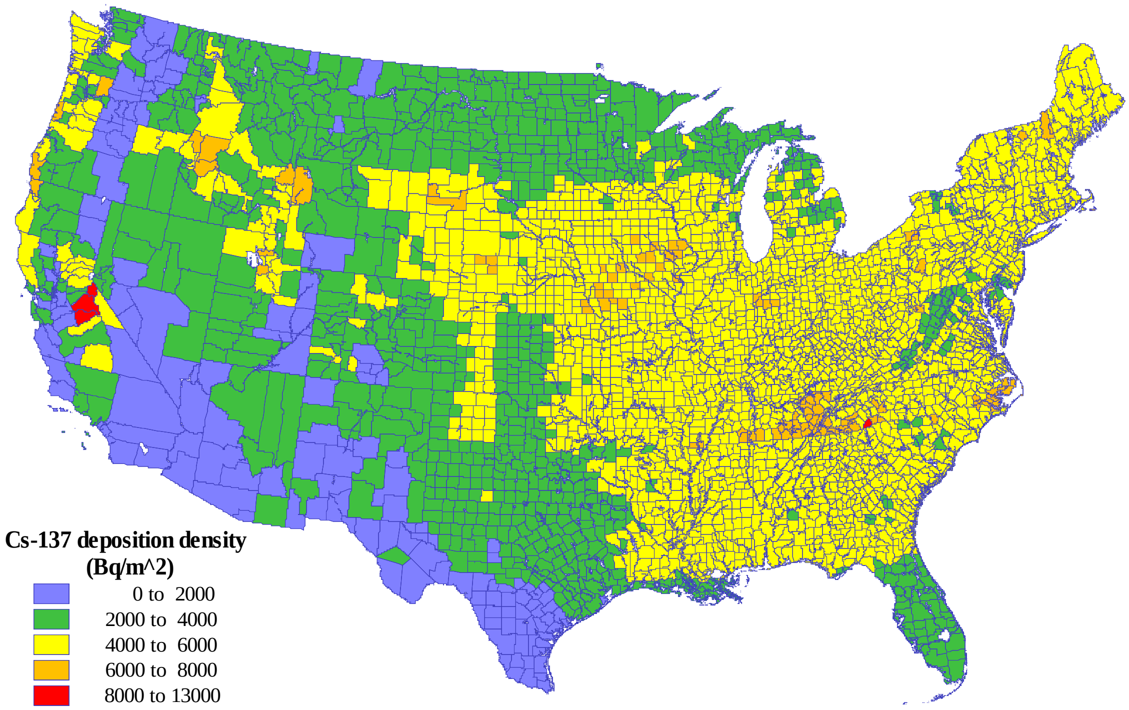

Figure 3.18. Cesium-137 deposition density due to global fallout.

This table (3.13) shows that the deposition of long-lived radionuclides from global fallout is about a factor of 10-15 greater than that from NTS fallout. However, the total deposition of short-lived nuclides such as ^{131}I was much less for global fallout than for NTS fallout. In general, the deposition density of NTS fallout generally declined as the distance from NTS increased. The higher relative proportion of global fallout in the more populous (and wetter) eastern United States resulted in a relatively higher per capita exposure from global fallout.

Table 3.13. Total deposition and population-weighted deposition density of selected radionuclides for NTS fallout and global fallout (sorted by decreasing half-life).

		Total Deposition (10^{15} Bq)		Population weighted deposition density (kBq m^{-2})		
Nuclide	Half-life	NTS	Global	NTS	Global (this study)	Global*
$^{239+240}$Pu	24,100 y/ 6560 y	0.13	~0.4	~0.015	~0.06	0.06
^{137}Cs	30.1 y	2.3	29	0.26	4.4	5.2
^{90}Sr	28.8 y	1.8	19	0.11	2.9	3.2
^{106}Ru	374 d	24	150	2.6	24	24
^{144}Ce	285 d	40	300	4.6	46	48
^{95}Zr	64.0 d	220	310	25	50	38
^{89}Sr	50.5 d	330	210	36	35	20
^{103}Ru	39.3 d	430	210	46	35	28
^{95}Nb	35.0 d	0	400	0	65	64
^{141}Ce	32.5 d	500	210	54	34	21
^{140}Ba	12.8 d	1400	290	140	46	23
^{131}I	8.02 d	1500	110	190	18	19

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

3.3.2 Global Fallout External Dose

The exposure rate in air was calculated as an intermediate step to estimating the dose to an exposed adult (see Appendix F). Doses were calculated from each radionuclide present in the soil as a result of the cumulative deposition density; those calculations used conversion factors from Beck (1980). The dose contributions from each radionuclide were summed to estimate the total monthly effective dose, the annual effective dose from external radiation, and the total effective dose for an individual resident in the same county throughout the period 1953-2000. Population-weighted (per capita) effective doses were also calculated by weighting the individual county estimates by the county population during the time of testing. As for external dose from NTS fallout, it was assumed that the absorbed dose to the red bone marrow and the thyroid (expressed in mGy) is numerically equal to the effective dose (expressed in mSv), and there is no age dependency in the conversion factors from exposure rate to effective dose rate. The radionuclides that contributed most to both gamma and beta-particle exposures are identified.

The calculations that convert exposure rate to dose assumed the activity of all radionuclides was distributed shallowly in the soil for the first 20 days and then penetrated deeper (due to rainfall) during the next 200 days, with still deeper penetration at later times. These concepts are important to the calculations because as the activity washes to deeper depths, the ground above it shields people to some extent from the gamma rays emitted by the radionuclides. The actual rate of penetration into the soil will, of course, vary from site to site depending on soil type, amount of precipitation, etc.

The geographic distribution of external dose from global fallout is shown in Figure 3.19. There was little variation across the United States; in general, external doses received were 1 mGy or less. This map pertains equally well for the dose to red bone marrow and to the thyroid gland, both in adults and in children.

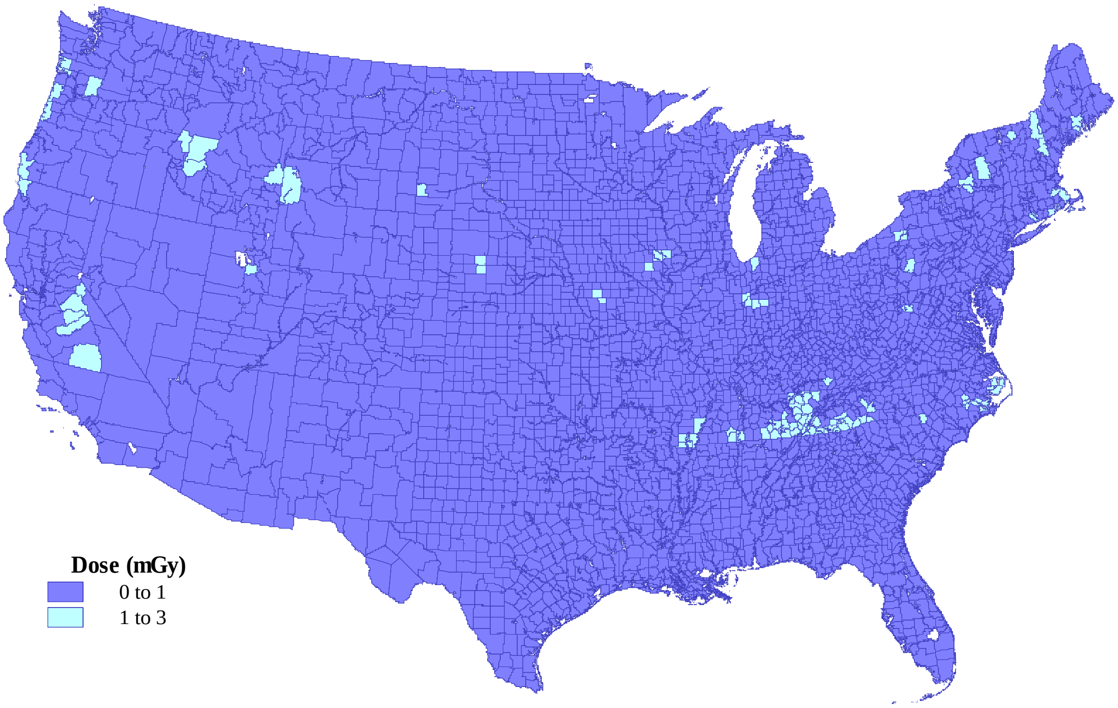

Figure 3.19. External dose to the red bone marrow and the thyroid gland resulting from global fallout.

The collective dose delivered as a function of time was investigated by calculating the collective dose for each county (the product of the average dose for a given county multiplied by its population) and then summing over all counties. The annual collective dose versus year of exposure is given in Table 3.14. The population-weighted (per capita dose) dose is also shown. The corresponding estimates for NTS fallout are provided for comparison.

Table 3.14. Collective dose and population-weighted external dose versus year of exposure

	Global Fallout		NTS Fallout[a]	
Year	Collective Dose (10^3 person-Gy)	Population-weighted Dose (mGy)	Collective Dose (10^3 person-Gy)	Population-weighted Dose (mGy)
1951			6.5	0.039
1952			15	0.093
1953	1.1	0.007	19	0.12
1954	2.8	0.017	0.2[b]	0.001[b]
1955	1	0.006	12	0.072
1956	4.1	0.025	0.1[b]	0.001[b]
1957	4.9	0.03	20	0.12
1958	6.8	0.042	0.8[b]	0.005[b]
1959	7.7	0.047		
1960	1.6	0.01		
1961	3.3	0.02		
1962	14.5	0.089	4.7[c]	0.029
1963	12.6	0.077		
1964	5.9	0.036		
1965	3.7	0.023		
1966	3.0	0.019		
1967	2.4	0.015		
1968	2.3	0.014		
1969	2.1	0.013		
1970	2	0.012		
1971	1.8	0.011		
1972	1.8	0.011		
1973-2000	34.4	0.211	0.33 (1963-2000)	0.0028
Total	119.8	0.74	79	~0.5

[a] Based on 1960 United States population of 1.63 x 10^8

[b] From previous years fallout.

[c] Value is imprecise (Test SEDAN)

From Table 3.14, it can be seen that the collective effective dose and the population-weighted dose from global external radiation through the year 2000 were about 50% higher than those from NTS fallout. The population-weighted effective dose from global fallout was estimated to be 0.74 mGy. UNSCEAR in 1993 estimated a population-weighted dose from global fallout in the latitude band 40-50 degrees to be about 1 mGy. Considering the variations in fallout with latitude discussed earlier in this report, the present dose estimates and the UNSCEAR estimate agree well. The highest annual per capita doses occurred in 1962 and 1963 and are comparable to the annual per capita doses from NTS fallout in 1952, 1953, 1955 and 1957. In fact, the collective dose from global fallout through 1972 was comparable to that from the NTS for the same period.

As noted earlier, a large number of fission products are produced in a nuclear explosion, however, only a relatively few account for most of the external dose. Table 3.15 shows the radionuclides in global fallout that are the largest contributors to lifetime exposure. The percentages from each radionuclide vary only slightly with location but vary significantly from year to year as shown in Figure 3.20. Figure 3.21 shows the population-weighted dose that resulted from each radionuclide and the total as a function of time. The short-lived radionuclides have been grouped. As can be seen, during periods of testing the shorter-lived isotopes contribute relatively more to the dose while for years with no testing the longer-lived radionuclides are dominant. In contrast to the doses from NTS fallout, very short-lived radionuclides such as ^{132}Te-^{132}I and ^{131}I were insignificant contributors to exposure rates while ^{95}Zr-^{95}Nb accounted for a large portion of the exposure. Most of the cumulative dose from global fallout was due to ^{95}Zr-^{95}Nb and the longer-lived nuclides. Cesium-137 and ^{95}Zr-^{95}Nb accounted for about 70% of the cumulative population exposure (see Table 3.15). In contrast, ^{137}Cs contributed only a small amount (about 2%) of the total dose from NTS fallout.

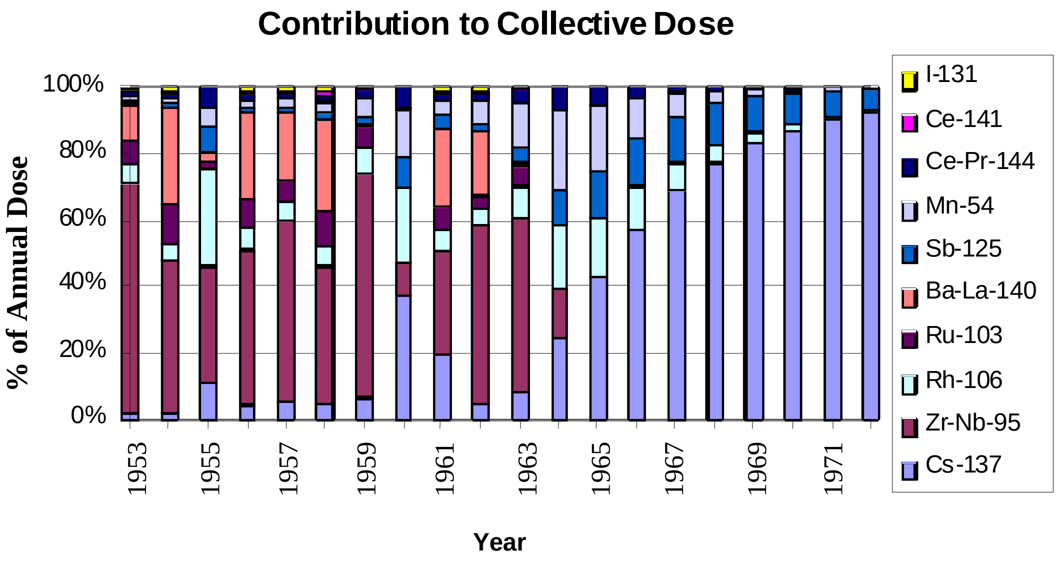

Figure 3.20. Contribution to external exposure from global fallout from individual radionuclides as a function of year.

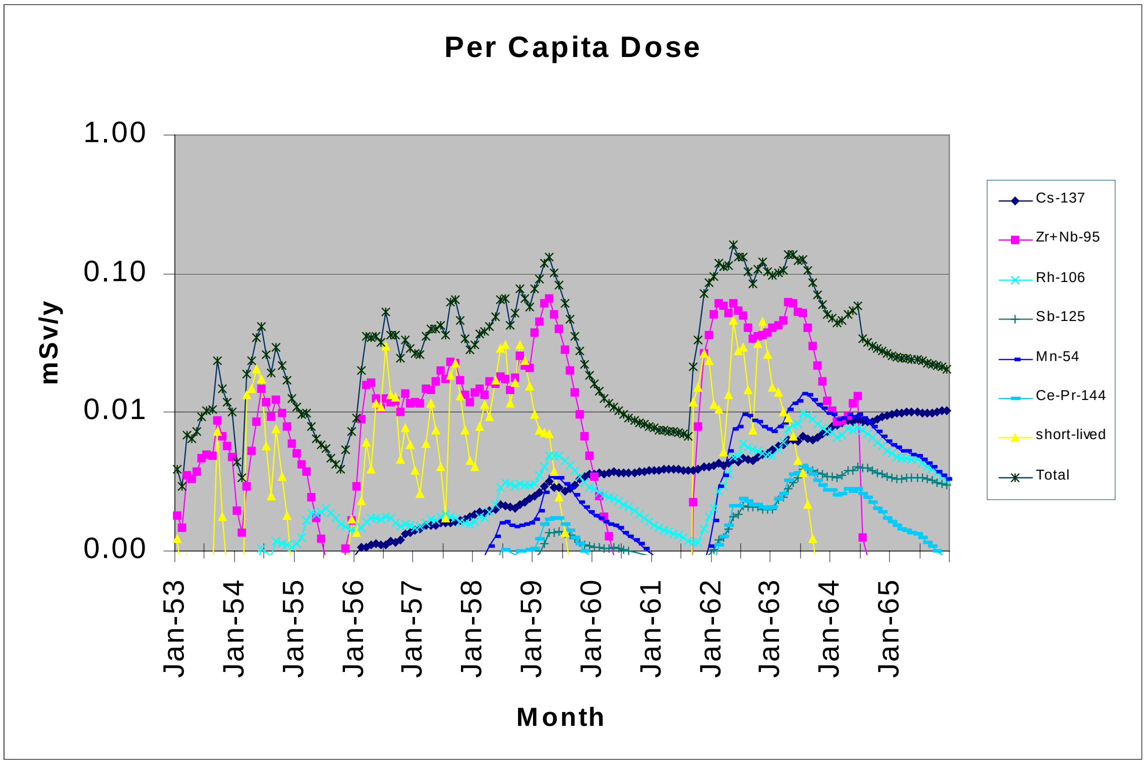

Figure 3.21. Time-dependence of external dose (population-weighted or per capita) from global fallout from individual radionuclides and as sum total.

Table 3.15. Percentage of external dose contributed by various fission products from global and NTS fallout.

Nuclide	Global fallout (1953-2000) (%)	NTS (%)
^{54}Mn	6	0
^{95}Zr-Nb	26	16
$^{97, 97m}$ Zr-Nb	<<1	4
^{103}Ru	3	6
^{106}Ru	6	<<1
^{125}Sb	4	<<1
^{131}I	<1	4
^{132}Te-I	<1	22
^{133}I	<<1	4
^{135}I	<<1	3
^{137}Cs	45	2
^{140}Ba-La	7	34
^{141}Ce	<1	<1
^{144}Ce-Pr	2	<<1
^{239}Np	<<1	4

3.3.3 Global Fallout Internal Dose

In section 3.2.3, absorbed and effective doses to selected organs from internal irradiation were presented for representative residents of the 48 contiguous states as a result of exposure to fallout derived from the tests of nuclear weapon related devices exploded at the Nevada Test Site (NTS). For that effort, doses from the ingestion of contaminated foods were estimated for 19 radionuclides and seven progeny products that would have originated from decay in the body following ingestion. These radionuclides were selected for analysis on the basis of screening calculations that had been performed previously by Ng et al. (1990) for the ORERP (Off-Site Radiation Exposure Review Project). Those radionuclides were estimated to be responsible for about 95% of the total internal dose from the radionuclides released at the NTS. Most of these radionuclides had relatively short half-lives, but were more important in a dosimetric sense than the long-lived radionuclides due to the rapid transport of the radioactivity into local consumable foods.

In this section, the dose from ingestion of food contaminated by global fallout for the five radionuclides likely contributing the largest exposures (^{3}H, ^{14}C, ^{90}Sr, ^{131}I, and ^{137}Cs) is addressed. Some of the useful information for the reconstruction of these doses comes from historical measurements. In particular, ^{90}Sr was studied extensively during the 1950s and 1960s and its deposition densities were measured throughout the world. At that time ^{90}Sr was considered to be one of the most important radionuclides, as it is long lived and, when injected into the stratosphere, it remained there for a few years before being deposited on the earth's surface. It is worth noting that for this feasibility report, the doses from ^{90}Sr, ^{131}I, and ^{137}Cs were estimated from calculated deposition densities. This is in contrast to the doses from ^{3}H (tritium) and ^{14}C that were estimated from the total amount of activity released in all of the northern hemispheric testing. In general, more accurate doses to individuals can be estimated from deposition density estimates. Furthermore, it should be realized that the effective doses from ^{3}H and ^{14}C are numerically equal to the dose they deliver to any organ. This is a consequence that both ^{3}H and ^{14}C become uniformly distributed among body organs due their chemical properties.

The role of ^{131}I in contributing dose to Americans was considerably different for global fallout as compared to NTS fallout. Due to the long time required for fallout debris injected into the stratosphere to fall back to the ground, ^{131}I dispersed from the high-yield tests resulted in much less of a health risk compared to that released as part of NTS fallout. However, from time to time it was noted that high concentrations of ^{131}I in milk did occur in the U.S from global fallout. For this feasibility report it has not been possible to estimate the deposition density of ^{131}I on a county-by-county basis with great accuracy, primarily due to data limitations.

Due to widespread concern about global fallout and its effects beginning in the 1950s, scientists from many countries have been involved in numerous fallout-related studies. For example, concern about global fallout was one of the main reasons that led to the formation of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). That committee has studied global fallout over many years and has issued a number of assessments of the dose from global fallout with primary interest on calculating global averages of dose. The dose estimates provided by UNSCEAR (1993) will be compared to those estimated in this report.

Dose From ^{90}Sr and ^{137}Cs. Ingestion doses from ^{90}Sr and ^{137}Cs originating in global fallout were estimated by a process similar to that used for radionuclides from NTS fallout (see equation 3.1, this chapter). Monthly average values of the integrated intake were derived from Whicker and Kirchner (1987) by interpolation of the date-specific values given. The values used in this study are shown in Figures 3.9 and 3.11 for ^{90}Sr and ^{137}Cs, respectively. The ICRP (1998) age-dependent dose coefficients for the general public were used to convert intake to dose. Doses were calculated on a county-by-county basis for adults and for a representative individual assumed to be born on 1 January 1951.

Values of deposition density of ^{90}Sr were calculated on a county-by-county basis averaged over each month for the years of 1953 through 1972. Values for the deposition density of ^{137}Cs were derived from those of ^{90}Sr by multiplying the ^{90}Sr results by a factor of 1.5 [a similar relationship has been used by UNSCEAR (1993)].

Dose From ^{131}I. For the case of exposure to ^{131}I in global fallout, very approximate values of deposition density were estimated on a population-weighted basis, as it was not possible in this feasibility study to provide precise estimates on a county-by-county basis. Age-dependent integrated intake values were derived from the ORERP calculations. The values used in this study are shown in Figure 3.10. Dose coefficients were taken from the ICRP (1998), and calculations were made for adults and for an individual assumed to be born on 1 January 1951. Because the dose from ingestion of ^{131}I varies strongly with age, population-weighted values of dose were calculated by considering the age distribution of the population in 1960 and by calculating a weighted average value of dose.

Population-weighted ingestion doses from ^{131}I in global fallout from 1953 through 1963 (and the sum) are presented in Table 3.16 and average doses from ^{131}I in global fallout for a person born on 1 January 1951 are presented in Table 3.17. As expected, the thyroid dose dominates the dose to other organs. Figure 3.22 shows the annual thyroid dose from ^{131}I in global fallout as a function of year. The years of highest thyroid doses from global fallout were 1956 through 1958 though the years 1952 through 1954 were nearly as great.

Table 3.16. Population-weighted (adult) organ doses (mGy) and effective dose (mSv) from ingestion of ^{131}I deposited in global fallout during 1953-1963.

Year	Thyroid (mGy)	Red Bone Marrow (mGy)	Effective Dose (mSv)
1953	4.42×10^{-03}	1.03×10^{-06}	2.26×10^{-04}
1954	2.51×10^{-02}	5.84×10^{-06}	1.28×10^{-03}
1955	6.22×10^{-04}	1.45×10^{-07}	3.18×10^{-05}
1956	6.41×10^{-02}	1.49×10^{-05}	3.28×10^{-03}
1957	4.38×10^{-02}	1.02×10^{-05}	2.24×10^{-03}
1958	9.38×10^{-02}	2.18×10^{-05}	4.80×10^{-03}
1959	5.79×10^{-05}	1.35×10^{-08}	2.96×10^{-06}
1960	0.00	0.00	0.00
1961	2.34×10^{-02}	5.43×10^{-06}	1.20×10^{-03}
1962	1.32×10^{-01}	3.08×10^{-05}	6.77×10^{-03}
1963	6.71×10^{-04}	1.56×10^{-07}	3.43×10^{-05}
Sum	3.8×10^{-01}	8.9×10^{-05}	2.0×10^{-02}

Table 3.17. Population-weighted (child) organ doses (mGy) and effective doses (mSv) to an individual born on 1 January 1951 from ingestion of ^{131}I deposited in global fallout during 1953-1963.

Year	Thyroid (mGy)	Red Bone Marrow (mGy)	Effective Dose (mSv)
1953	3.03×10^{-02}	3.17×10^{-06}	1.44×10^{-03}
1954	1.28×10^{-01}	1.34×10^{-05}	6.08×10^{-03}
1955	2.98×10^{-03}	3.12×10^{-07}	1.42×10^{-04}
1956	3.96×10^{-01}	4.14×10^{-05}	1.88×10^{-02}
1957	2.63×10^{-01}	2.76×10^{-05}	1.25×10^{-02}
1958	2.61×10^{-01}	4.18×10^{-05}	1.36×10^{-02}
1959	1.01×10^{-04}	1.62×10^{-08}	5.26×10^{-06}
1960	0.00	0.00	0.00
1961	6.46×10^{-02}	1.03×10^{-05}	3.36×10^{-03}
1962	3.60×10^{-01}	5.77×10^{-05}	1.87×10^{-02}
1963	1.54×10^{-03}	2.47×10^{-07}	8.02×10^{-05}
Sum	1.5	2.0×10^{-04}	7.5×10^{-02}

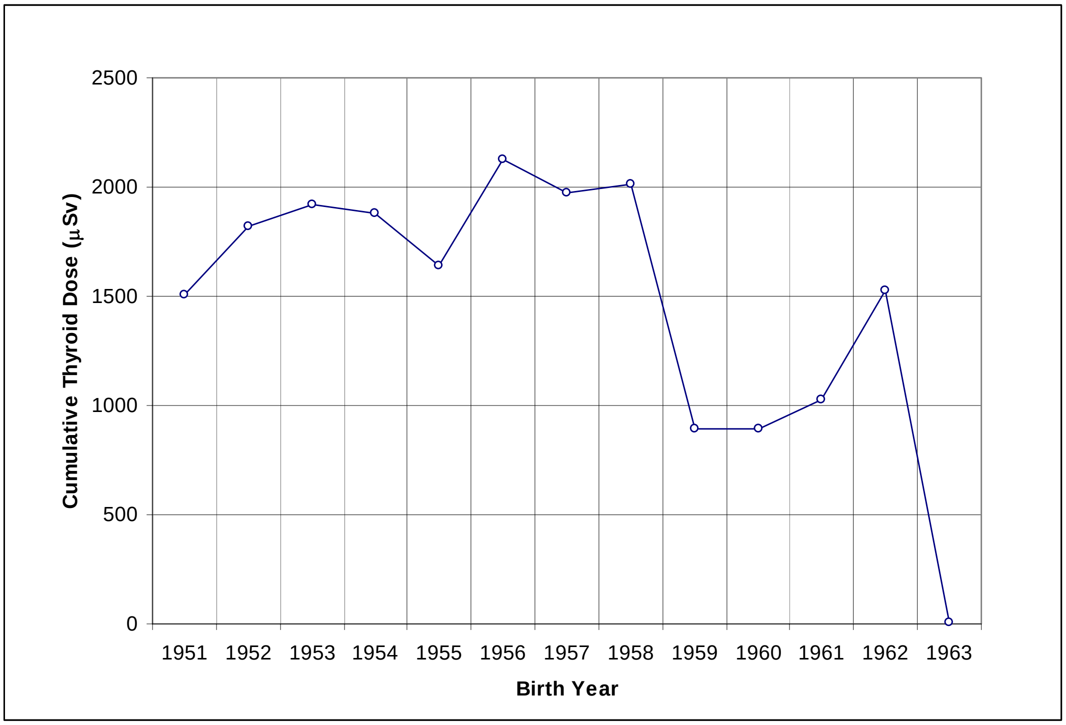

Figure 3.22. Cumulative (1953 through 1963) thyroid dose as a function of birth year. The cumulative dose for an adult, or a person who was born in 1935 or before is about 400 µSv.

Dose From ^{3}H and ^{14}C. The assessment of dose from ^{14}C is particularly difficult, due to its long half-life of 5730y. The UNSCEAR (1993) has assessed the inter-generational dose due to this radionuclide, and under such considerations, it is the most significant radionuclide in global fallout. The relative importance of ^{14}C is much less if only the dose during the first 50 y is considered. Furthermore, the global carbon cycle is complex – as evidenced by the current controversy over global warming due to the release of carbon dioxide – and dose assessments must rely on complicated models. Thus, the projections of dose into the future for this radionuclide are only approximate, but estimates of dose through the year 2000 are firmly based upon measurements of ^{14}C in food, water, and humans.

Doses for ^{3}H and ^{14}C – two globally dispersed radionuclides – were calculated on the basis of the specific activity approach which differs considerably from the methods used for other radionculides that depend on first estimating deposition density. As the fusion yield in the northern hemisphere is an important input to the calculation for both radionuclides, the data shown in Table 3.11 were used as input values. Another important input is the amount of ^{3}H and ^{14}C that are created per Mt of fusion. These values are given by UNSCEAR (1993) as 740 PBq Mt^{-1} for ^{3}H and 0.67 PBq Mt^{-1} for ^{14}C.

Doses from ^{3}H were calculated with use of the NCRP (1979) model which simulates the worlds hydrological cycle through the use of seven compartments consisting of atmospheric water, surface soil water, deep groundwater, surface streams and fresh water lakes, saline lakes and inland seas, ocean surface, and the deep ocean. The use of the hydrological cycle is appropriate, as most of the ^{3}H released is in the form of tritiated water or is soon converted to that form in soil. Calculations also consider the specific activity of ^{3}H in the various water compartments and the rate of change among the compartments. Example results of the dose over time from the release of 1 PBq of ^{3}H to the northern hemisphere are shown in Figure 3.23. The annual dose decreases rapidly with time after the release due to the mixing of the released ^{3}H into the larger compartments. The summary result of the data shown in that figure is that the release of 1 PBq of ^{3}H to the atmosphere in the northern hemisphere would result in a dose of 0.38 nSv to each person living in the hemisphere.

For comparison, a rough estimate of the dose from naturally occurring ^{3}H can be made on the basis of the estimated natural production rate of 37 PBq y^{-1} per hemisphere and the measured concentrations of ^{3}H in surface waters. The annual absorbed dose in tissue from naturally occurring ^{3}H was derived in UNSCEAR (1982) to be 10 nGy. Based upon these values a rough estimate of the dose from ^{3}H (through the year 2000) is

$$240\,\text{Mt} \times 740\,\frac{\text{PBq}}{\text{Mt}} \times 10\,\frac{\text{nGy}}{\text{y}} \times \frac{1\text{ mGy}}{1{,}000{,}000\text{ nGy}} \times \frac{1}{37}\,\frac{\text{y}}{\text{PBq}} = 0.048\,\text{mGy} \qquad \text{Equation 3.3}$$

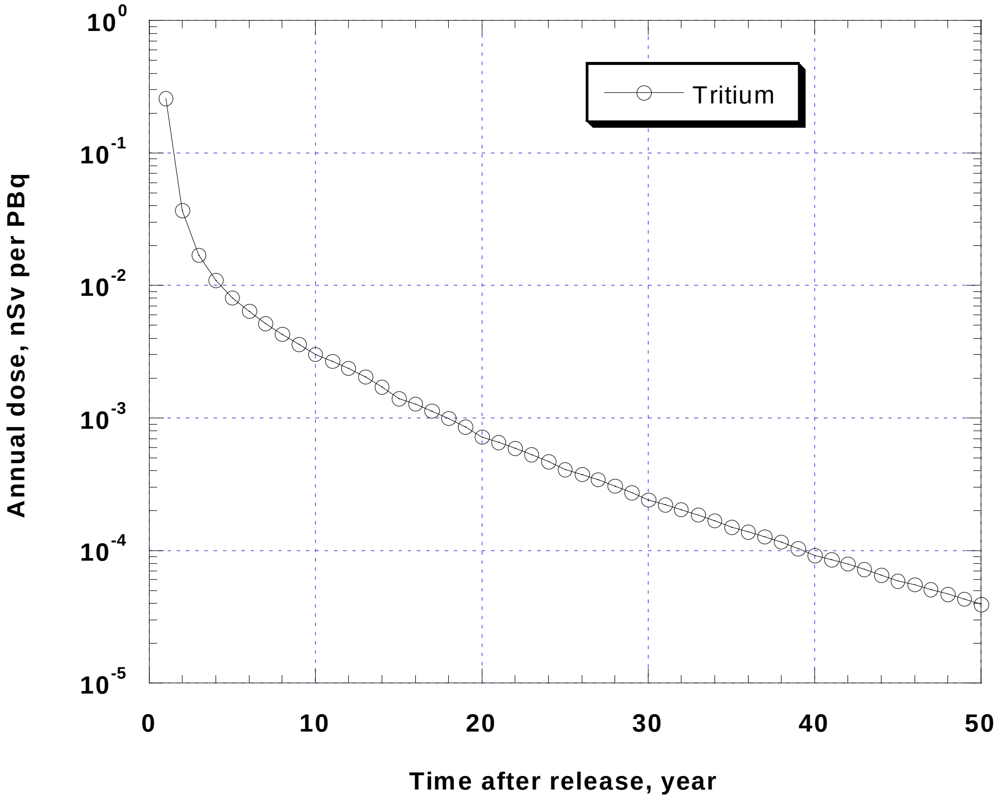

Figure 3.23. Annual dose as a function of time following the release of 1 PBq of ^{3}H to the atmosphere of the northern hemisphere. Results are based upon the NCRP (1979) model of tritium in the hydrological cycle.

The dose from the release of ^{14}C can be assessed in a rather similar way, although the carbon cycle is much more complicated. As discussed in UNSCEAR (1982, 1993), the natural production rate of ^{14}C is about 1 PBq, and the resulting equilibrium specific activity produces an annual effective dose of about 0.012 mSv. A calculation similar to that of Equation 3.3 could be made, but it would be potentially misleading due to the very long half-life of ^{14}C and the very long time (more than one individuals life time) to achieve equilibrium. Thus, in order to calculate doses over the first 50 y from the release of ^{14}C, a compartment model for the global circulation of carbon was used. The model chosen is that of Titley et al. (1995), which is the latest model that has been widely accepted and builds on previously accepted models. The Titley et al. model is complicated, and contains 23 compartments with separate compartments of two to four layers in each ocean. Carbon is considered to be in the form of CO_2, which is the only form that can enter the food chain. The model takes into account temperature changes, photosynthesis in the surface layers of the oceans, and transfers of carbon down the water column.

Example results of model calculations are shown in Figure 3.24, which is a plot showing the annual doses from the release of 1 PBq of ^{14}C to the northern hemisphere. The summary result of the data shown in that figure is that the release of 1 PBq of ^{14}C to the atmosphere of the northern hemisphere would result in a dose of 0.0007 mSv to each person living in the hemisphere.

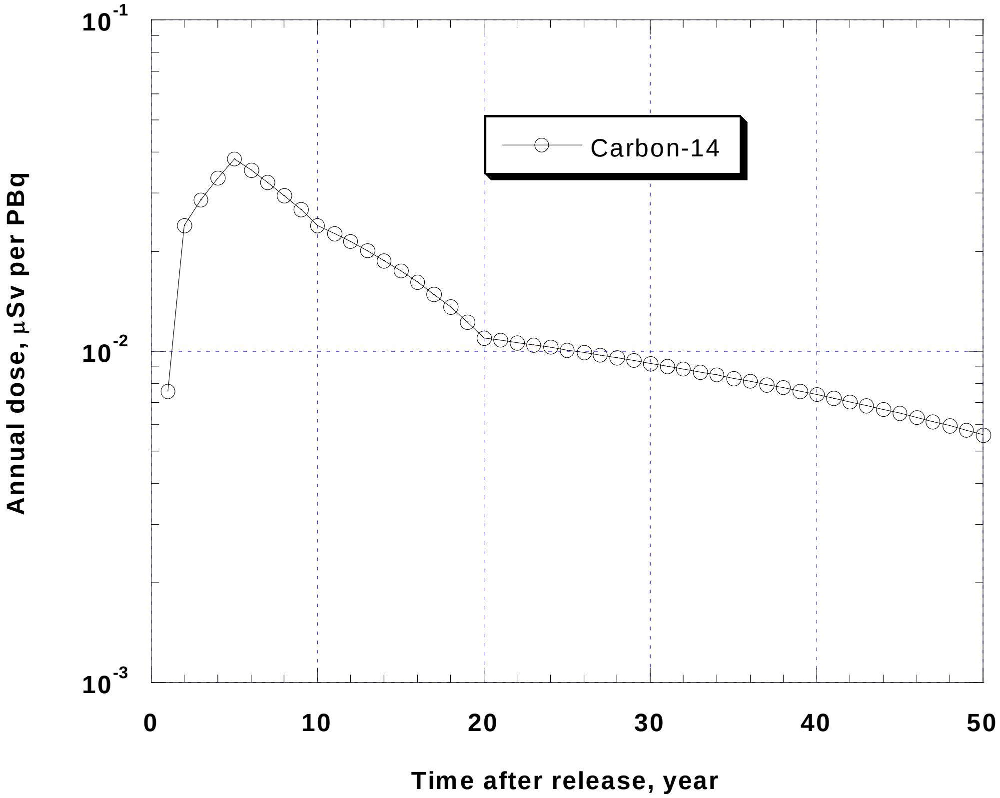

Figure 3.24. Annual effective dose normalized to intake (mSv Bq^{-1}) following the release of 1 PBq of ^{14}C to the atmosphere of the northern hemisphere. Results are based upon the model of Titley et al. (1995).

The calculated effective dose to representative persons from ^{3}H and ^{14}C in global fallout is summarized in Table 3.18. Doses from 1952 through the year 2000 are presented there.

Table 3.18. Effective dose (mSv) from ingestion from the creation or release of ^{3}H and ^{14}C during the testing of large fusion weapons in the Northern Hemisphere.

Year	Fusion Yield (Mt)	^{3}H Effective Dose (mSv)	^{14}C Effective Dose (mSv)	Year	Fusion Yield (Mt)	^{3}H Effective Dose (mSv)	^{14}C Effective Dose (mSv)
1952	5	0.001	0.000032	1977	-	0.00018	0.0026
1953	0.36	0.0002	0.0001	1978	-	0.00016	0.0024
1954	17	0.0034	0.00024	1979	-	0.00014	0.0023
1955	0.88	0.00069	0.00051	1980	-	0.00012	0.0021
1956	13	0.0028	0.00068	1981	-	0.00011	0.002
1957	3.9	0.0013	0.00095	1982	-	0.000097	0.002
1958	31	0.0063	0.0013	1983	-	0.000087	0.0019
1959	0	0.0011	0.0017	1984	-	0.000078	0.0019
1960	0	0.00058	0.0019	1985	-	0.000069	0.0019
1961	69	0.014	0.0024	1986	-	0.000061	0.0018
1962	99	0.021	0.004	1987	-	0.000056	0.0018
1963	-	0.0038	0.0054	1988	-	0.000051	0.0017
1964	-	0.002	0.0056	1989	-	0.000046	0.0017
1965	-	0.0014	0.0062	1990	-	0.00004	0.0017
1966	-	0.0011	0.0063	1991	-	0.000036	0.0016
1967	-	0.00086	0.0058	1992	-	0.000033	0.0016
1968	-	0.00071	0.0053	1993	-	0.000031	0.0015
1969	-	0.00059	0.0048	1994	-	0.000028	0.0015
1970	-	0.0005	0.0044	1995	-	0.000025	0.0015
1971	-	0.00043	0.0041	1996	-	0.000023	0.0014
1972	-	0.00038	0.0038	1997	-	0.000021	0.0014
1973	-	0.00033	0.0035	1998	-	0.000019	0.0014
1974	-	0.00028	0.0032	1999	-	0.000017	0.0014
1975	-	0.00024	0.003	2000	-	0.000015	0.0013
1976	-	0.0002	0.0028				
Total =					**240**	**0.066**	**0.12**

Internal Doses From Other Radionuclides. The estimates of the population-weighted internal radiation doses from deposition of globally dispersed ^{90}Sr and ^{137}Cs during the years of 1953–1972 are summarized in Table 3.19. The dose from ^{137}Cs to tissues and organs other than the colon are essentially the same as the effective dose. The total population-weighted effective dose from both ^{90}Sr and ^{137}Cs is estimated to be 0.17 mSv. Wide variations in the total population-weighted dose occurred throughout the country, ranging from 0.007 mSv (Imperial County, CA) to 0.38 mSv (Alpine County, CA) in the Sierra Mountains.

Table 3.19. Total population-weighted organ (mGy) and effective doses (mSv) from the deposition of 90Sr and 137Cs in global fallout during 1953–1972. Upper values are for adults; lower values are for a person born on 1 January 1951.

	Individual organ or Effective dose				
	Adult				
Radionuclide	Bone surface (mGy)	Colon (mGy)	Red marrow (mGy)	Thyroid (mGy)	Effective (mSv)
^{90}Sr	0.54	0.017	0.24	0.0086	0.037
^{137}Cs	0.16	0.16	0.15	0.14	0.14
	Person born on 1 January 1951				
^{90}Sr	1.6	0.034	0.53	0.0023	0.087
^{137}Cs	0.13	0.16	0.16	0.12	0.12

As in the case of NTS fallout, individual county estimates for global fallout ingestion doses are imprecise. Hence, it is not worthwhile to attempt to identify the counties predicted as having the highest or lowest ingestion doses from global fallout. Until the precision of dose estimates is examined in detail, only generalizations can be drawn. Hence, the accompanying maps should only be used to envisage the approximate geographic pattern of doses from global fallout.

Figures 3.25 and 3.26 show the geographic distribution of the estimated internal dose to red bone marrow from global fallout, and the sum of external and internal dose to red bone marrow (both for adults), respectively. As can be seen, the geographic pattern of doses reflects pattern of ^{137}Cs deposition density from global fallout shown in Figure 3.18.

Figure 3.27 shows the internal dose to red bone marrow in children. The ranges of doses received by children were similar to that for adults; however, the portion of the country covered by the 1 to 3 mGy range is larger for children.

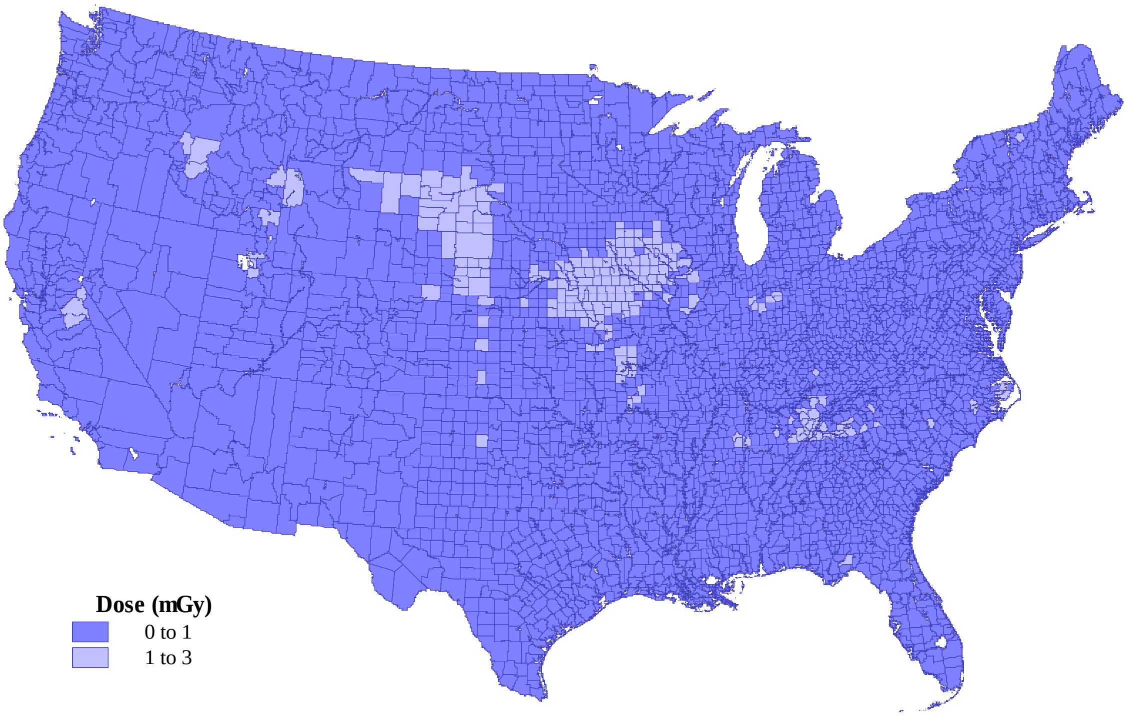

Figure 3.25. Internal dose to red bone marrow of an adult from global fallout.

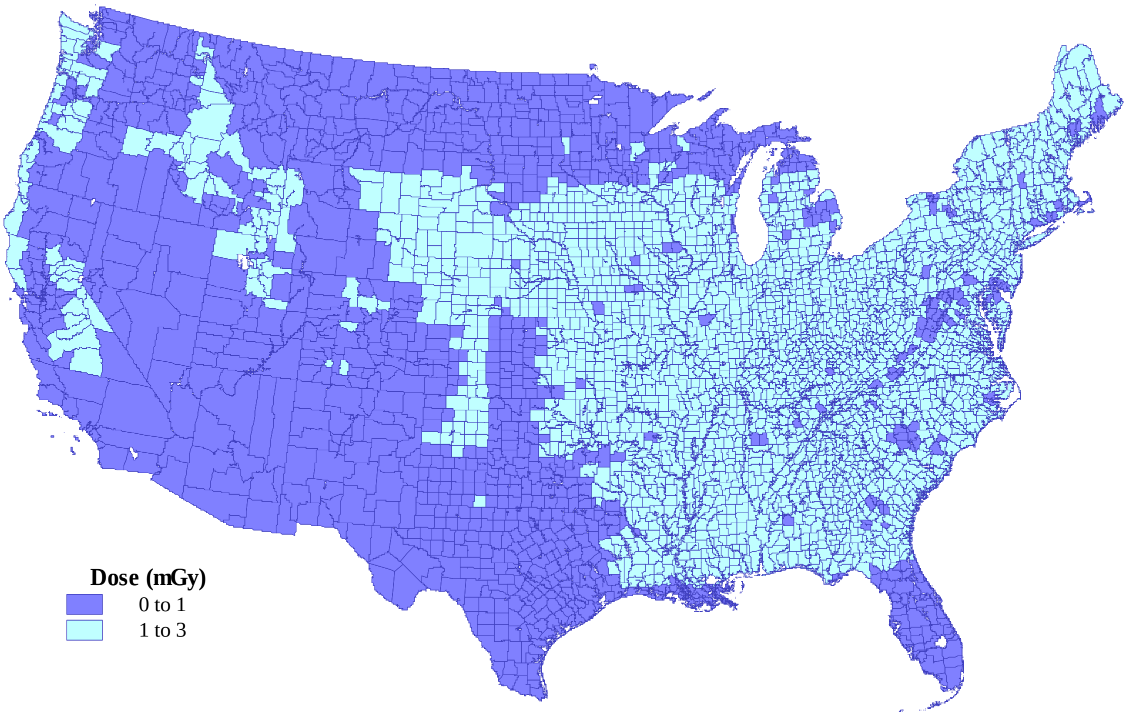

Figure 3.26. Total (external + internal) dose to the red bone marrow of an adult from global fallout.

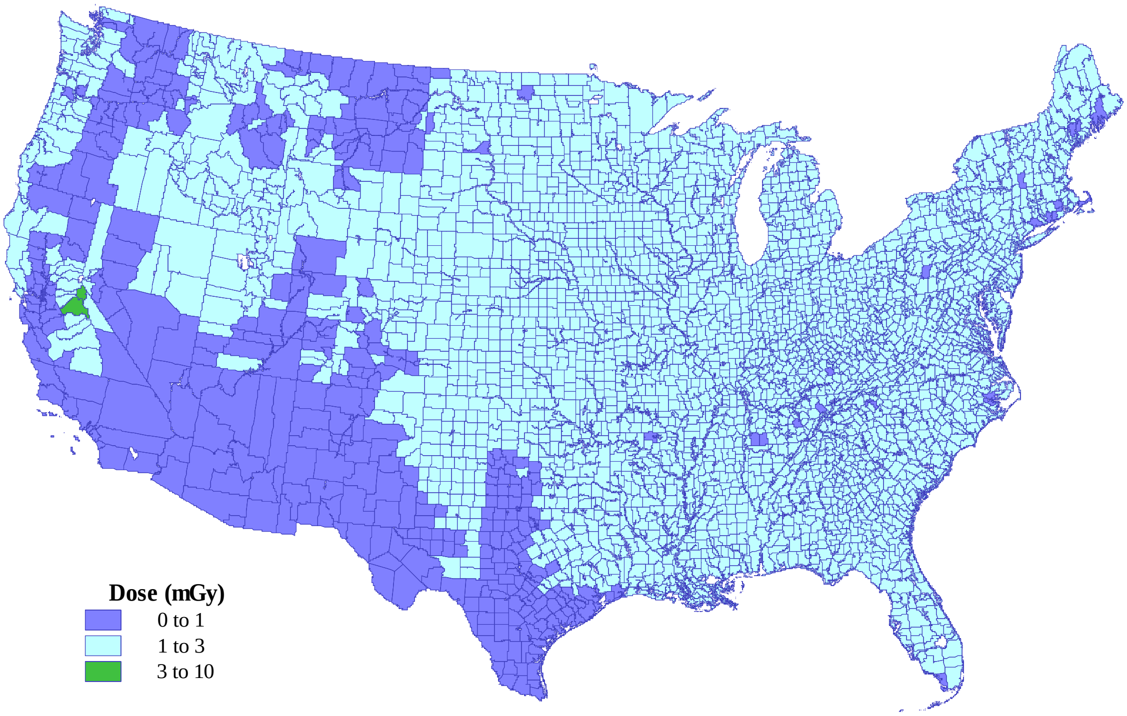

Figure 3.27. Total (external + internal) dose to the red bone marrow of a child born 1 January 1951 from global fallout.

Comparison To Dose Estimates From UNSCEAR and Other Sources. One important means of corroboration of the doses estimated here is through a comparison to the doses published by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR 1993) for the 40°–50° latitude band that includes part of the United States. The UNSCEAR dose estimates are from global fallout, originating from the large explosions conducted by the United States in the Pacific Region and by Russia near the Arctic Circle, whereas the doses calculated in this report are for local and regional fallout from the relatively small tests at the NTS. Calculated doses are population-weighted doses for adults and focus on cumulative effective dose with the only age correction having been made for doses from ^{131}I. A comparison of total dose arising from the ingestion of contaminated foods is shown in Table 3.20.

In addition, data presented to the United States Congress by Terrill (1963) on concentrations of radionuclides in milk were used to perform calculations useful for validating the assumptions and models used in this report. The results of those comparisons are shown in Table 3.21.

Table 3.20. Comparison of total fallout doses from internal irradiation from NTS and from global fallout sources.

Radionuclide	Cumulative Population-Weighted Effective Dose (mSv)		
	This project		UNSCEAR (1993)
	Nevada Test Site	Global fallout[a]	Global fallout[b]
^{3}H	-	0.066[c]	0.048
^{14}C	-	0.12[c]	0.078[d]
^{55}Fe			0.014
^{89}Sr	0.017		0.0023
^{90}Sr	0.0037	0.037	0.17
^{91}Sr	0.0000065		
^{97}Zr	0.00015		
^{99}Mo	0.001		
^{103}Ru	0.0038		
^{106}Ru	0.0072		
^{105}Rh	0.000086		
^{132}Te	0.0078		
^{131}I	0.25	0.020	0.032
^{133}I	0.0019		
^{136}Cs	0.0036		
^{137}Cs	0.01	0.13	0.28
^{140}Ba	0.012		0.00042
^{143}Ce	0.0004		
^{144}Ce	0.0053		
^{147}Nd	0.0011		
^{238}Pu			0.0000009
$^{239+240}$Pu	0.0012		0.0005
^{241}Pu	0.000087		0.000004
^{241}Am			0.0015
Total	0.33[e]	0.4[e]	0.63

[a] Averaged over the United States.

[b] North temperate zone (40°–50°).

[c] To the year 2000.

[d] The UNSCEAR (1993) value of 2.6 mSv was multiplied by a factor of 0.03, the portion estimated to be delivered in 50 y.

[e] Incomplete sum for the radionuclides considered.

Table 3.21. Comparison of effective dose from reported concentrations of ^{90}Sr, ^{131}I, and ^{137}Cs in milk with predicted doses from models used in this report.

	Effective dose to adults (μSv)					
Time Period	From milk concentration			From Anspaugh (2000), see Appendix G		
	^{90}Sr	^{131}I	^{137}Cs	^{90}Sr	^{131}I	^{137}Cs
1960	1.3	0	0.74	0.81	0	3.0
1961	1.3	2.5	0.74	0.84	1.2	3.6
1962	2.1	4.0	3.3	4.4	6.8	17
1963, first quarter	0.64	<0.31	1.3	0.69	0.034	0.48

In general, the results of this comparison are considered to be satisfactory and indicate that there are no gross errors in the assumptions used in the modeling process. Comparisons such as this can never be perfect and agreement within a factor of two or so is considered very good. Further refinements of the models, however, could likely improve the model predictions.

3.4 Comparison of NTS and Global Fallout Doses

As noted earlier, the small nuclear tests conducted in the atmosphere at the NTS would not have created significant of 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 United States in the Pacific Region and by Russia near the Arctic Circle. For that reason, those two radionuclides were not included in the assessment of doses from the NTS.

Also as discussed earlier, radioactive debris from the NTS originated from relatively small explosions, and much of the debris remained within the lower regions of the atmosphere. Thus, a large fraction of NTS debris was deposited within the United States during the first few days following the explosions. Rainfall was an important determinant of the amount of NTS fallout deposited in each county, but also important was the distance from the NTS. Thus, the variation in the amount of NTS fallout deposition among the counties is likely to be larger than it would be for global fallout.

In general, the cumulative effective dose from the NTS was dominated by short-lived radionuclides, such as ^{131}I, ^{89}Sr, and ^{140}Ba. In contrast, the estimates of cumulative dose from global fallout were dominated by long-lived radionuclides, such as ^{137}Cs and ^{90}Sr.

A summary of population-weighted doses (effective external and organ doses for thyroid and red bone marrow) is presented in Table 3.22. The population-weighted external effective doses were similar (0.5 mGy for NTS, 0.7 mGy for global). The internal dose from ^{131}I, however, differed significantly for the two sources of fallout (5 mGy from NTS, 1 mGy from global). Lower iodine doses from global fallout were a result of the decay of the relatively short-lived ^{131}I (8 d half-life) as it was transported globally from sites worldwide. Conversely, red bone marrow doses were significantly larger for global fallout (about 0.8 mGy) compared to NTS fallout (about 0.08 mGy). The larger red bone marrow doses result from long-lived radionuclides, e.g., ^{90}Sr and ^{137}Cs, which can persist in the environment and in man and can deliver their dose over many years time.

Table 3.22 Summary of population-weighted effective (mSv) and organ doses (mGy) from NTS and global fallout as a result of exposure to the most important radionuclides. Unless otherwise specified, the values are for adults at the time of the tests.

		NTS Fallout			Global Fallout		
Radionuclide	Half-life	External (Effective) Dose (mSv)	Thyroid Internal Dose (mGy)	Red Bone Marrow Internal Dose (mGy)	External (Effective) Dose (mSv)	Thyroid Internal Dose (mGy)	Red Bone Marrow Internal Dose (mGy)
^{3}H	12.3 y					0.066	0.066
^{14}C	5700 y					0.12	0.12
^{54}Mn	312 d				0.04		
^{89}Sr	50.5 d		0.001	0.031			
^{90}Sr	28.5 y			0.024		0.0009 0.002[a]	0.23 0.53[a]
^{95}Zr-Nb	64.0 d	0.08			0.19		
^{97}Zr-Nb	16.7 h	0.02					
^{103}Ru	39.3 d	0.03			0.02		
^{106}Ru	374 d		0.001	0.002	0.04		
^{125}Sb	2.76 y				0.03		
^{131}I	8.02 d	0.02	4.9 28[a]	0.001		0.39 1.5[a]	0.00009 0.0002[a]
^{132}Te-I	3.2 d	0.11	0.06	0.001			
^{133}I	0.9 d	0.02	0.04				
^{136}Cs	13.2 d		0.002	0.002			
^{137}Cs	30.1 y	0.01	0.009	0.009	0.33	0.13	0.13
^{140}Ba-La	12.8 d	0.17		0.006	0.051		
^{144}Ce	285 d				0.02		
^{239}Np	2.36 d	0.02					
Total (rounded)		0.5	5 30[a]	0.1	0.7	0.7 2[a]	0.6 0.9[a]

[a] Child born 1 January 1951

3.5 Summary

The radioactive fallout released from nuclear testing at the Nevada Test Site (NTS) and at other sites worldwide resulted in a combination of many exposures of short duration (primarily from the NTS) as well as a continuum of exposures (from global fallout) to the

American people. Figure 3.28 shows the combined deposition density from NTS and global fallout (a summation of Figures 3.2 and 3.18) for ^{137}Cs. The deposition density in the eastern half of the United States is dominated by the contribution from global fallout.

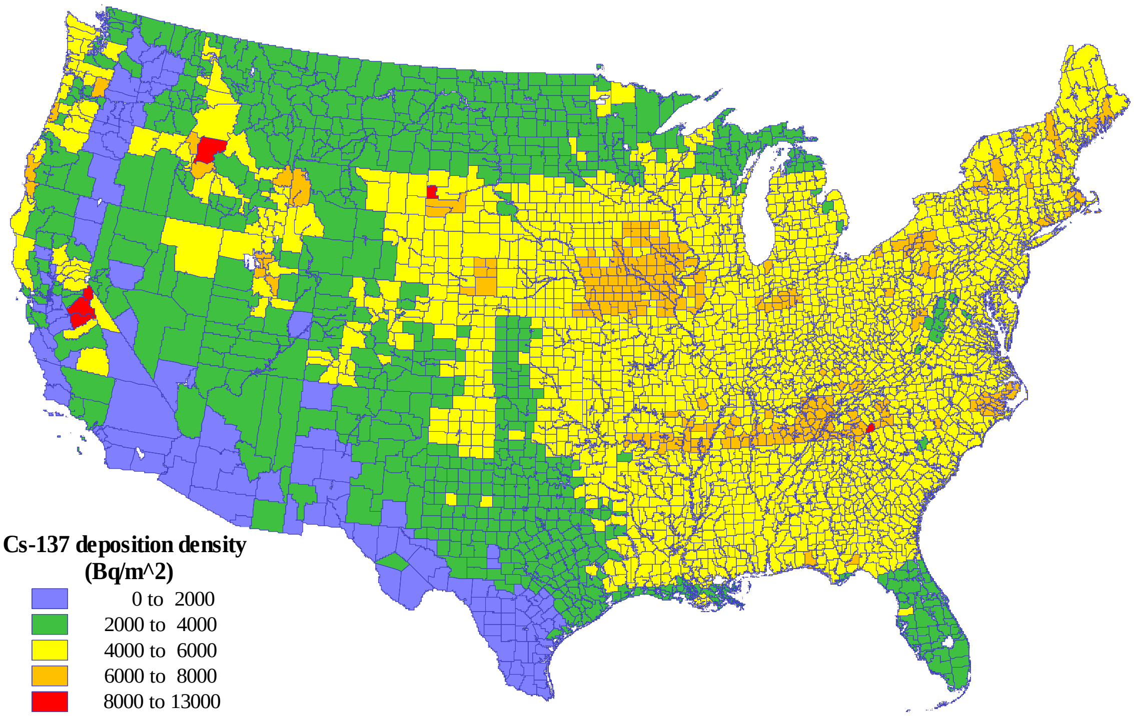

Figure 3.28. Cesium-137 deposition density due to NTS and global fallout.

It is possible to mathematically sum the doses received from both NTS and global sources though it should be understood that there are numerous assumptions inherent in such calculations. In particular, summing the doses implies that a person lived continuously in a county and was there during the entire fallout and exposure period. Furthermore, inherent in the estimates is the assumption of a representative person, either one who was an adult at the time of fallout or who was a child born on 1 January 1951. The representative person is one with moderate consumption habits who lives in structures that provide a specific level of shielding from external radiation. With these assumptions in mind, the following maps are provided to summarize the geographic variation in total dose received from weapons testing fallout at both the NTS and other northern hemisphere locations.

Figure 3.29 shows the estimated external dose to red bone marrow from NTS and global fallout combined. Figure 3.30 shows the estimated internal dose to red bone marrow from NTS and global fallout combined for a child.

Figures 3.31 and 3.32 show the estimated total dose (external plus internal) to red bone marrow from NTS and global fallout combined. Figure 3.31 is for adults, while Figure 3.32 is for children.

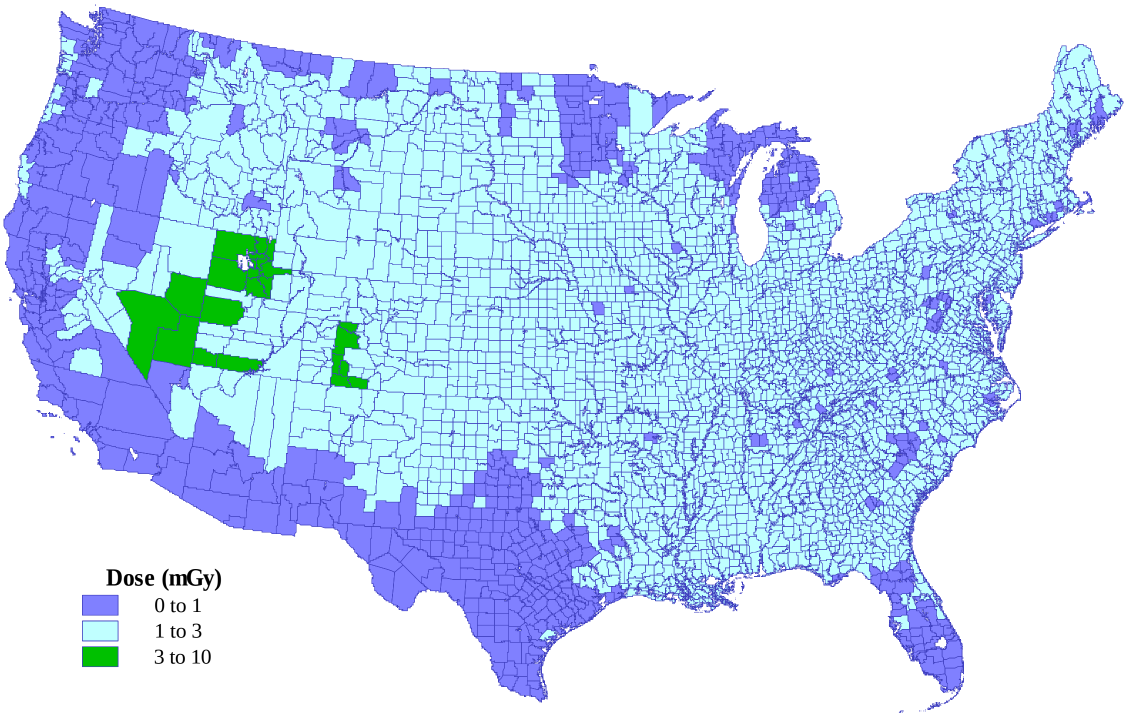

Figure 3.29. External dose to the red bone marrow of an adult resulting from NTS and global fallout.

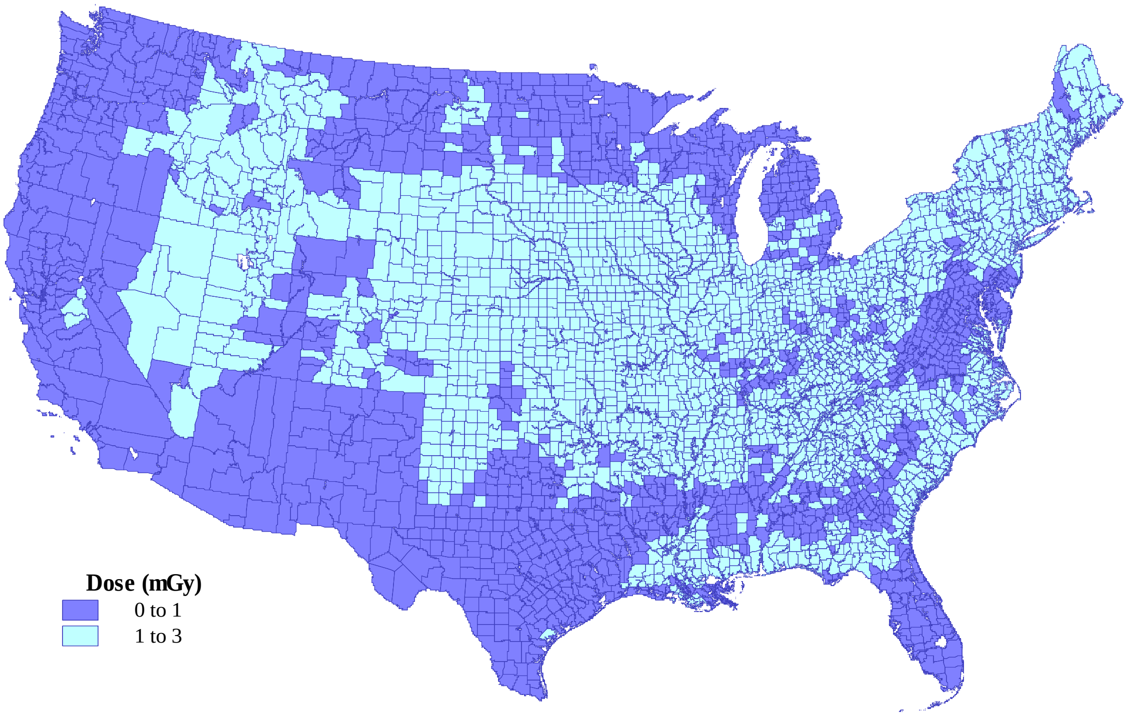

Figure 3.30. Internal dose to red bone marrow of a child born 1 January 1951 from NTS and global fallout.

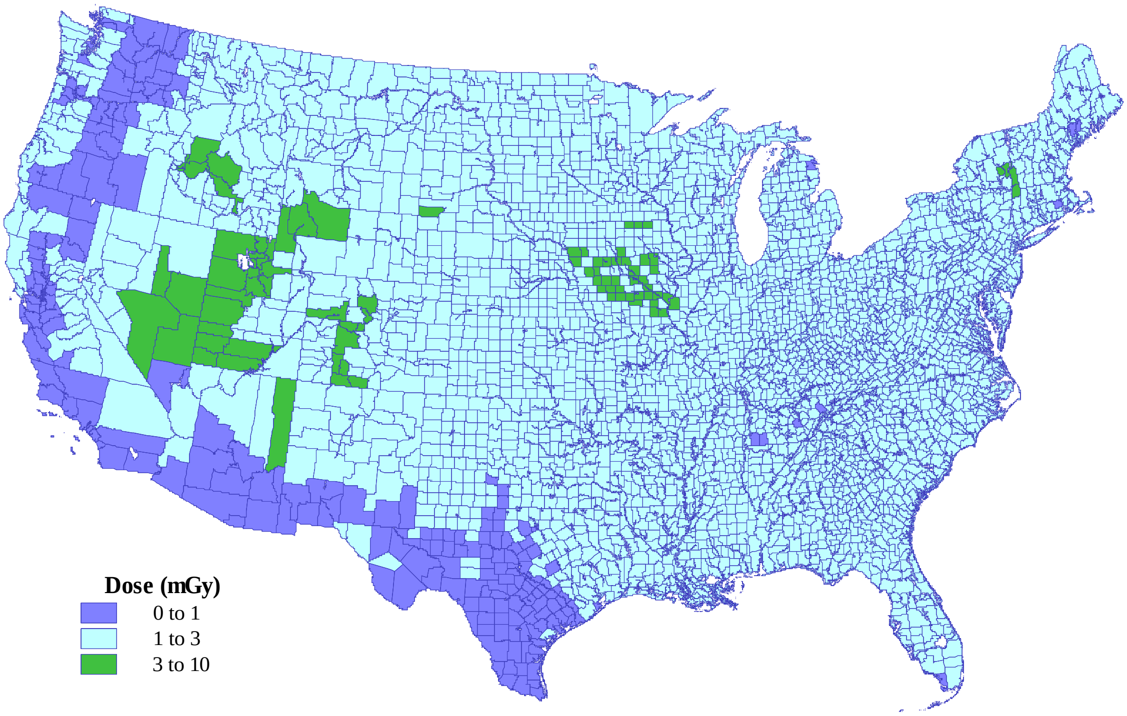

Figure 3.31. Total dose to the red bone marrow of an adult from NTS and global fallout.

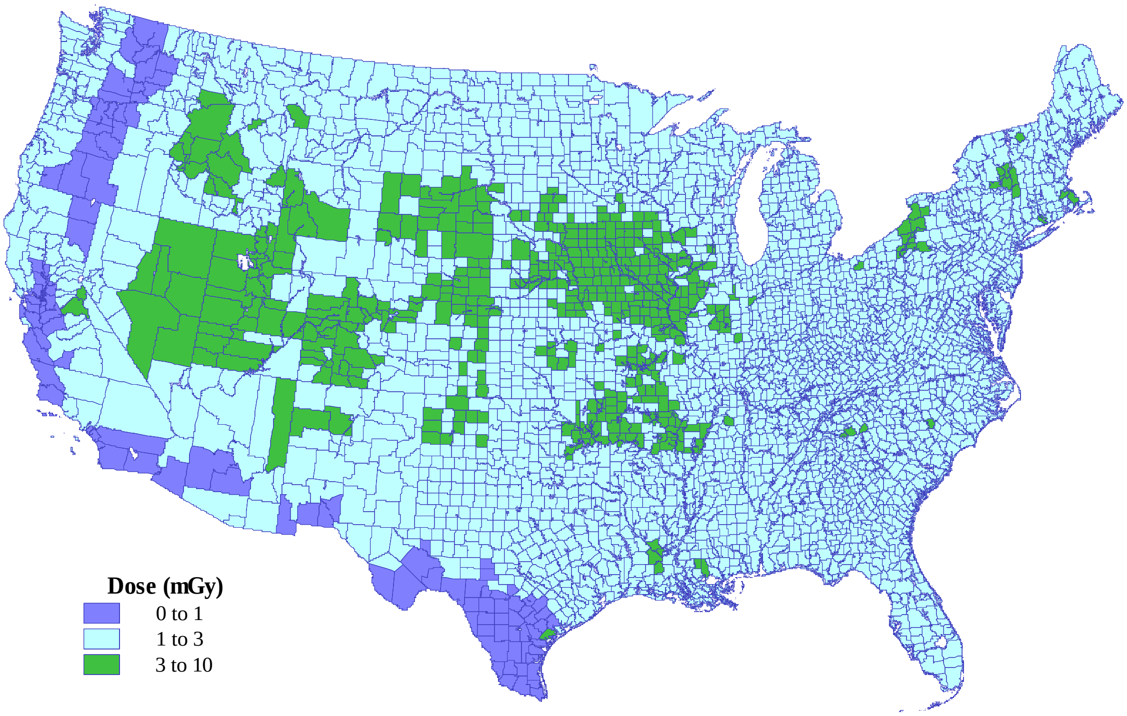

Figure 3.32. Total dose to red bone marrow of a child born 1 January 1951 from NTS and global fallout.

In addition to the maps, a number of general and specific points can be concluded from the calculations and discussion presented in this chapter. Those points follow.

3.5.1 NTS Fallout

- Residents of the contiguous United States received external radiation exposure from nuclear weapons tests carried out at the Nevada Test Site during the period 1951-1962. The average committed collective dose from all NTS tests was about 0.5 mSv, equivalent to approximately 1-2 years of external radiation exposure from natural background.
- Residents in the counties immediately downwind from the NTS received much higher exposures than the average, in excess of 3 mSv, while people in the western and northwestern United States and some areas of the Midwest and Southeast received

much less than the average. Most of this exposure occurred with the first 3 weeks after each test and was due to relatively short-lived radionuclides.

- Most of the effective external dose received by each person was from gamma rays emitted by fission products deposited on the ground. The actual dose received by any individual depended on the fraction of time he/she spent outdoors 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.
- Beta radiation from fission products in the surface soil resulted in an additional dose to the skin when outdoors. However, this contribution was not large enough to be considered an important component of total fallout radiation exposure except perhaps for children who played in the soil for very long lengths of time.
- About 1/3 of the fission products produced by NTS explosions was deposited within the area of the contiguous United States. A larger percentage of the fallout from surface and tower tests was deposited in the United States.
- Doses were calculated for 61 of the most significant events that occurred at the NTS during 1951, 1952, 1953, 1955, 1957, and 1962. The total cumulative population-weighted internal effective dose was about 0.68 mSv.
- The larger proportions of the total ingestion dose from NTS fallout 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 precision of the estimated doses for that event is low due to the absence of information regarding its fission yield and other factors.
- Iodine-131 dominates the ingestion dose received by the American public from tests at the NTS. 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.

- The radionuclide ^{131}I was by far the most important contributor to collective effective dose from ingestion 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 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 person-Sv) and the bone surface (31,000 person-Sv).
- 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 total contribution of internal dose from $^{239+240}$Pu, even from inhalation, is relatively small compared to other radionuclides.
- The results provided here establish that a reconstruction of external and internal (i.e., ingestion) doses from NTS fallout is feasible, though this conclusion is contingent on availability of estimates of deposition density for each radionuclide of interest.

3.5.2 Global Fallout

- The results presented in this report are not intended to be definitive estimates of the geographical and temporal variations in global fallout across the United States. They are preliminary estimates though they do demonstrate the feasibility of making such estimates given sufficient data.
- Fallout from atmospheric tests resulted in a per capita external radiation exposure of about 0.7 mSv to the population of the United States, about one and one-half times as great as that resulting from NTS fallout. However, residents in the states immediately downwind from the NTS received much higher than average exposures from NTS fallout while the exposures in the western and northwestern United States and some areas of the Midwest and Southeast were much less than the average. The doses from global fallout were more uniformly distributed across the United States with differences from place to place reflecting differences in average precipitation. Thus, residents of counties in the eastern and Midwestern United States that received above average rainfall were impacted more than the residents of the more arid Southwestern states. Since the states downwind from the NTS that were affected most by the NTS

fallout are, in general, more arid than the eastern United States, the areas most affected by NTS fallout were in general least affected by global fallout.

- Annual per capita doses from global fallout were comparable to annual doses from NTS fallout during the years of testing. However, most of the exposure from the NTS tests occurred within the first 3 weeks of each test and was due to relatively short-lived radionuclides. In contrast, the exposure from global fallout occurred over a much greater span of time, thus the dose-rate was more uniform with time.
- The actual dose received by any individual depended on the fraction of time he/she spent outdoors and the degree of shielding provided by his/her dwelling. The most exposed individuals at any particular location would have been outdoor workers or others who spent most of their day outdoors. Beta radiation from fission products in the surface might have only been important for children who played in the soil for significant intervals of time.
- In contrast to fallout from the NTS, where most of the external exposure was due to the short-lived radionuclides (primarily ^{132}I-^{132}Te and ^{140}Ba-^{140}La), ^{95}Zr-^{95}Nb was the major contributor to external dose from global fallout during the years of testing. The cumulative dose through 2000 was dominated by the long-lived ^{137}Cs. Cesium-137 present in soil continues to result in a small radiation exposure to the public even at the present time. As was the case for NTS fallout, the most exposed individuals were outdoor workers, and the least exposed were persons who spent most of their time indoors in heavily constructed buildings.
- The more important contributors to internal dose from NTS fallout were short-lived radionuclides (^{131}I, ^{89}Sr, and ^{140}Ba), whereas for global fallout the more important contributors to internal dose were long-lived radionuclides (^{137}Cs, ^{90}Sr, and ^{14}C).
- Deposition density of short-lived radioactivity (e.g., ^{131}I) cannot be easily estimated for global fallout. Reconstruction of deposition densities of short-lived activity would require review of all relevant literature to supplement the presently sparse data.
- Doses from the NTS and global sources would have been received at different times, primarily during the 1950s for NTS fallout and during 1963-1965 for global fallout.

- This report has demonstrated that it is feasible to estimate the exposure of the population of the United States from global fallout as a function of location and time. However, the monthly estimates for individual counties are probably quite imprecise and the deposition density and exposure rate probably varied significantly from place to place within a county, particularly for counties with large variations in topography.

3.6 Considerations for Further Research

There are numerous possible subject areas that can be researched for the purpose of improving the preliminary dose estimates provided in this report and to provide a more complete historical record of the nature of the releases from the weapons testing and the resulting exposures received by Americans from NTS and global fallout. These areas primarily have emerged from noting the limitations of the input data and available models to conduct the work reported here. The research items provided here can generally be categorized as those related to (1) availability of nuclear test data, (2) improvement in models, (3) inclusion of specific locations, and (4) public health.

3.6.1 Possible Research Related to Availability of Nuclear Test Data

- The ability to estimate fallout deposition density from NTS tests was made possible by the calculations based on cloud measurements of the production of the various fission products from each test. However, the composition of the radioactive debris is very dependent on the energies of the neutrons produced in the explosion. Useful information for improving dose assessments would include a comparison of such data for tests carried out by the United States and U.K. in the Pacific as well as for tests carried out in the Soviet Union. These comparisons may require the declassification of certain data.

- Also classified is the fraction of the total yield of each nuclear test that resulted from fission as opposed to fusion. Again, this information will be needed to make more accurate estimates of deposition density and resultant doses from tests held outside the United States. In some cases, even the exact value of the total yield is classified. Since tritium is a by-product of fusion, any information on the amount of tritium released from a particular test is probably also classified.

- Declassification of the fission yields and ratios of ^{137}Cs/Pu activity, particularly for NTS tests, would allow for more accurate estimates of plutonium deposition density across the United States.
- In addition to improving the input data, the deposition density estimates and doses might be improved if additional data can be located on the ratios of the deposition of the various nuclides as a function of location in the United States. This would require searching all available archives.

3.6.2 Possible Research Related to Improvement in Models

- The models used to estimate exposure rates and deposition densities until now have been crude. In addition, monthly and individual county estimates are imprecise particularly for estimates of short-lived radionuclides such as ^{131}I from global fallout. However, comparisons made to date with environmental measurements suggest that the overall geographical distribution of fallout and external dose to the United States population, and the per capita or the collective dose, are all reasonable estimates. Hence, the issues raised in this report are primarily oriented towards improving location-specific (e.g., county) doses.
- There are a variety of ways that considerable improvements in models could be made, thus allowing for more accurate estimates of deposition densities and doses for particular time periods, particularly for years prior to 1958, as well as more accurate predictions of the geographical variation at any particular time. In particular, by weighting the various precipitation measurements in a given county by the population one might be able to calculate a population-weighted ^{90}Sr deposition density that in turn would allow a better estimate of the dose to a typical resident of that county than the present estimate. An analysis of the gummed-film data for the years prior to 1958, in a manner similar to that carried out for NTS fallout (see Beck et al. 1990;

NCI 1997), might also allow better estimates of deposition density as a function of location for years prior to 1958. A further assessment of the variations in precipitation within counties might identify some local hotspots and populations that were exposed to much higher doses than presently known. Areas with large amounts of thunderstorm activity during months of testing could be identified since this was believed to be one mechanism that resulted in episodes of high fallout of short-lived radionuclides such as ^{131}I.

- By determining the precision of data used for critical parameters in each of the steps used in this preliminary study, one could estimate a credibility interval for the estimated monthly doses for each county in a manner similar to that provided by NCI (1997). Without such a systematic analysis it is difficult to assess the validity of any particular county's monthly dose estimate.

- Additional data could also be used to develop a more sophisticated, higher resolution, model of the distribution of global fallout ^{90}Sr specific activity with latitude and longitude. This might be accomplished using a technique such as kriging to provide estimates of specific activity that vary smoothly across the country. A more sophisticated model would also attempt to account for the impact of "dry" deposition in arid locations. A thorough review and assessment of the vast amount of other scattered sources of data might also allow the estimates of isotopic ratios for particular months to be improved. It may also allow improvements to the atmospheric model used for estimating nuclide ratios, which would then allow one to more confidently utilize the model for periods with no data. Because the current effort was limited in scope and resources, only a small subset of the vast literature could be evaluated and utilized.

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

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

3.6.3 Possible Research Related to Inclusion of Specific Locations

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

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

3.6.4 Possible Research Related to Public Health

- There are a number of public health related topics that should be considered for future research. These include the determination of individual and life-style related characteristics that would assist in identifying high-risk subpopulations, the inclusion of in utero exposures and exposures to nursing infants in the dose calculations, and refinements to current methodologies for making more precise estimates of dose for representative individuals.

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Chapter 4

Potential Health Consequences from Exposure of the United States Population to Radioactive Fallout

Contents: This chapter provides a brief summary of what is currently known about the health consequences of low level radiation exposures. The feasibility of analyzing the risk of cancer and non-cancer health outcomes resulting from fallout is discussed. Methods for estimating the number of cancers expected to occur in the United States population as a result of fallout exposure are illustrated for total cancer and leukemia using dose estimates provided in Chapter 3. Issues relating to the uncertainty in these estimates are described.

4.1 Introduction

Health effects of radiation exposure have been extensively studied and documented. These effects are diverse and vary with radiation doses. From the preliminary dose estimates presented in Chapter 3, it is clear that the health effects of interest with regard to fallout radiation are those that can be attributed to relatively low dose radiation exposure; the estimated thyroid dose averaged over the population of the entire country is about 10 mGy while the average bone-marrow dose is about 2 mGy. For most individuals, the doses are expected to have been less than 1,000 mGy for the thyroid gland and less than 100 mGy for bone marrow. At these dose levels the most important health effect is likely to be cancer, which typically occurs many years after the exposure. On an individual basis, the risk of developing excess cancers as a consequence of exposure to low dose radiation is considered small. However, on a population basis, widespread exposure of large numbers of people to fallout may potentially lead to a large number of excess cancers and hence a public health problem. One goal of this chapter is to familiarize the reader with the weight of evidence linking cancer with low dose radiation exposure and to evaluate the magnitude of the impact of fallout radiation on the cancer burden of the United States population.

In addition to cancer, some non-cancer diseases have been reported to occur as late effects of radiation. Some of these are of neoplastic in nature, though benign in their behavior (benign tumors). Recent data from the Japanese atomic bomb survivor studies suggest that the risk of certain diseases of non-neoplastic nature such as heart diseases may also be increased after exposure to radiation; however, the magnitude of the risk is considerably uncertain, especially at low dose levels, and plausible biological mechanisms involved are unclear (Shimizu et al. 1999; Kodama et al. 1996).

Quantifying the risk of cancer and non-cancer health effects depends on the availability of information about the disease-exposure relationship from high quality observational studies (e.g. epidemiologic studies). Using this information, several standards-setting organizations and scientific committees have already developed mathematical models for estimating cancer risks to populations exposed to specified doses of radiation. (NAS 1990; ICRP 1991; NRC. 1993; EPA 1994; UNSCEAR 1994, 2000). However, much less has been done to quantify non-cancer disease risk. Thus, while there is little question that estimates of the fallout-related lifetime risk of cancer for the United States population can be obtained if dose estimates are available, only a qualitative assessment of risk can be provided for non-cancer health effects. Cancer risk estimates are appropriately represented by a range of numbers in order to account for the large uncertainty in these estimates. Therefore, the question remains as to whether or not these uncertain estimates of population risk (that is, the likely number of additional cancer cases) will be useful for developing public health policy.

This chapter provides an overview of what is currently known about the relationship between radiation exposure and cancer and other late-occurring health effects. Two issues fundamental for understanding this relationship between radiation and health effects, dose response and time response patterns of the risk, are examined. Additionally, this chapter provides preliminary estimates of cancer risk resulting from exposures from atmospheric nuclear weapons testing and indicates the degree of uncertainty in these estimates. While the main emphasis of this chapter is on cancer as a health effect of radiation exposure, non-cancer health effects are also discussed.

4.2 Health Effects of Ionizing Radiation

The most relevant sources of scientific information on the health effects of ionizing radiation are the large number of epidemiological studies that have been conducted to date. One of the most important investigations of radiation health effects is the epidemiological study of a large cohort of Japanese atomic bomb survivors. The continuing follow-up of this cohort provides information on long-term health risks associated with radiation exposure and is the major contributor to quantitative risk estimates. Others include studies of occupational groups such as uranium miners and nuclear production workers, populations exposed to radiation as a result of living in areas contaminated with fallout from nuclear weapons tests, and adults and children exposed for medical (diagnosis or treatment of diseases) and other reasons. Contributions to quantitative risk estimates from most of these studies are much less than from the atomic bomb data, except for the uranium miner data for radon-related risks. Laboratory studies of animals, microorganisms, and cells grown in vitro also provide information helpful in understanding the mechanisms of radiation-induced diseases. The data accrued from new or continuing epidemiological and laboratory studies are regularly reviewed and updated by international and national organizations such as the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), the International Commission on Radiological Protection (ICRP), the National Academy of Sciences (NAS) and the National Council on Radiation Protection and Measurements (NCRP). Reports from these organizations provide comprehensive information on health effects of radiation. The overview presented in this chapter is largely drawn from conclusions and summaries derived by these national and international expert groups and are supplemented by additional literature considered relevant for this report.

4.2.1 Cancer (Malignant Tumors)

Before discussing radiation-induced cancer risk, a brief overview of the possible biological basis of cancer formation is relevant. It is currently thought that cancer (and possibly some other late effects) reflects DNA damage (mutations). The exact mechanisms by which radiation (or any other cancer-causing agent) leads to cancer are not completely understood. However, it is generally believed that the development of cancer requires a series of mutations accumulated over many years. Some of these mutations occur spontaneously. Others result from exposure to any of a wide range of mutagens, including radiation. Since many years may have to pass for an irradiated cell or its progeny to acquire sufficient mutations to present itself as clinical cancer, it may take years before excess cancers accountable to radiation exposure are recognized. The process of incurring DNA mutations from radiation is thought to be random in nature. Thus, the probability of cancer resulting from radiation exposure is a function of the number of affected cells and is dependent on radiation dose. The excess cancers that arise as a result of radiation exposure, with or without contributions from other agents, are not distinguishable from those occurring due to other reasons. At present there are no established biological markers that can characterize radiation-induced cancers.

As noted previously, conclusions and inferences about the cancer (and other health) effects of radiation are drawn from statistical associations obtained from epidemiological data. Results from laboratory experiments are also considered to judge the biological basis or plausibility of the epidemiological data. The principal feature of the cancer risk associated with radiation is that the probability that a person will develop cancer due to radiation exposure depends on such factors as the dose received, age at exposure, attained age (or time since exposure) and gender. The relationship of cancer risk to radiation doses (dose response) is essential in estimating the risk at low doses, and the time pattern of the risk associated with age is important in projecting the resulting cancer increase in exposed populations.

The way excess cancer risk increases with an increasing radiation dose is mathematically described by a dose response curve (dose response function or model), and the shape of this curve is important in estimating the risk at low dose levels. There are basic limitations in estimating the cancer risk at low doses using epidemiological data. At low doses, the cancer risk becomes so small relative to the background risk that it may not be possible to find and study a large enough exposed population to detect the small risk.

Furthermore, the background cancer rates often vary by amounts that are comparable to or even greater than the low-dose radiation risk that the study intends to detect. So even if a sufficiently large population were available, it would not be possible to rule out the potentiality that biases may actually explain the observed difference. Despite these limitations, much progress has been made recently in estimating the cancer risk at low doses.

Although the Japanese atomic bomb study is generally regarded as a high dose study, about 80% of the survivors in this cohort received doses that were less than 100 mSv (Pierce et al. 1996). Thus, substantial information can be obtained on low-dose risk from this study. Moreover, the atomic bomb survivor study has several important advantages over other studies including size of the cohort (about 87,000 exposed persons of both genders and all ages, who were exposed to a wide range of doses distributed throughout the body), and a follow-up period of more than 5 decades. The dose response for solid cancers (cancers excluding leukemia and other cancers of the blood and blood forming organs) obtained from this cohort data is remarkably linear. In other words, the increase in risk is directly proportional to the increase in dose. The data do not suggest the existence of a threshold below which there is no excess risk (Pierce et al. 2000). Unlike solid cancers, the relationship between radiation dose and leukemia risk is non-linear (either linear-quadratic or quadratic) indicating less of an increase in risk per unit dose at low dose levels than high dose levels.

Studies of nuclear workers have a potential of providing more direct data on the cancer risk associated with protracted exposures to low doses of radiation. However, because of very low doses, most of the individual studies do not have adequate statistical power to detect small effects. To overcome this problem, the International Agency for Research on Cancer (IARC) carried out an international pooled analysis of data from studies of nuclear workers in the United States, Canada and the United Kingdom (Cardis et al. 1995). The combined cohort in this analysis includes 95,000 people with a mean dose of 40 mSv and represents over 2 million person-years of follow-up. A statistically significant dose response was found for leukemia but not for other cancers. The confidence intervals for both risks of leukemia and of cancers other than leukemia are still considerably broad but that they are consistent to those estimated from the atomic bomb survivors exposed to single doses of radiation.

In general, two distinctly different time-response patterns - one for leukemia and the other for solid cancers - are recognized. Acute exposure to radiation is followed by the excess risk of leukemia, beginning shortly after exposure, increasing with time, reaching its peak 5-10 years after initial exposure, and then declining gradually thereafter. The time-response pattern is strongly dependent on age at exposure, and generally the younger the age at exposure, the steeper the initial rise and faster the subsequent decline (Preston et al. 1994, Pierce et al. 1996). Similar time response patterns are seen in populations with protracted exposure. In contrast to leukemia, the excess risk of solid cancer, starting 5-10 years after exposure, increases gradually and continues to rise as the background cancer rates increase with age. The latest data from the atomic bomb survivor cohort suggest that the excess solid cancer risk may be persistent for many decades after exposure and remain throughout life (Pierce et al. 1996). The excess risk of solid cancer is also dependent on age at exposure for most types of cancer; those exposed at younger ages have relatively high risk compared to those exposed at older ages. How the cancer risk behaves over time in relation to age at exposure, time after exposure and attained age is still not completely understood. More definitive answers to this issue are expected from continued follow-up of the atomic bomb survivors. Further discussion of the relationship between radiation and some specific cancers follows. Radiation-related excess risks have been observed for cancers of many parts of the body. Since exposures to radiation from fallout result in higher doses for the thyroid glands and bone marrow, thyroid cancer and leukemia (which originates in bone marrow cells) are first discussed, followed by other cancers.

4.2.1.1 Thyroid Cancer

Thyroid cancer is one of the less fatal forms of cancer (Ries et al. 2000). The excess risk of thyroid cancer associated with exposure to external radiation (x-rays and gamma rays) has been widely studied and is well established (Ron et al. 1995). Age at exposure is the most important factor that modifies the radiation-induced risk: risk decreases dramatically with increasing age at exposure. In the atomic bomb studies, the excess thyroid cancer cases are primarily seen in those who were exposed at ages less than 20 years (Thompson et al. 1994). The carcinogenic effect of radiation is prolonged and persists at least 40 years after exposure during childhood. Although thyroid cancer occurs 2-3 times more frequently in women than in men, men and women are equally affected by radiation in terms of relative excess risks. In absolute terms, however, this means that more women are afflicted with thyroid cancer than men for a given amount of radiation.

In the case of fallout, internal exposure to ^{131}I is a major concern, but the internal exposure effect has been less extensively studied. Studies of people who received ^{131}I treatment for medical reasons (non-cancer thyroid diseases) have not shown a demonstrable excess thyroid cancer risk. However, this should not be interpreted to suggest the lack of the carcinogenic potential of ^{131}I because the large majority of the study subjects were adults at the time of ^{131}I administration, not allowing inferences on childhood exposure. The thyroid is more radiosensitive in children than in adults, possibly due to differences in metabolism or concentration of radionuclides (Mettler and Upton 1995). It is noteworthy that following the Chernobyl accident, dramatic increases in childhood thyroid cancer cases were reported in areas heavily contaminated with radioactive fallout including ^{131}I. This has suggested a strong carcinogenic potential of ^{131}I on the thyroid in infants and children, but the presence of other radioactive contaminants and limited and uncertain dose estimates are among the major obstacles in developing more precise risk estimates. Thus, the relative biological effectiveness of ^{131}I to induce thyroid neoplasia (malignant or benign) remains the subject of considerable uncertainty.

4.2.1.2 Leukemia

Leukemia is among the rarer forms of cancer, but there is a considerable amount of epidemiological information on the risk of leukemia from radiation exposure. This may in part be due to the higher relative risk compared to other cancers and the relatively short period of time for the leukemogenic effect to be manifested. There are various sub-types of leukemia, the frequencies of which are age dependent. Most leukemias found in childhood are acute lymphocytic types whereas chronic myeloid and chronic lymphocytic types make up a large proportion of adult leukemias. Radiation has not been found to increase the risk of chronic lymphocytic leukemia, which represents about half of adult leukemia cases in the United States and other western populations.

There are some differences in the shape of the dose response for various non-chronic lymphocytic leukemias reported from the atomic bomb survivors and other studies, but they are likely to reflect the uncertainty due to small numbers of cases or different dose distributions. As noted previously, there is clear evidence of non-linearity in the dose response that indicates the risk (per unit dose) is lower if given in a smaller dose. However, this dose response pattern is based on analyses of the total dose received. The issue regarding fallout is whether a chronic cumulative dose (from fallout) is equivalent in risk to a fractionated or acute dose. Therefore, it is of special interest to see whether chronic or fractionated exposure to radiation leads to a lower risk than expected from acute exposure (dose rate effect). As discussed earlier, a large international study of radiation workers (chronic exposure) suggests that the range for the elevated leukemia risk among workers receiving chronic low dose exposures is consistent with the risk estimates obtained from the atomic bomb survivor studies (acute exposure). A number of studies are underway to further address this issue, including updating and expanding the worker study and follow-up of exposed populations in the former Soviet Union and other countries.

4.2.1.3 Other Cancers

Excess cancers due to radiation exposure occur in a wide variety of body sites although different organs and tissues have different sensitivities to this cancer-causing agent. In addition to leukemia and thyroid cancer, cancer types for which excess risks have been reported include cancer of the salivary glands, esophagus, stomach, colon, liver, lung, bone, urinary bladder, ovary, female breast, skin, thyroid, and brain and central nervous system. Evidence is currently inconclusive for non-Hodgkin’s lymphoma and multiple myeloma and is weak for establishing a radiation effect for a number of other cancer types such as Hodgkin’s Disease, cancers of the pancreas, prostate, testis, uterine cervix, uterine corpus, small intestine, pharynx, larynx, and nasal cavity and certain childhood cancers such as retinoblastoma and Wilm's tumor (Boice et al. 1996; NAS 1990; UNSCEAR 1994; UNSCEAR 2000). As previously noted, factors such as gender, age at exposure, characteristics of the exposure such as the type of radiation and the rate at which dose was received, as well as exposures to other risk factors (e.g. smoking), and susceptibility factors influence the risk of specific cancers resulting from radiation exposure (NAS 1990).

4.2.2 Benign Tumors

The induction of benign tumors appears to be similar to cancer induction, but benign tumors are almost always non-fatal, with the exception of brain tumors. Several issues related to studying benign tumors, as summarized in the next paragraph, have limited the conduct of research. Despite this, some progress has been made in studies of benign tumors, and data available to date suggest radiation exposure is capable of causing excess benign tumors, especially of the thyroid.

Benign tumors are difficult to identify adequately and their diagnoses also difficult to validate for epidemiological studies. Because the medical significance of benign tumors can be minor compared with malignant tumors, benign tumors are not routinely reported to cancer registries, do not usually require hospitalization, and are rarely the underlying cause of death listed on death certificates. Autopsy studies and screening programs are potentially useful sources of information, but the differing levels of effort in tumor diagnosis complicate these investigations and can lead to biased ascertainment of cases. The limited data available presently suggest that the risk of benign tumors increases in direct proportion (linearly) to radiation dose and the rate of increase in risk with dose is generally similar to that for cancer. The risk of benign tumors following radiation exposure appears to persist for many years, but currently only limited information is available on the modifying effects of gender and age and time patterns.

Radiation-associated benign tumors tend to occur in the same organs and tissues as malignant tumors, such as the thyroid glands (Schneider et al. 1993) salivary glands (Schneider et al. 1998; Land et al. 1996; Modan et al. 1998), parathyroid glands (Fujiwara et al. 1992; Schneider et al. 1995), gastrointestinal tract (Ron et al. 1995), female breast (Tokunaga et al. 1994), and central nervous system (Ron et al. 1988; Schneider et al. 1985). For fallout exposure, tumors of the thyroid are the major concern because of the potential for relatively high exposure to radioactive iodine. Thyroid adenomas are the major benign tumor of the thyroid and present themselves as nodules. Thyroid adenomas do not appear to have a malignant potential. Childhood exposure to external radiation, such as from the atomic bombs or given for medical reason, has been linked to excess risk of thyroid adenomas (Ron et al. 1989; Shore et al. 1993; Yoshimota et al. 1995). Therefore, one could expect that internal irradiation to radionuclides resulting from fallout exposure is capable of increasing the risk of benign thyroid tumors. Although the limited data currently available from Utah (based on small numbers) support this (Kerber et al. 1993), there are no data that provide quantitative information on risk estimates. Studies are currently ongoing on benign thyroid tumors in other irradiated populations, such as in Chernobyl, Ozyorsk in Russia and Kazakhstan.

4.2.3 Other Diseases (Non-Neoplastic Diseases)

Exposure to ionizing radiation can directly affect health by damaging the structure and function of various tissues and organs in the human body. Clinical manifestation of an effect is thought to occur after a sufficient proportion of cells are affected by radiation exposure (Mettler and Upton 1995). This would imply that there may be a dose level under which no health risk is observed. Most radiation-induced non-neoplastic diseases are believed to occur through this process, and the ICRP has estimated threshold dose levels for certain deterministic effects for the reproductive organs, eyes, and bone marrow (ICRP 1991). Non-neoplastic diseases do not represent a major concern for fallout exposures that usually are below threshold values. However, non-neoplastic diseases are discussed here because of new data coming out of the atomic bomb survivor study as well as studies of various exposed populations around Chernobyl. Concern has been expressed by members of the public regarding non-neoplastic diseases and radiation, particularly, non-neoplastic thyroid disease.

4.2.3.1 Thyroid Disease

Clinical experience has demonstrated that exposure to high-dose radiotherapy to the head and neck or radioiodine therapy for thyrotoxicosis causes subsequent non-neoplastic thyroid disease (IOM 1999; Maxon and Saenger 1996; Barsano 1996; UNSCEAR 1993). The response at lower levels of exposure is not well understood. Results from studies of environmental exposures have been inconsistent. The occurrence of non-neoplastic thyroid disease in relation to environmental radiation exposure has probably been best studied in the various populations near the Chernobyl nuclear power plant. As a result of the Chernobyl accident, these populations were exposed to a mix of radioiodines, which included ^{131}I, other shorter lived radioiodines, and ^{137}Cs among others. Besides thyroid cancer, non-neoplastic thyroid conditions have been investigated in children who were exposed to fallout from the accident. The largest study reviewed, which addresses both neoplastic and non-neoplastic thyroid abnormalities, comes out of the screening program conducted by the Chernobyl

Sasakawa Health and Medical Cooperation Project (Sasakawa Memorial Health Foundation 1994; Sasakawa Memorial Health Foundation 1995). In this large examination program, carried out in about 160,000 children less than 4 years of age at the time of the accident, no increased risk of hypothyroidism, hyperthyroidism or goiter related to radiation exposure was found. Reviewing these and other Chernobyl data, UNSCEAR has recently concluded that there has been no increased risk of thyroid abnormalities, with the exception of thyroid cancer in those exposed at young ages, in affected populations following the Chernobyl accident (UNSCEAR, 2000).

4.2.3.2 Other Non-Neoplastic Diseases

An increased risk of heart disease following high doses of radiation therapy has been reported previously (Mettler and Upton 1995; Hancock et al. 1993). More recently, the atomic bomb survivor data have shown a small excess risk for non-neoplastic diseases, mostly heart disease and stroke (Shimizu et al 1999). The excess non-neoplastic disease in the atomic bomb survivors is seen at a level below that given for medical purposes. However, the shape of the dose response is not clear, especially at low dose levels, from the current data. A linear dose response cannot be ruled out but the data are also consistent with the possibility of essentially zero risk below 0.5 Sv. No animal experiments have shown cardiovascular changes following this level of low-dose exposure, so the biological mechanisms for non-neoplastic disease related to low-dose exposure are currently speculative. Given the lack of a clear dose-response curve, no quantitative assertions on non-neoplastic risks resulting from radiation exposures can be made conclusively.

There has not been any demonstrable inherited adverse health effect, including untoward pregnancy outcome, birth defects or cancer, in a cohort of over 70,000 children whose parents were exposed to radiation from atomic bombs in Hiroshima and Nagasaki (Neel and Schull 1991). This suggests that the excess health risks inherited from radiation-exposed parents are very small and much less than those found for people who were directly exposed to radiation.

4.3 Risk Analysis

The large amount of epidemiological and experimental data on the health effects of exposure to radiation, and specifically the quantitative data that relates cancer to radiation dose, makes it possible to estimate the risk as well as the likely number of people developing cancer as a result of fallout radiation exposure. As noted earlier, several national and international scientific committees periodically review the literature relevant to radiation risk assessment, and recommend models for estimating risks of several types of cancer. These models can then be used to estimate risks – or number of cases to be expected - which result from exposures of specific populations, such as those among the United States population alive during the years of fallout and exposed to its radiation. In contrast, little has been done to attempt to develop similar models to quantify non-cancer disease risk. As observed in previous sections of this chapter, a great deal is still unknown about the relationship between radiation and non-cancer health effects.

Because models for estimating risks of cancer have been developed by several groups of investigators, there is little question that estimates for risk of cancer for the United States population resulting from fallout exposures could be obtained if dose estimates are computed. It must be noted, however, that the populations and exposures for which risk projections are needed nearly always differ from those for which epidemiological data are available. This means that resulting risk projections must be based on assumptions about which there is considerable uncertainty. This raises the question of whether or not uncertain estimates of population risk (that is, the likely number of additional cancer cases) can be useful for developing public health policy. To address this question, preliminary example estimates of population risk are provided later in this chapter. Additionally, the degree of uncertainty in these example estimates is evaluated. First, however, various measures of risk are defined, a description of how cancer risk models have been developed and applied is provided, and the major sources of uncertainty in the risk estimates obtained from these models are discussed. This section on risk analysis focuses primarily on cancer as a health effect of radiation exposure; however, non-cancer health effects are also discussed. Although the discussion of risk measures, model development, and uncertainty are framed in terms of cancer risk, the concepts reviewed are applicable to non-cancer risk as well.

4.3.1 Measures of Risk

An important measure of risk that has been emphasized in most recent risk assessments is the ‘lifetime risk’ or probability that a given radiation exposure will lead to death from cancer in the remaining lifespan of the individual. Although radiation risks have commonly been measured in terms of mortality, projections of lifetime risks of cancer incidence can also be made. Mortality and incidence are both of interest, the former because it can be considered the most serious adverse effect of exposure and the latter because it more fully reflects the public health impact. The measures of lifetime risk that are emphasized here are the risk of radiation-induced death or radiation-induced cancer incidence.

As previously noted, epidemiological data generally support the use of linear dose-response relationships for most cancers, that is, a relationship in which risk is proportional to dose. For this reason, lifetime risk, at least at lower doses, is usually specified by a numerical coefficient expressing the risk per unit of radiation dose. This means that the lifetime risk resulting from a specific dose can be obtained by multiplying the 'lifetime risk coefficient' by the radiation dose.

'Lifetime risk coefficients' depend on gender and age at exposure, because both sensitivity to radiation exposure and the years of life remaining for cancer to develop depend on these factors. Lifetime risks for an entire population can be estimated by first carrying out the calculations for each age at exposure and gender and then averaging the risks according to characteristics of the population of interest. Overall risk coefficients presented in reports such as those of the National Academy of Science's BEIR V Committee (NAS 1990), the International Commission on Radiological Protection (ICRP 1991), or the U.S. Environmental Protection Agency (EPA 1994, 1999) have usually been obtained as averages reflecting the age-gender composition of a specified population. For example, the most recent EPA estimates (EPA 1999) reflect the 1990 population of United States. Although it is recognized that there is considerable variation in risk from a given dose of radiation among individuals within any population, 'lifetime risk coefficients' are summary measures that provide information on the average risk for a group that shares common characteristics. Available epidemiological data make it possible to obtain estimates that are specific for categories defined by age at exposure and gender, but are inadequate to take account of all factors that affect risks. Hence, these average risks are useful for estimating overall public health impact, but are much poorer for estimating the likelihood of an individual developing cancer.

In evaluating risks from fallout exposure, there is interest not only in risks for the overall United States population, but also for groups of people living in certain geographic locations or for groups born near to the same time. Within those groups, there may be considerable variation in the doses that individuals have received. However, multiplying the 'lifetime risk coefficient' by the average dose for the group will yield an estimate of the average risk. Multiplying this average risk by the size of the population will then yield the estimated number of radiation-induced cancers in the population that may occur in addition to those expected without any nuclear fallout exposure.

4.3.2 Risk Model Development

The first step in developing risk estimates is to develop a model for describing the relevant epidemiological data. This means expressing age-specific cancer mortality or incidence rates as a function of baseline cancer rates and parameters that characterize the relationship between risk and radiation dose. The risk from radiation is often expressed as a function of dose, age at the time of exposure, time since exposure, gender, and sometimes other factors. A model that describes the epidemiological data can then be used to calculate the lifetime risk for a group of people with specific ages at exposure and gender. To do this, one essentially follows the group forward in time and calculates the risk of developing a radiation-induced cancer at each age subsequent to the age at exposure. This requires probabilities of survival to each subsequent age, and these are obtained from life tables, and may also require background rates, which are usually obtained from cancer mortality vital statistics for the population of interest (or incidence rates if cancer incidence is to be estimated). For more detail on risk model development, the reader is referred to Bunger et al. (1981), Thomas et al. (1992), or any of several reports from international committees and agencies that provide risk models (NAS 1990; UNSCEAR 1994; ICRP 1991; UNSCEAR, 2000).

4.3.2.1 Uncertainties in quantifying risk due to radiation

As noted above, risk models cannot precisely predict the number of health effects; hence, all risk projections are inherently uncertain. The more important assumptions and associated uncertainties involved in estimating risks in persons exposed to doses from fallout in the United States are discussed below.

Uncertainties in the epidemiological data. Estimates obtained from epidemiological data are subject to random or chance fluctuation, which is referred to as “statistical uncertainty”. This source of uncertainty can be quantified, and is often expressed by presenting 90 or 95% confidence intervals that reflect a range of values that are reasonably compatible with the data. Statistical uncertainty tends to be larger when risks are small than when they are large, and this is the primary reason that risk estimates have been based mainly on epidemiological data from populations exposed at high doses.

Uncertainties also come about because of imperfect disease detection and diagnosis and errors in the dose estimates that are used. In particular, mortality studies often rely on death certificate information, which is often inaccurate, especially for providing information on specific types of cancer. In addition, because epidemiological studies are not controlled experiments, estimates of risk may be biased (that is, may be too high or too low) by unknown factors that differ by level of dose. For example, if subjects with higher doses tended to smoke more than subjects with lower doses, estimates of lung cancer risks resulting from radiation exposure could be biased. This type of bias is known as confounding, and is especially problematic in studying populations where radiation risks are small.

Extrapolating to low doses and dose rates. Probably the most important source of uncertainty in risk estimates for persons exposed to fallout radiation is the extrapolation from high to low doses and high to low dose rates. Preliminary estimates presented in Chapter 3 indicate that most doses from weapons testing fallout are orders of magnitude smaller than those that have been used to estimate risks, and in addition, they are received at low dose rates.

Estimates obtained directly from epidemiological data on populations exposed to low doses and low dose rates, such as nuclear workers, are very imprecise (Cardis et al. 1995). The few studies of persons exposed to fallout are also inadequate for estimating risks with any precision. With small doses, the increased cancer risk from radiation is very small relative to the baseline cancer risk, so that random fluctuation and the possibility of confounding make it difficult if not impossible to detect risk or to estimate it with any precision.

For this reason, it is necessary to extrapolate from risks estimated for persons exposed to much higher doses and dose rates than those received from fallout. Specifically, data on atomic bomb survivors have played an important role in developing models for risk estimation. Although the atomic bomb survivors include individuals who were exposed at low doses, risk estimates derived from these data tend to be driven by those doses exceeding

1 Gy (1000 mGy). To a lesser extent, medically exposed populations have also been used in developing risk estimates, and these also primarily involve relatively large doses. Usually, linear dose-response functions in which cancer risk is proportional to radiation dose have been used to extrapolate from high to low doses. Although most epidemiological data are compatible with such a relationship, other models such as a linear-quadratic relationship cannot be excluded. Because experimental data have suggested that risk per unit of dose is lower when radiation is received at low rates than when it is received at high rates, linear estimates of risk at low doses and dose rates are often reduced by a factor known as the dose and dose rate effectiveness factor (DDREF). A factor of 2 for the DDREF has been used in several risk assessments, but the magnitude of the factor, or whether it is needed at all, is uncertain. Some think that there may be a threshold, that is a dose below which there is no risk, though as noted previously (Section 4.2.1), this hypothesis is not supported by currently available data.

Because of the large uncertainty in the risks associated with exposures at low doses, the National Academy of Science's BEIR V committee (NAS 1990) did not publish estimates of risk for single doses below 0.1 Gy (100 mGy), and also noted the possibility of no risk at very low doses. It should be noted that with the exception of dose to the thyroid, most doses from fallout that were estimated for this feasibility report are much smaller than 0.1 Gy, and preliminary estimates of average doses tend to be in the range of 0.001 to 0.003 Gy (1-3 mGy). The uncertainties in estimating risks at these low doses are especially large.

Transfer from Japanese atomic bomb survivors to the United States population. Another important source of uncertainty results from applying risks estimated from studying a particular exposed population to another population that may have different genetic and lifestyle characteristics and different baseline cancer risks. Specifically, the application of risk estimates based on Japanese atomic bomb survivors to a United States population is a concern, particularly for estimating risks of specific cancers for which baseline rates differ greatly between the two populations. For example, colon cancer rates in Japan are less than half those in the United States, whereas liver cancer rates in Japan are several times as great as those in the United States; colon and liver are two of the cancer sites where fallout doses may be of concern. To address this general problem, the NAS BEIR V committee calculations were based on the assumption that relative risks resulting from radiation exposure were proportional to baseline risks, whereas the earlier NAS BEIR III committee based their estimates on the assumption that risks (on an absolute scale) did not depend on baseline risks, and thus would be similar for Japanese and United States populations. Some recent efforts have used intermediate approaches with allowance for considerable uncertainty (EPA 1999; NIH 2000).

Differences in relative biological effectiveness (RBE). Some doses from fallout involve internal exposure from ^{131}I - which primarily exposes the thyroid gland - and from other radionuclides that expose a variety of organs including colon, liver, kidney, red bone marrow, and bone surfaces. By contrast, Japanese atomic bomb survivors were primarily exposed to external gamma rays, with some exposure to neutrons. This means that both dose rate and the uniformity of the dose within the organ may be different for fallout exposures compared with doses to atomic bomb survivors. The manner that this might affect risk is not known with certainty. The ratio of the tissue damage resulting from equal doses of different types of radiation is known as the relative biological effectiveness or RBE.

Projection of risks over time. Many of the atomic bomb survivors who were young at the time of the bombings (1945) are still alive, and thus their risks at older ages - when baseline cancer risks are largest - have not yet been studied. This is also true for other exposed groups who are being studied. Thus, estimating lifetime risks for those exposed at very early ages and who have lived for decades afterwards requires assumptions about the time-response patterns of disease. Recently developed risk models for cancers other than leukemia and bone cancer are based on the assumption that, after a minimal latent period, the risk (measured on a scale relative to the baseline cancer risk) remains constant over the entire lifespan. This could possibly overestimate risk if the relative risk decreases over time as is suggested by some epidemiological data (Pierce et al. 1996). For leukemia, the risk to those exposed early in life seems to have decreased to near zero by 20-30 years following exposure (Preston et al. 1994); however, there is some uncertainty in risks for the period 2-5 years following exposure since data on atomic bomb survivors are not available before 1950.

Quantifying uncertainties. Recently, there has been increased attention to quantifying the degree of uncertainty in risk estimates [NCRP 1997; EPA 1999; and NIH 2000]. The approach that is taken is first to quantify the uncertainty from each of several sources by specifying distributions, or the probabilities associated with a range of plausible values. For most uncertainty sources, this requires subjective judgments by those conducting the analysis. For this reason, intervals reflecting uncertainty are often referred to as “credibility intervals” instead of confidence intervals (which are usually determined by more rigorous statistical procedures). In order to allow flexibility in the distributions used to indicate the uncertainties in the separate sources, computerized simulations, called Monte Carlo calculations, are often needed.

In evaluating the uncertainty in the risk estimated for a group of individuals exposed to a particular level of dose, it is necessary to include the uncertainty in the dose estimate. Doses estimates are subject to several sources of uncertainty as discussed in Chapter 3. In principle, the uncertainty in dose can be included in risk calculations.

4.3.3 Illustrations and Discussion of Problems in Estimating Cancer Risks From Fallout Doses

In this section, the problems involved in estimating risks of several types of cancer are illustrated. With the exception of the thyroid cancer, the examples were developed using approaches that could be applied quickly, and are given for illustration only. The results presented here need careful re-evaluation if a more detailed dose and risk assessment for radioactive fallout is undertaken.

4.3.3.1 Thyroid Cancer Risks From Internal Exposure From ^{131}I

A detailed evaluation of dose to the thyroid gland from ^{131}I from tests in Nevada has already been conducted (NCI 1997). Doses to the thyroid are predicted to be much larger than those to other organs. Results of this feasibility study indicate most of the dose to the thyroid is from NTS rather than global fallout. Since it is dose received in childhood that is important in evaluating thyroid cancer risks, consideration of global fallout likely would increase the thyroid cancer estimates for the United States (discussed in this section) by about 10% (Table 3.22). Land (IOM 1999) has already evaluated risks of thyroid cancer (see Appendix A), and estimated that between 11,300 and 212,000 thyroid cancers would be expected to occur among the United States population from exposure to ^{131}I from the NTS with a median estimate of 49,000. The risk coefficient used in this evaluation was based on a pooled analysis of data from seven epidemiological studies of persons exposed externally (Ron et al. 1995). Because both thyroid doses and ‘lifetime risk coefficients’ depend strongly on age at exposure, the calculation of Land gave separate consideration to different ages at exposure with the largest risks for the youngest age groups and with no risk for those exposed at ages 20 and older. Although the range of predicted cancer cases did not include all sources of uncertainty, it included two of the most important sources – statistical uncertainty and uncertainty in the estimated average dose. Estimates of lifetime risks for groups of individuals sharing certain characteristics could have also been made, such as groups defined by age at exposure and geography. For example, based on tables describing the Land calculations (Appendix B of the Institute of Medicine’s review of NCI’s fallout report), the average lifetime risk for the entire United States for persons exposed under age 5 can be estimated to be about 0.002 (or about 1 in 500), while no risk is estimated for persons exposed at ages 20 and older (IOM 1999). The uncertainty estimates for specific groups are likely to be larger than that for the population as a whole. This example for thyroid cancer illustrates the feasibility of estimating risks. In addition, the wide range in the number of thyroid cancer cases predicted (11,300-212,000) illustrates the large uncertainty that such estimates carry.

4.3.3.2 Total Cancer Risks from External Exposure to NTS and Global Fallout

For tissues other than thyroid, the preliminary dose estimates in Chapter 3 suggest that the contribution from external dose is larger than that from internal dose. Specifically, the per capita external dose over the period 1951-2000 from both NTS and global fallout is estimated to be about 1.2 mGy (Table 3.14), whereas, with the possible exception of bone surfaces, internal dose even to the more heavily exposed tissues is likely to be less than this. External dose can be expected to expose all tissues of the body in a reasonably uniform manner so that estimating the risk of all cancers is important. An ideal assessment would evaluate risks for each year of birth taking account of the age at exposure in each subsequent year. An assessment for groups exposed in separate geographic areas could also be made to the extent that doses can be estimated for such groups. However, because a substantial portion of the external dose is from exposure to global fallout, geographical variability may be much less than for internal dose.

Several scientific committees and groups have provided models for estimating the risks of all fatal cancers combined. Here, we apply the ICRP (1991) coefficient of 5% per Sv for total cancer mortality. To predict the number of cancers that would occur, it is necessary to consider the size of the exposed population. The population doses given in Table 3.14 are based on the assumption that the population was 163 million (1960 population) throughout the period 1951-2000, which does not allow for increases in the United States population over time. For the purpose of this illustration, we have made a crude correction by using a population of 250 million (1990 population) for the exposure received in the years 1973-2000, resulting in a total population dose of 217,000 person-Sv. Applying the ICRP coefficient of 5%, it can be estimated that about 11,000 extra cancer deaths would be predicted to occur among the United States population alive during the years of fallout. These 11,000 deaths would be spread out over the period extending from the 1950s through much of the 21st century, and would be in addition to the far larger number of cancer deaths that occur every year in the United States; for example, about 500,000 cancer deaths occurred in 1990 (Bureau of the Census 1997) and about 40 million cancer deaths might be predicted to occur over a 75-year period. Cancer incidence estimates (including non-fatal cases) would be about double those for cancer mortality (Ries et al. 1996), resulting in a prediction of about 22,000 radiation-induced incident cases. In this preliminary evaluation, we have not attempted to provide detail on the distribution of the excess deaths and cases by birth cohort, gender, or by age and calendar year of occurrence.

Another perspective is provided by evaluating risks for the 3.8 million people born in the United States in 1951 (Bogue 1985), a group that would, on average, have received larger doses at earlier ages than those born earlier or later. The average dose for this population is estimated to be about 1.2 mSv resulting in a population dose of about 4600 person-Sv. If the ICRP coefficient of 5% per Sv is applied, about 230 cancers would be predicted to result from this exposure (a risk of about 1 in 16,500). However, because much of the dose would be received in childhood for this group, risks might be larger; for example, calculations shown in UNSCEAR (1994) indicate that risks for those exposed under age 20 might be 2 or 3 times risks for those exposed in adulthood. It seems unlikely, however, that consideration of age at exposure would result in an estimate of more than 1000 excess cancers in this group (about 1 in 3800). Since more than 20% of all deaths are due to cancer (Greenlee et al. 2000), this can be contrasted with about 760,000 cancer deaths that might be predicted in this group in the absence of radiation exposure from fallout.

Risks for other birth cohorts could also be evaluated and would have smaller risks than those for the 1951 cohort. For example, the 1931 birth cohort would receive about the same external dose, but it would all be received in adulthood. The number of excess fatal cancers predicted in the 2.5 million persons born in 1931 (Bogue 1985) would be about 150, compared to about 500,000 fatal cancers that would be predicted in the absence of fallout exposure. This can be further contrasted to risk estimated for persons born in 1971. The average dose for this birth cohort is only about 0.23 mSv (dose received by the year 2000), with most of this dose received in childhood. The predicted number of excess fatal cancer among this cohort of 3.6 million persons is likely to be less than 100, compared with about 720,000 cancer deaths that would be predicted in the absence of fallout. Estimates for the 1931, 1951, and 1971 birth cohorts are summarized in Table 4.1.

Table 4.1. Preliminary estimates of the total number of excess cancer deaths resulting from external exposures from NTS and global fallout for persons born in 1931, 1951 or 1971.

Birth cohort (Population size)	Estimated excess cancer deaths*	Estimated excess risk	Cancer deaths expected in the absence of fallout	Risk of cancer death in the absence of fallout
1931 (2.5 million)	About 150	About 0.006% (1 in 17,000)	About 500,000	About 20% (1 in 5)
1951 (3.8 million)	Less than 1000	Less than 0.03% (1in 3800)	About 760,000	About 20% (1 in 5)
1971 (3.6 million)	Less than 100	Less than 0.003% (1 in 36,000)	About 720,000	About 20% (1 in 5)

* Includes deaths from leukemia

The National Council on Radiation Protection and Measurements evaluated sources of uncertainty in the ICRP risk coefficient of 5% per Sv (NCRP 1997). Uncertainty from each source was quantified, and computer simulations were conducted to evaluate the overall uncertainty from all sources. Using that approach, the 90% credibility interval for the lifetime risk coefficients for fatal cancer covered a range from about 3 times lower than the best estimate to about 3 times higher than the best estimate (1.2% per Sv to 8.8% per Sv with a median value of 3.4% per Sv). Applying that range to the total population dose from external fallout, the number of excess cancer deaths among the United States population is predicted to be from 2,600 to 19,100 with a median estimate of 7,400. The range for the number of incident cases would be about double these values.

The range for the 'lifetime risk coefficient' does not account for uncertainties in the estimated external doses from fallout. Inclusion of all sources of uncertainty could be accomplished by conducting computer simulations that used both the uncertainty distributions given by the NCRP and a distribution reflecting uncertainties in the dose estimates. This computer simulation has not been performed, but its solution can be approximated by algebraic expressions. For this purpose, it is assumed that the 90% credibility interval for dose extends from a factor of three below the estimate to a factor of three above the estimate. Incorporating all of the above uncertainties results in risk projections that range from 1,700 to 32,500 excess cancer deaths.

Although the estimates above should be regarded as illustrative only, they indicate that the total number of incident cancers from external fallout exposure (about 22,000 cancers) would be about half the estimated number of thyroid cancers from ^{131}I exposure (49,000). It is likely that the number of deaths (roughly 11,000) might exceed deaths from thyroid cancer, which generally has a low fatality rate. Doses from external exposure, especially those from global exposure, vary less than doses to the thyroid from ^{131}I by geographic location, birth cohort, and dietary habits (such as milk consumption). Risks for cancers other than thyroid cancer are also less strongly dependent on age at exposure. For these reasons, risks for all cancers from external exposure are likely to vary less by geographic location, age at exposure and other factors than risks of thyroid cancer from NTS ^{131}I exposure, which makes it more difficult to identify groups with particularly large risks.

It should also be noted that total cancer risk from external exposure can be estimated with greater certainty than can risks of most individual types of cancers or risks from internal exposure. This is because of the relative wealth of epidemiological data on external exposure (including the atomic bomb survivors studies), and because both statistical uncertainties and uncertainties in extrapolating risks from atomic bomb survivors to a United States population are smaller. Nevertheless, the above discussion demonstrates that even risks due to external exposure cannot be estimated precisely.

4.3.3.3 Leukemia Risks from External and Internal Exposure

Leukemia is perhaps of special interest because it has been strongly linked with radiation in several epidemiological studies, and because of the strontium-90 component of fallout exposure. Also, increased rates of leukemia have been reported in persons living downwind of the NTS (Stevens et al. 1990) and in participants in the Smoky nuclear weapons test inducted at the NTS in 1957 (Robinette et al. 1985). In addition, during numerous CDC public meetings on other radiation-related issues, members of the public have consistently identified leukemia as one of their main cancer concerns.

For leukemia, the ICRP (1991) lifetime risk coefficient is 0.5% per Sv. Since this estimate was based on atomic bomb survivor data at a time when nearly all leukemias were fatal, it can appropriately be considered as an estimate of lifetime leukemia incidence as well as mortality. Actually, modern leukemia survival rates would reduce mortality, but this is seldom taken into account in estimating leukemia risks.

It is noted first that the estimate for total cancer mortality from external dose includes deaths from leukemia, and that about 10% or 1,100 of the 11,000 cancer deaths from external exposure would be predicted to be from leukemia. As shown in Table 3.22 internal exposures would result in additional dose to the red bone marrow, mostly from global fallout. The average dose for an adult from internal sources is estimated to be 0.7 mSv, whereas the average dose for a person born 1 January 1951 is estimated to be 0.9 mSv. Estimation of the number of leukemias resulting from these internal exposures would require taking account of the number of adults and children receiving them. This could be done, but is beyond the scope of this feasibility report. A rough estimate can be obtained by noting that the adult internal exposure is about half of that due to external exposure. If it is assumed that risk coefficients are similar for internal and external exposure, about 550 leukemias from internal exposure might be added to the 1,100 leukemias estimated to result from external exposure. Lifetime risks for leukemia do not depend strongly on age at exposure (UNSCEAR 1994).

Leukemia risks can also be evaluated for the 3.8 million persons born in 1951, who would have received a dose of about 0.9 mSv to the red bone marrow from internal sources, or a population dose of about 3400 person-Sv. Multiplying by the ICRP coefficient of 0.5% per Sv leads to an estimated 17 excess leukemia cases in this group (a risk of 1 in 220,000) due to internal exposure.

4.3.3.4 Risks from Internal Exposure (Other Than Thyroid and Leukemia)

Dose from internal exposure varies considerably by organ, making it important to separately consider risks of cancers in specific organs. Preliminary data on NTS and global exposures indicate that the tissues or organs that can be expected to receive the largest internal doses are thyroid, colon, kidney, liver, red bone marrow, and bone surfaces. Risks of thyroid cancer and leukemia from internal exposure were discussed earlier in this section.

Several groups of scientists have made estimates of risk coefficients for at least some of these cancers. For illustrative purposes, those lifetime risk coefficients developed by the EPA (1999) for cancer mortality are provided in Table 4.2. These risk estimates are reasonably recent and include estimates for all the tissues noted above. Estimates of cancer incidence are also available.

Table 4.2. Environmental Protection Agency's age-averaged site-specific lifetime cancer mortality risk estimates from low-dose, low-LET uniform irradiation of the body.

Site	Percent per Sv
Colon	1.04
Liver	0.15
Bone	0.01
Kidney	0.05
Leukemia	0.56
All cancer	5.75

Except for leukemia and all cancer, the EPA has not carried out a detailed analysis of the level of uncertainty in the risk coefficients listed in Table 4.2, but sources of uncertainty are discussed and approaches for evaluating them are suggested (EPA 1999). Uncertainty for specific cancers is likely to be larger than that for all cancers combined, both because statistical variation is greater, and, for estimates based on atomic bomb survivor data, differences in United States and Japanese baseline risks are greater.

Risk estimates for exposures involved in fallout could be obtained by multiplying those coefficients by the dose to the tissue or organ that was exposed. This preliminary report does not go through this exercise. However, several observations are important to note. First, the preliminary dose assessment indicates that most tissues received little dose from internal sources (Tables 3.10, 3.19 and 3.22). Secondly, with the exception of the thyroid, there are no organs that are likely to receive doses that are substantially larger than those from external exposure. For these reasons, the total risk of cancer (other than thyroid cancer) from internal exposure is likely to be less than that from external exposure.

4.3.4 Future Possibilities for Analyzing Cancer Risk

The examples above were intended only for illustration, hence, the methods were based on readily available ‘lifetime risk coefficients’. If a more detailed assessment of doses from fallout is undertaken, several improvements can likely be undertaken. In the illustrations provided, no attempt was made to give detailed attention to developing risk estimates for specific years of birth that took account of both specific ages at exposure and specific population sizes for different exposure years. Such estimates would help to provide information on which persons were at greatest risk, and would also provide a slightly more accurate estimate of the overall risk. In addition, risk estimates for specific geographic locations could be developed, again providing information on those at greatest risk. This latter refinement is probably of greater interest for doses from NTS fallout since these show greater geographic variation than doses from global fallout. Better information on the predicted age and calendar period of appearance of predicted cancer deaths and incident cases could also be developed.

Evaluation of uncertainty in risk estimates should include both the uncertainty in the lifetime risk coefficient and uncertainty in the estimated dose. To allow full flexibility in the distributions used to describe uncertainties, computer simulations would be needed. Although we have not used this approach in our illustrations, the feasibility of conducting such simulations has been demonstrated by the NCRP (1997), EPA (1999), and most recently by the NCI (NIH 2000) as discussed below.

The NCI (NIH 2000) has recently updated the Radioepidemiological Tables that were published in 1985 (NIH 1985). This revision required developing risk models for more than 20 specific cancers, including those organs and tissues that are of interest following exposures to radioactive fallout. Although the tables are being developed to estimate the "probability of causation", that is, the probability that a cancer that has been diagnosed in an individual is the result of some previous exposure to radiation, the models could be used to estimate the lifetime risk of developing cancer. The evaluation of uncertainty in the revised tables is probably the most comprehensive that has been undertaken in the field of radiation risk assessment. The overall uncertainty distributions include statistical uncertainty of parameters, as well as subjective evaluation of uncertainties in the errors related to extrapolating to low doses and dose rates, the differences between Japanese and United States populations, and uncertainties in the dosimetry of atomic bomb survivors. Software has been developed that allows a person interested in a specific 'probability of causation' to specify the type of cancer and when it occurred, the age at exposure and gender, the radiation dose and when it was received and, if desired, the uncertainties in the dose estimate. A computer calculation (simulation) is then performed, and the person is provided with a range of estimates of the probability the cancer was a result of radiation exposure.

Although the software is now limited to evaluating ‘probability of causation’, it could be expanded to estimate lifetime risks – a more useful quantity for those exposed to fallout and who as yet have no observable health effects. In addition to providing a comprehensive evaluation of uncertainty, the NCI approach has the advantage that it is based primarily on atomic bomb survivor cancer incidence data from the Hiroshima and Nagasaki tumor registries. This means that diagnostic information on specific cancer types is likely to be more reliable than for the mortality data used in most other risk assessments.

In addition, the National Academy of Science’s BEIR VII Committee is beginning its work, and is expected to recommend models for risk estimates of the health effects of exposure to low levels of ionizing radiation. The models to emerge from that study are likely to make use of both the latest incidence and mortality data from the atomic bomb survivors (Thompson et al. 1994; Pierce et al. 1996) as well as from other epidemiological studies that provide relevant information. Furthermore, analyses of updated atomic bomb survivor cancer incidence data are currently underway and will extend the period covered by seven years (covering 1958-94 instead of 1958-87 as previously).

Although the approaches and resources noted above are expected to provide a stronger basis for estimating risks and particularly for quantifying their uncertainties, they cannot greatly reduce some important sources of uncertainty in estimating the risks from exposures received from fallout. These include uncertainties in extrapolating from high to low doses and dose rates, uncertainties in using estimates from Japanese atomic bomb survivors for a United States population, and uncertainties in the relative biological effectiveness of some of the exposures involved in nuclear fallout.

4.3.5 Analyzing the Risk of Non-Cancer Health Effects

Data presented earlier in this chapter described the relationship between radiation and non-cancer health effects, including benign tumors of the thyroid, the stomach, and other sites and non-neoplastic diseases such as hypothyroidism and heart disease. While a number of epidemiologic studies have demonstrated an association between radiation and non-cancer health effects, more fundamental research is needed clarify the biological mechanisms by which low dose, and low dose rate radiation exposure causes disease. Also, dose response and time response patterns of the disease-exposure relationship require further assessment before risk analyses can be performed reliably.

In considering the dose data available in this feasibility assessment, the most likely non-cancer health outcomes that may affect the American people are those involving the thyroid gland. Preliminary estimates of dose from fallout radiation indicate that the internal organ-specific dose to the thyroid is much higher than the dose to other organs/tissue evaluated (Tables 3.10 and 3.22). Internal and external exposures (delivering a uniform dose to the whole body) to fallout radiation are unlikely to result in an increase in other non-neoplastic disease at the currently estimated dose levels. However, it is conceivable that select individuals may have much greater sensitivity to radiation than has been found on average. For example, individuals with pre-existing disease could be more radiosensitive.

4.3.5.1 Benign Tumors of the Thyroid

While considerable effort has gone into quantifying the lifetime risk of cancers, much less has been done to quantify non-malignant disease in a similar manner. Among those benign tumors that have been related to radiation exposure in various studies, lifetime projections of risk are available only for benign thyroid nodules. This lifetime risk coefficient was developed for the Nuclear Regulatory Commission (NRC 1989, 1993) for predicting health effects from nuclear power plant accidents and has been reviewed by the NCRP (1993). The risk estimate is based on data from studies of external x-ray irradiation of children and is based on the assumptions that women are more sensitive to exposure than men are and children are more sensitive than adults are. Internal exposure to ^{131}I is assumed to be substantially less effective than external irradiation in inducing benign neoplasms in the general population (NRC 1993).

At this point in time, however, quantifying the lifetime risk of benign thyroid nodules resulting from fallout exposure is not advisable. Although risk estimates can be developed using available risk coefficients, these estimates do not take into consideration recent studies of the relationship between radiation and thyroid disease, specifically those studies conducted in populations exposed to ^{131}I from the Chernobyl accident. More importantly, existing risk coefficients do not adequately account for uncertainty. Given the important issues surrounding the detection and diagnosis of these benign nodules, the uncertainty associated with this health endpoint will likely be much greater than that seen for thyroid cancer. Additionally, issues related to the effectiveness of internal exposure to ^{131}I in inducing benign nodules, extrapolation of risk estimates from one population to another, and projection of risk over a lifetime need to be considered.

Separate from actually developing risk estimates, but, equally important in determining whether it is advisable to estimate the lifetime risk of benign thyroid nodules, is the clinical significance of these tumors. Currently, the significance of small ultrasound detected lesions remains unknown. Most thyroid nodules are benign (IOM 1999) and there is no evidence to date to suggest that radiation exposure induces adenomas that are more likely to progress to malignant disease than adenomas occurring in unexposed individuals (Wang and Crapo 1997; Mettler and Upton 1995).

4.3.5.2 Non-Neoplastic Thyroid Disease

Clinical and epidemiological data clearly indicate an association between high dose radiotherapy and hypothyroidism; however, the association with low dose exposures and, in particular with low doses of ^{131}I, is less clear. Hyperthyroidism after radiotherapy has also been reported (IOM 1999). The IOM, in reviewing the NCI ^{131}I report, did not consider the impact of thyroid dose from NTS fallout on other nonmalignant thyroid diseases because the review committee felt the data describing these health effects were inconclusive for the range of doses estimated for average Americans (NAS 1999). And, a recent review of the Chernobyl studies by UNSCEAR was unable to conclude that non-malignant diseases were increased as a result of low dose radiation exposure (UNSCEAR 2000). Given the current state of knowledge, a quantitative risk analysis of non-neoplastic thyroid disease from fallout is not feasible. Additional studies of exposed populations, especially those exposed from the Chernobyl accident, that have longer follow-up periods, sufficient sample size, and individual dosimetry, may be necessary to provide adequate data on which to base a risk assessment. It is likely, however, that the uncertainty associated with any future quantitative risk estimates will be quite large.

The IOM reported that the risk of non-malignant thyroid disease resulting from exposure to ionizing radiation could extend into the range of doses of less than 1 Gy (1000 mGy). Maxon and Saenger (1996) reported that hypothyroidism from radioiodine exposure is unlikely to occur at doses less than 0.1 to 0.2 Gray (100 to 200 mGy). These lower values can be used as a "threshold" to qualitatively assess the potential risk of hypothyroidism from fallout exposures. Using these values will more likely result in an overestimate than an underestimate of a health effect. Based on the data presented in Chapter 3, the average American was exposed to a significantly lower dose than the dose range described by Maxon and Saenger (1996). However, it is clear from Figure 3.17 that there may be subgroups of the population who, based on their age during the testing period and place of residence, have received doses approaching 0.2 Gy. Higher doses for some individuals would be expected if non-commercial milk sources (backyard cow or goat) and above-average milk consumption patterns were considered. Thus, this health effect is the most likely non-cancer health consequence of fallout exposure.

4.4 Conclusions

It is feasible to estimate fallout-related risks of developing cancer among population groups or for representative exposure scenarios, and to quantify the range of uncertainty in these risks. This range is likely to be large because of uncertainties in dose estimates and in the risk models that are used. In spite of the large uncertainties, it is likely that there is an increased risk of cancer from fallout, but it is also highly likely that this increase is very small relative to the usual risk of cancer in the absence of fallout exposure. For example, the 3.8 million people born in the United States in 1951 might experience a few hundred extra fatal cancers as a result of fallout exposures compared with more than a half a million fatal cancers that would be predicted in the absence of fallout. Persons born in 1951, on average, have received larger doses than those born earlier or later. Because doses from global fallout vary less by geographic location and birth cohort than do thyroid doses from NTS ^{131}I exposure, it would be more difficult to identify groups with unusually large risks. At this time, not enough information is available to perform a quantitative radiation risk analysis for non-cancer health outcomes. A preliminary evaluation of the doses estimated for this feasibility report and the available epidemiological literature indicate, however, the most likely non-cancer health outcomes are those affecting the thyroid gland.

With regard to the exposures of the American people from Nevada Test Site fallout, the Institute of Medicine has indicated that further epidemiologic studies could help to clarify the extent to which the Nevada tests increased the incidence of thyroid cancer. The University of Utah is currently extending the follow-up for a previous epidemiological study of children who lived in the vicinity of the Nevada Test Site in the 1950s; results are expected to be available in a few years. Outcomes evaluated will include neoplastic and non-neoplastic thyroid disease.

A number of non-United States populations have been exposed to substantially higher levels of radioiodine and other radionuclides than the United States population. These populations include the residents of the Republic of Marshall Islands; the people living near the nuclear weapons test site in Semipalatinsk, Kazakstan; those exposed in the former Soviet Union to accidental releases from the Chernobyl nuclear power station in Ukraine; and persons living near the Mayak nuclear fuel reprocessing plant in Russia. Ongoing dosimetric and epidemiological studies of these populations are expected to provide additional data regarding the health consequences of fallout exposure. In particular, it is fairly clear from the preliminary results from the Chernobyl studies that exposure to ^{131}I in childhood can increase thyroid cancer risks, although these risks cannot yet be quantified accurately and only time will tell how long they will persist. Also, on-going studies of populations living near the Mayak nuclear fuel reprocessing plant in Russia may improve the risk estimate for leukemia at low dose rates. Expansion or enhancement of these investigations may be useful to better characterize risks. The results from these epidemiological studies should be available before further health research is considered.

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Chapter 5

Communications Approach

Contents: *This chapter outlines the many steps and challenges that may be associated with a public awareness and education effort conveying the results of a detailed study of the health consequences of nuclear weapons testing. The informational needs as defined by various stakeholder groups are identified and current work being conducted by the NCI on its ^{131}I/NTS Communications Project is discussed.*

5.1 Introduction

Effective health communication and education efforts increase the awareness and knowledge of a potential health risk. Often, such efforts are launched with hopes to motivate people to seek more information and possibly seek individual care and examination from a health care provider. This is not a simple task, and communicating effectively with multiple audiences about their exposures and the potential health consequences resulting from nuclear weapons tests conducted 4 –5 decades ago is particularly challenging. A comprehensive effort to communicate the results of an in-depth scientific assessment of dose and risk, and to address the numerous issues that have been raised by stakeholders regarding fallout, would likely be an extremely complex and resource intensive public awareness and education effort. This is not only because of the technical nature of the science used to develop the exposure estimates and potential health risks, but also because of the breadth of information that must be included. A study of the health consequences of nuclear weapons testing encompasses exposures to multiple radionuclides present in radioactive fallout and estimates of the likelihood of a number of health consequences resulting from these exposures. In addition, because exposure occurred across the country, information must be designed with sensitivity to educational, cultural, and other differences in population groups. It is clear that the development, implementation and evaluation of any communications plan will require extensive collaboration with state and local health departments, health professional organizations, advocacy groups and community organizations and the use of multiple channels to disseminate the information once developed.

Given the historical, social justice and political contexts enveloping testing programs (for example, the United States tests at the NTS and the Marshall Islands), a public awareness and education campaign could engender additional public mistrust of government and possibly intensify demands for Federal government policy and legislative changes. It will be a formidable task to communicate information in a way that is perceived as believable as well as understandable by those concerned about the consequences of the testing program. Nevertheless, one of the most important public health implications of performing a detailed dosimetric and risk analysis study in the future will be the need to clearly communicate the results of this more detailed study to the American public and health-care providers.

This chapter provides general information about the discipline of risk communication and focuses on the many steps and challenges that may be associated with a public awareness and education effort to convey the results of a detailed study of the health consequences of nuclear weapons testing. The informational needs, as defined by various stakeholder groups, have been identified through work currently being conducted by NCI to communicate the results of its report on *Estimated Exposures and Thyroid Doses Received by the American People from Iodine-131 (*^{131}*I) In Fallout Following Nevada Atmospheric*

Nuclear Bomb Tests (NCI 1997) (hereafter referred to as ^{131}I/NTS Communications Project). While this chapter deals specifically with communicating the results of a more in-depth study of the health consequences to the American public of fallout exposures, a number of the issues and strategies discussed would be applicable to communicating the results of this feasibility report.

5.2 Components of a Proposed Communications Plan

There are multiple components of a communications plan. However, it is clear that any communications effort must target both the public and health care providers to be effective.

5.2.1 Public Communication and Education

The objectives of a nationally coordinated public awareness and education effort on informing the American public of their potential exposure from fallout from United States and global nuclear weapons testing are:

- **To Satisfy the Public's 'Right to Know'**

  Specifically, to alert Americans alive in the 1950s and the early 1960s that they were exposed to fallout from tests conducted at the NTS and from other global testing events, the potential health consequences of such exposure, and what, if any, steps concerned individuals may take to get answers to questions related to potential health effects from global fallout. This could include educational information on the history and conduct of nuclear testing programs within the United States and globally (for atmospheric testing ending in 1962). This information could also provide the public with the information it needs to enter into a public debate regarding issues of Federal responsibility with regard to the potential health outcomes associated with the United States and global nuclear weapons programs. Additionally, this could be structured to provide a central information repository for educational materials regarding these issues.

- **To Enable the American Public to Understand the Level of Exposure from Fallout and the Potential Risk of Disease Associated with that Exposure Level**

  Specifically, to educate the American public about factors that may have increased their chances of exposure or their risk of disease so that they can self-identify whether or not they may be in a high exposure and/or high-risk group. Additionally, to provide information on the potential health consequences of radioactive fallout so that people have the knowledge they need to make informed decisions about their health and are motivated to act on recommended follow-up activities (i.e., seeing their health care provider). Emphasis would be on reaching those population groups estimated to have received the greatest exposure and having the greatest likelihood of resultant health risks.

- **To Address Special Information Needs Including Access to Health Care and Ability-to-Pay Issues**

  Specifically, to address the special information needs of those who are potentially at high-risk and/or who are concerned, but do not have a source for medical care.

5.2.2 Health Care Provider Education

The nation's health care providers will likely have the greatest impact on improving the health status of persons who may have been adversely affected by radioactive fallout. This health care provider group includes local health care providers, national, state, and local medical associations, academic medical centers, medical schools, and schools of public health. The objectives of this component of a communications program would be to:

- **Inform Physicians/Health Care Providers about the Radionuclides of Concern and Potential Health Consequences**

  Specifically, to target health care professionals in the geographic regions that received high doses and those practicing near former United States Nuclear Weapons Program sites. Information should also include current recommendations by professional organizations and others regarding screening, diagnostic and treatment options.

- **Build Expertise**

This could entail educating health care providers about radiation fallout-related disease and potential high-risk populations in their area and building skills through the use of training programs and short courses for health care professionals that guide them through the screening, diagnosis, treatment, and surveillance of specific illnesses.

5.3 Using NCI's ^{131}I/NTS Communications Project as a Model

In its review of NCI's 1997 report, the IOM (IOM 1999) recommended that the Department of Health and Human Services (DHHS) take additional steps to develop and implement a communication plan to fully explain the potential health implications of ^{131}I exposure to the American public from nuclear weapons testing at the Nevada Test Site (NTS). In response to the IOM recommendations (IOM 1999), NCI began collaborating with CDC to develop and disseminate accurate, yet understandable, information regarding the potential risks of thyroid cancer and thyroid disease associated with exposure to ^{131}I released during nuclear bomb testing in the 1950s and early 1960s at the NTS. In January, 2000 NCI and CDC sponsored a communications workshop entitled "^{131}I Fallout from NTS: Informing the Public." Subsequent to this workshop, NCI, in consultation with a group of citizens, scientists, physicians, communication experts, and representatives of the advocacy community and state public health departments, developed its ^{131}I/NTS Communications Plan (see **Appendix H.1**). NCI is currently implementing the strategies outlined in this plan.

Because a great deal of work has already been accomplished by NCI to structure its ^{131}I/NTS Communications Project to ensure ongoing public involvement in the development and implementation, it would seem appropriate to use a similar approach for future communication planning efforts associated with a detailed study of the health consequences of nuclear weapons testing by the United States and other countries. In planning for this future work, the specific recommendations made by the IOM in its review of NCI's 1997 report concerning communicating with health care providers and the public (IOM 1999) should also be considered.

5.3.1 The January 2000 ^{131}I Communications Workshop

In January 2000, NCI (along with a working group consisting of CDC, citizen, advocacy group, state health department, and the Advisory Committee on Energy Related Epidemiologic Research (ACERER) representatives and a health educator) planned and convened a Workshop to begin the process of designing and implementing the ^{131}I/NTS Communications Project. The Workshop, entitled *"^{131}I Fallout from NTS: Informing the Public,"* was held January 19-21, 2000 in Rockville, Maryland (see Workshop Agenda and Summary in **Appendices H.2 and H.3**). This multi-day Workshop was structured with expert panels that explored relevant issues and public health communications recommendations. Through the Workshop, NCI sought input from affected and concerned citizens, health and environmental nonprofit organizations, health care providers, public health and other local government officials, experts in radiation sciences, and experts in health and risk communications on how to best plan and implement the ^{131}I/NTS Communications Project.

Over 70 participants and presenters were directly involved throughout the Workshop (see **Appendix H.3** for the participant list). Workshop participants discussed the need for a more comprehensive ongoing information campaign.

At the end of the Workshop, participants agreed that NCI should proceed with plans to communicate to the American public what is known about ^{131}I/ NTS exposures and the potential health consequences. Participants understood that CDC and NCI would be providing Congress with a feasibility study regarding potential doses and health risks from exposures from United States and global testing, and that any communications effort associated with a more in-depth study would be resource dependent. They agreed that the ^{131}I/NTS Communications Project should be structured such that it could be broadened as more is learned from continuing work on exposures to global fallout and other radionuclides from the NTS. Thus, DHHS would be able to utilize the model developed for the ^{131}I/NTS Communications Project in planning for future communications efforts.

The Workshop ended with recommendations for further action and for creation of a citizen review group that would be involved in the planning phases of the ^{131}I/ NTS Communications Project. NCI incorporated these recommendations as it developed the plan for its ^{131}I/NTS Communications Project.

Keeping in contact with workshop participants

In order to meet Workshop participant expectations, NCI and CDC have made a commitment to communicate frequently and fully with the community about their timetable and progress toward meeting milestones. One of those milestones was to provide participants with a copy of the feasibility report to review and to inform them of Congressional response to this report. NCI and CDC have developed a process for on-going communication with Workshop participants to keep them informed about the progress in implementing the ^{131}I/NTS Communications Plan, any new efforts initiated (for example, if

Congress decides to appropriate funds to carry out the work detailed in this report) or the reasons for any delays. This process includes:

- Progress reports sent out via an electronic mailing list – utilizing the National Institutes of Health (NIH) LISTSERV facility. Workshop participants (and any other interested individuals) who subscribe to this service receive updates on NCI's progress implementing the plan for the ^{131}I/NTS Communications Project. This process is also used to disseminate draft documents and to collect review comments. Workshop participants also "discuss" topics via group email exchanges.
- Mailings (for those Workshop participants who do not have internet access, those who prefer mailings or those who are not subscribed to the Listserv).
- Other avenues of communication such as postings on NCI's or CDC's websites.

5.3.2 The ^{131}I/NTS Communications Development Group

During the ^{131}I/NTS Communications Workshop, participants determined that a structure was needed for continued public participation in the communication planning process. Workshop participants decided that NCI should form a working group of concerned citizens and health professionals to provide guidance to NCI as it developed the plan for the ^{131}I/NTS Communications Project. NCI used the feedback received during the Workshop to solicit and select eight people to comprise the Communications Development Group. These individuals represented activists, Native American groups, minority citizens, local and state public health departments, physicians and health care providers, and health educators. This eight-member group provided input and feedback into the development of the ^{131}I/NTS Communications Plan. Specifically, the group assisted in efforts to:

- Identify all potential target audiences;
- Identify the cultural sensitivities of those audiences;

- Choose appropriate strategies to reach the intended audiences;
- Develop project message concepts;
- Identify appropriate delivery channels (e.g., face-to-face, group, organizational, community and media);
- Identify appropriate information sources (credible persons to deliver the information); and
- Identify appropriate materials to use.

5.3.3 Assessing the Effectiveness of the ^{131}I/NTS Communications Project

Because there would be a significant time lapse between the implementation of the ^{131}I/NTS Communications Plan and the completion of in-depth research on exposure to radionuclides from global fallout and radionuclides other than ^{131}I from NTS fallout, sufficient time exists to evaluate the effectiveness of the ^{131}I/NTS Communications Project. Such an evaluation is necessary to determine if the ^{131}I/NTS Communications Project could actually be used as a model for communicating the results of other fallout related scientific research.

An evaluation should focus on determining the public reaction to the ^{131}I/NTS Communication Project and the degree to which the original objectives (i.e., determining changes in public awareness, the “reach” of the project, and the effectiveness of the communication channels, etc.) were met. Additionally, an evaluation should assess the appropriateness of any changes in public perceptions and actions. (For example, an assessment could reveal if there were any unintentional results, such as individuals becoming unduly alarmed or taking unnecessary precautions or otherwise misinterpreting or misusing the exposure/risk information). Any changes discovered from an assessment would be relevant to the development of a communications plan based on possible future research described in this report. The structure and content of a communications plan would also need to take into account the publication of new research that could potentially change what is known about the relation between radiation exposure and a health risk or new policies and programs that change how the risk affects the public.

5.4 Audience Profiling and Message Development

Health communication is the crafting and delivery of messages and strategies, based on consumer research, to promote the health of individuals and communities.

Characteristics of a successful national public health communication and education effort include (Arkin 1999):

- Careful planning;
- Sufficient funding and staffing;
- Long-term legislative and public support;
- In-depth audience identification, focus and involvement;
- Clearly identified changes and challenges;
- Multiple dissemination channels, activities, and strategies;
- Trustworthy spokespersons and credible information sources;
- Multiple partners; multiple types of evaluation;
- Evaluation; and the
- Flexibility to be modified as changes are identified.

5.4.1 Determining the public's awareness

Before the implementation of any communication effort, the level of public awareness must be examined and considered. Prior to the January 2000 Communications Workshop, NCI conducted limited research to measure the level of public awareness, concern, and familiarity with the United States' nuclear weapons atmospheric tests conducted during the 1950s and early 1960s at the Nevada Test Site. (See **Appendices H.4 and H.5** for a copy of the reports on the key findings from this market research). This market research, along with work currently being conducted in implementing the ^{131}I/NTS Communications Project, will be extremely useful to DHHS in developing future communication plans to address fallout issues. What follows is a brief description of the type of research conducted by NCI and a discussion of the main areas where DHHS would need to conduct supplemental research.

5.4.1.1 In-depth Interviews with Subject Experts

In the Fall/Winter of 1999, NCI conducted 19 in-depth interviews with individuals who were identified by agency and public representatives as having expertise in areas related to the issue of nuclear fallout (see **Appendix H.4**). The main objective of these qualitative interviews was to provide NCI with useful and detailed insights into the perceptions and views of different organizations and experts involved in the ^{131}I fallout issue and, as such; they were not intended to represent the views of all such groups or persons (NCI 2000a). The interviews yielded results that have helped NCI determine the direction and scope of further research for the ^{131}I/NTS Communications Project.

5.4.1.2 Public and Physician Focus Groups

In December 1999, NCI conducted six focus groups with three audience segments, referred to as the "higher-exposure public," the "lower-exposure public," and "physicians" (see **Appendix H.5**). The higher-exposure and lower-exposure definitions were extracted from NCI's 1997 report, *Estimated Exposures and Thyroid Doses Received by the American People from Iodine-131 (*^{131}*I) In Fallout Following Nevada Atmospheric Nuclear Bomb Tests* (NCI 1997a and b), which outlined the key risk factors for health effects from ^{131}I exposure.

Conducting research with both the higher- and lower-exposed public was done to obtain a preliminary sense of how exposure status might affect one's awareness, knowledge, and concerns about the NTS and potential health effects from ^{131}I exposure. Physicians were defined as general practitioners, family physicians, or general internists who had been practicing medicine for at least 3 years in a high-exposure state (NCI, 2000b).

5.4.1.3 Current Focus Group Research

NCI has recently conducted twelve additional focus groups; four groups in each of the following regions: Chicago, Illinois; Tulsa, Oklahoma; and Denver, Colorado. These locations were selected based on geographic diversity and the ability to recruit lower-exposed as well as higher-exposed individuals. NCI conducted the groups with lower-exposed and higher-exposed African-Americans, Caucasians, Hispanics, and Native Americans. Determination of higher-exposure was based on age (birth-15) and state of residency during the testing years. These additional focus groups were conducted to test messages and concepts for the development of educational materials about I-131 exposure from NTS. NCI is currently summarizing the focus group findings in a report that will help identify which messages and concepts resonate with the public.

5.4.2 Additional Research Needed

Development and testing would also be necessary for the expanded communication efforts outlined in this feasibility report - specifically, communicating dose and risk information for radionuclides from global testing and from radionuclides other than ^{131}I in fallout from the NTS. This research should help identify the outstanding issues the public may have as they begin to absorb and understand "the big picture" of the potential health consequences associated with atmospheric nuclear weapons testing.

Qualitative and quantitative research would need to be conducted to collect information about the concepts, messages, channels, activities, materials, and strategies appropriate for a far-reaching and large-scale communications and education campaign on the health consequences of fallout from nuclear testing (see **Appendix H.6** for a description of the types of "tools of research" that could be used). Research methods should be selected to augment research collected by NCI for the ^{131}I/NTS Communications Project. The following section discusses the main areas where further formative research should to be conducted.

5.4.3 Defining Target Audiences

There is no uniform "general public," but rather numerous smaller, sometimes intersecting groups of individuals sharing common concerns, interests, perspectives, or demographic characteristics (Arkin 1999). The consumer research NCI has conducted for its ^{131}I/NTS Communications Project provides a good sense of the target population groups for ^{131}I dose and risk information related to nuclear weapons testing at the NTS. However, as the list of radionuclides and potential health consequences expands, more research would need to be conducted in this area to segment the target population groups into main audiences, then select and profile these target audiences (see Figure 5.1). These audience profiles would be used to help frame messages - providing DHHS with the information to address audience-specific needs and issues.

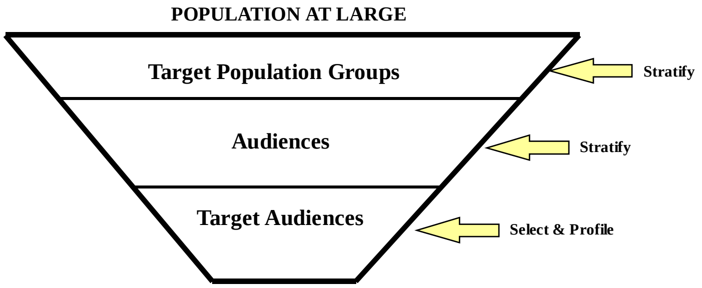

Figure 5.1 Selecting Target Audiences.

It would also be necessary to profile and link with the proposed communications campaign's secondary audience(s). Secondary audience refers specifically to the audience(s) that can also benefit the campaign by reaching and influencing primary target audiences (e.g., health care providers, grassroots organizations, etc.) (CDC 1998).

In the ^{131}I/NTS Communications Project, exposure information on ^{131}I fallout from the NTS was utilized from NCI's 1997 report. Specifically, it was used to define potentially higher and lower exposed populations based on geographic residence and age. With this information in hand, NCI is designing educational messages that address both higher and lower ^{131}I/NTS exposed populations based on the focus group findings.

Because dose and risk information on radionuclides from global testing sources and other radionuclides from NTS are not yet fully quantified, work to further identify audiences cannot yet occur. The dose and risk estimates with accompanying uncertainty, that would result from more in-depth research than has occurred in this feasibility study, would more clearly identify the subgroups of the general population that may have received higher exposures and be most at risk. When available, these results would help the Federal government explain to subgroups of the American public how the potential public health impact of ^{131}I fallout from the NTS and from global fallout compares with that of the other biologically significant radionuclides in fallout as well as other health threats.

To date, the broad target population groups already defined through research and stakeholder input include:

- The United States population;
- Native American populations;
- People at higher risk – those who meet research-identified factors for higher exposure and risk (e.g., lived in high fallout areas during testing years, were children during time of testing, drank or ate certain foods, etc.);
- People at lower risk – those who meet research-identified factors for lower exposure and risk (e.g. born after cessation of testing; did not eat or drink foods of concern, etc.);
- People who worked at, lived adjacent to (or currently live adjacent to) the NTS or a United States nuclear weapons production facility;
- People who are concerned about potential risk from multiple radiation sources;
- Mobile populations (e.g., migrants and farm workers);
- Family and friends of those potentially at high risk;

- Health care providers in areas determined to have had high fallout;
- Health care providers in areas determined to have had low fallout;
- State and local health departments;
- Public health and medical organizations;
- State and local elected officials;
- Environmental Health Advocates, Professional and Citizen-based Associations/Organizations;
- Other Federal Agencies; and
- Media.

As stated, the target population groups listed here represent a broad sweep of the preliminary work conducted for the ^{131}I/NTS Communications Project. Table 5.1 illustrates some broad assumptions made by participants of the ^{131}I/NTS Communications Workshop regarding target population groups, the potential information needs and perceptions of those groups as well as potential communications channels and activities. These general assumptions could be used as starting points to define and select target audiences and their subgroups

5.4.4 Developing Messages

Work on the ^{131}I/NTS Communications Project has revealed broad and basic assumptions and information about the target population groups already identified (see Table 5.1, second column). These broad assumptions could serve as a preliminary guide in developing messages for work relating to global fallout and other radionuclides contained in NTS fallout. In addition, the following discussion highlights some of the challenges and issues to consider when developing messages for a fallout-related communications and education campaign.

Table 5.1. Broad Target Population Groups, Assumptions And Potential Communications Channels & Activities

Target Population Groups *	**Broad Assumptions**	**Potential Communications Channels & Activities**
THE UNITED STATES POPULATION (National plan to educate American public on history of the United States nuclear weapons program, global testing and current knowledge about the potential health consequences of this legacy and to increase overall national "awareness" of current issues)	(Large portion of population uninformed) Potentially could need: historical context information on United States and global nuclear weapons programs • General information on fallout production mechanisms and fallout patterns • Information on radionuclides of concern (beginning with what is known about ^{131}I and as information becomes available about other radionuclides) • Information on general risk factors for disease (people will "self-identify" whether they are at "higher" or "lower" risk) • Information on history of government actions/inaction and acknowledgement • Information on ongoing work to address outstanding public concerns and issues • Campaign kickoff messages & materials should be provided at least in 1 other language & for low literacy audiences	National mass media • Targeted local media • Internet • Advocate groups • National, regional, local archival projects • Professional organizations • Grassroots organizations • targeted national organizations (i.e., AARP) • Library resource centers • Industry trade associations • Veteran's associations • National, state and local medical and public health associations • National and regional advertising • Toll-free telephone systems
NATIVE-AMERICAN TRIBES	*(Would be targeted simultaneously or soon after main campaign kickoff)* Same as "United States Population" Plus: Feel government is not meeting all desires/gov=t efforts are likely to disappoint • Believe that cultural differences never accounted for in Aformulas@ (scientific, communication, etc.) • May want dose information specific to Native American diet and migratory patterns • Information on ongoing work to address outstanding public concerns and issues	Mass media is not primary communication channel, intra/inter tribal is best • As sovereign nations, want control of information dissemination and outreach • Nontraditional media and interpersonal communications • Use tribal leaders and existing networks, such as tribal advocacy and grassroots environmental organizations • Indian Health Service • Tribal Councils • Tribal Enrollment System • Internet • Small Group • Toll-free telephone system(s)

Target Population Groups *	Broad Assumptions	Potential Communications Channels & Activities
PEOPLE AT HIGH RISK Those characterized by **factors that increased their likelihood of exposure and subsequent disease risk**, such as; geographic location, age and diet during testing period.	*(Would be targeted simultaneously or after campaign kickoff – many would "self-identify" through education on risk factors for disease learned through campaign kickoff messages & materials)* Potentially could need: Detailed information on risk factors for disease for exposure to each radionuclide of concern • Information to answer questions related to potential multiple exposures • Assurances that health care providers are getting same information • Information on what to do next, including what to do if health care is not available • May want more than studies can deliver (i.e., comprehensive care, long-term support, compensation) • Gov=t efforts are likely to disappoint • Information that addresses multiple literacy levels, languages, etc. • Many would be outraged at past perceived Government secrecy and actions • Need Government acknowledgement of involuntary risk • Concerned with physical impact of exposure and psychological stress from exposure • Information on national, regional, state and local support networks • Some percentage of population would be outraged at expenditure of Federal public health funds	*[Still geographically wide-spread]* Targeted and strategic local media • State and local health departments • Regional and Local Health Care providers • State and local medical institutions and health clinics • Internet • State and local advocacy groups and grassroots organizations • Library resource centers • Industry trade associations • Veteran's associations • Toll-free telephone systems • Internet • Community & Business Health Fairs
PEOPLE AT LOW RISK Those who are NOT characterized by factors that **increased** their likelihood of exposure and subsequent disease risk, such as; geographic location, age and diet during testing period.	*(Many would "self-identify" as low risk through Campaign kickoff, or would go the extra step to confirm low risk status with health care provider)* Potentially could need: Repeated information to confirm their understanding that they have low risk • May need to seek confirmation of low or no risk status through health care provider • Many would still be outraged at Government secrecy and past actions	Main messages received during campaign kickoff for all American public • Would remain updated mainly through Internet and other mass reach media • Advocacy groups and grass root organizations

Target Population Groups *	Broad Assumptions	Potential Communications Channels & Activities
PEOPLE WHO WORKED AT, LIVED ADJACENT TO (OR CURRENTLY LIVE ADJACENT TO) THE NTS OR A UNITED STATES NUCLEAR WEAPONS PRODUCTION FACILITY	Same as “People at High Risk” Plus: May have concerns about multiple doses • Information on what is scientifically known about releases from nuclear weapons research and productions facilities and potential health consequences of those releases • Information on worker compensation programs, where applicable	Same as “People at High Risk” Plus: CDC/ATSDR Health Effects Subcommittees (where applicable) • Unions • Trade organizations • Veterans’ organizations • Grassroot organizations • Internet
PEOPLE WHO ARE CONCERNED ABOUT POTENTIAL RISK FROM MULTIPLE RADIATION SOURCES	Same as “People at High Risk” Plus: Information that addresses multiple dose and “added dose” concerns • more detailed information on what is scientifically known about health effects from medical & diagnostic radiation exposures, occupational exposures (i.e., uranium mines, nuclear weapons production facilities, etc.) and exposures to naturally occurring radiation	Same as “People at High Risk” Plus: Information on CDC/ATSDR Health Effects Subcommittees (where applicable)
FAMILY AND FRIENDS OF THOSE POTENTIALLY AT HIGH RISK	Same as “People at High Risk” Plus: Information on national, regional, state or local support networks	Same as “People at High Risk”
MOBILE POPULATIONS *(E.g., migrants and farm workers)*	Same as “United States Population” Plus: Information tailored for multiple literacy and language needs	Non-traditional media & interpersonal communications • Member organizations • Unions & Worker Associations • Religious leaders • Small group & community channels • Internet

Target Population Groups *	Broad Assumptions	Potential Communications Channels & Activities
HEALTH CARE PROVIDERS IN AREAS DETERMINED TO HAVE HAD HIGH FALLOUT	*(Would likely be targeted before and simultaneous to information delivered in national campaign – geared toward primary care physicians, including those in family practice, general medicine, internal medicine, and other health care providers, such as nurses, physician assistants, and internists with specialties in those areas related to identified health outcomes.)* (Most under-informed) Information on exposures, risk factors for disease in their areas • Information on fallout pattern, why their area is estimated to have had high fallout • If applicable, patient decision aids • Training & credentials (e.g., CMEs) to evaluate potential patients • Would be primary information source sought by concerned public/potential patient • Information & referral resource list(s) • Receive volumes of educational information daily • Information on national, regional, state or local support networks	Professional journals • Professional associations • State health personnel, training courses and publications • CDC-produced CME sessions (e.g., Grand Rounds) • Satellite information conferences • CDC/ATSDR “case studies” • MMWR • ADear Colleague@ letters • Medical/professional conferences • Internet • Pharmaceutical representatives • Managed Health Care Organizations
HEALTH CARE PROVIDERS IN AREAS DETERMINED TO HAVE HAD LOW FALLOUT	*(Would likely be targeted same as above)* Same as Health Care Providers in “high fallout areas” Plus: Specific information materials designed for people at low risk and those living in “low fallout areas”	Same as health care providers in “high fallout areas” • More passive communication channels (self-motivating)
STATE AND LOCAL HEALTH DEPARTMENTS	Have a vested interest in activities • Concerned that past issue(s) not affect present perceptions • Some states may prefer to be “project lead,” • May want to be involved with communications strategies • States would communicate with local health officials • Would want to use their own information dissemination networks • Would want specific information tools for public health clinics (specific for multiple literacy & language needs) • Would want information for those underinsured	One-on-ones • Satellite and/or telephone conferences • Printed materials • Internet • ASTHO, NACCHO, NPHIC, ASTE and other affiliate organizations

Target Population Groups *	Broad Assumptions	Potential Communications Channels & Activities
PUBLIC HEALTH AND MEDICAL ORGANIZATIONS	Same as “Health Care Providers” Plus: Information on national, regional, state or local support networks	Same as “health care providers” and “environmental and health advocates” • Professional conferences • Professional organization newsletters • Mailings to organization memberships
STATE AND LOCAL GOVERNMENTS AND CONGRESSIONAL STAFF MEMBERS	Would want advance notice of campaign kickoff • Would want confirmation that their health departments have been engaged • Have a vested interest in all activities	Status reports • Correspondence • One-on-ones • Satellite or telephone conferences • Printed materials • Internet
OTHER FEDERAL AGENCIES	Have a vested interest in all activities • Would want to be informed of activities/issues that potentially concern their agency • May be interested in partnering with CDC/NCI	Headquarters and Regional Office correspondence • Email • Internet • Satellite and/or telephone conferences • one-on-one meetings • Internet
ENVIRONMENTAL & HEALTH ADVOCATES **PROFESSIONAL AND CITIZEN-BASED ASSOCIATIONS/ORGANIZATIONS**	Many have disparate viewpoints • Same information as “people at high risk” and “health care providers” • Need training and education materials • Regular, consistent messages/information • Have questions about government public health agenda(s) • Many would be viewed as more credible information sources to some target audiences • Some would like more service than study • Some may never be satisfied by actions taken ! Want to provide input on material development ! Desire innovative communication approaches	Professional journals • Direct mail with key information & camera-ready (Amat@) newsletter articles, fact sheets, etc. • Follow-up phone calls • Localized information • Pro-active approaches • National organization partnerships • Direct contact • Focus groups • Localized information/coverage • National, state and local media • Internet • Professional conferences • Professional organization newsletters • Mailings to organization memberships

Target Population Groups *	Broad Assumptions	Potential Communications Channels & Activities
MEDIA	Same as “United States Population” Plus: Need timely, clear, concise, interesting information • Simplified, clarified science to communicate to audiences • Probably would still make mistakes/ misinform public and communicate errors • They would seek other scientific information and viewpoints • Would need information on the “process of science” as well as the end results • Information and education on uncertainty involved in estimating doses and risk • Information on context with other causes of morbidity and mortality • Need to educate on difference between absolute and relative risk; individual and population risk• Information on what people can do about risk/what Gov't is doing	Editorial board meetings • Pre-written articles (for outreach activities) to local media outlets • Testimonials/first-person information (Areal people@) • AMass@ conference call link (i.e., tele. press conference, video conference) • Radio talk show host who is Aopinion leader@ • Info to community channels (cable, radio stations) • Celebrity spokesperson (media-related &/or star) • Environmental & Health Advocates • Grassroots organizations • Internet

* Would require further segmentation into main audiences, then selection and profiling of those target audiences

5.4.4.1 Understanding the social, political, and cultural context

Understanding the social, cultural, and political context associated with the perceptions of the target population groups will be the most important consideration in developing messages for this proposed public awareness and education plan. Over the past 50 years, Government secrecy, mass media reports and stories about radioactive contamination have influenced how people think and feel about nuclear issues and activities. Messages would need to be framed with consideration of societal and cultural perspectives that are dominated by nuclear and radioactive stigmatization. Therefore, in order to understand specific populations, communities, and regions that are targeted for risk messages, appropriate conceptual theories developed in behavioral science research on perceptions of risk, the social amplification of risk, and others would have to be utilized (Kasperson et al 1988; Weart 1988; Slovic et al 1991; Kasperson 1992; Gregory et al 1995; Flynn et al 1998; Flynn 1999).

Legacy of mistrust

Success in this communications endeavor will depend on the sensitivity of DHHS to the American public's views about the United States and global weapons programs. Given the legacy of mistrust that has developed over the past half-century, this is a formidable social and political context within which to communicate (Flynn 2000). For such an effort to succeed, it would require messages that acknowledge the Government's responsibility for past actions in the history of its nuclear weapons program.

Meeting racial/ethnic and/or cultural needs

Understanding ethnic differences can make or break a successful communication campaign (Huerta and Macario 1999). It is possible that the only broad public messages developed in this proposed campaign would be those constructed to provide historical context to the communications campaign - providing the American public with the facts and issues surrounding the United States and global nuclear weapons testing legacy. Otherwise, messages would need to be tailored so that they are meaningful and appropriate for target audiences and their subgroups. To do this, a two-pronged approach is recommended. This would include: 1) conducting research to determine the racial/ethnic and/or cultural subgroups in each identified target audience; and 2) working with a community group (such as the Communications Development Group formed to assist NCI in the development of the ^{131}I/NTS Communications Plan) to form partnerships with identified racial/ethnic and/or cultural groups to assist in the planning stages of the communications project. From that point, further research would then be conducted into the cultural sensitivities, diversity and culture-specific risk perceptions for each subgroup - resulting in unique project planning strategies for each.

Tribal Nations

Because many of the populations affected by the nuclear weapons program throughout the years of the Cold War were Native American populations, any communication efforts should include careful planning with Native American tribal leaders, tribal health care providers, tribal organizations, as well as with the Indian Health Service. Risk communication research shows that the interactive process of receiving and processing messages involves values, social-cultural perspectives, and emotional responses as well as knowledge (Peters and Slovic 2000; Peters and Slovic 1996; Gregory and Keeney 1994; Damasio 1994). Tribal governments interact and deliberate differently, and this also must be understood and protocols followed, as done with other sovereign nations. The challenge in this regard is daunting and will require careful planning, extensive resources and specific expertise. One possible approach would be to establish a separate Native American caucus where research, audience profiling, message testing and other communications planning tasks can be designed and conducted in partnership with a consultative panel of Native Americans. This panel could objectively review the communication and education plan for sensitivity to language, moral and religious structures, and cultural perspectives that are distinct to Native American nations.

5.4.4.2 The Challenge of Communicating Estimated Doses and Risks

Estimating the risk of exposure to radiation released from weapons tests involves reconstructing radiation doses from tests that took place 40 to 50 years ago, identifying estimated exposures to populations, and estimating the subsequent potential health effects. The only way this research is possible is to rely on limited data, complex mathematical models and expert judgments and assumptions. The results of such complex processes are not usually convincing to the average layperson -- especially when such results are presented with the appropriate range of uncertainty and are routinely subject to contradicting interpretations, even among scientists. Nor can such results be easily explained to the public in defense of their reliability or accuracy (Purchase, et al 1999; Slovic 1999; Flynn 2000). In this dose reconstruction and risk assessment work, scientists will not be able to make definite statements about cause and effect - and therefore may be seen as “waffling” when asked to definitively answer the question, “Will I get sick or not?” Thus, the very data that will serve as the basis for this public awareness and education effort may be perceived as “poor” or “inadequate” science.

In addition, not everyone identifies with or understands scientific concepts. It is especially confusing when different definitions apply to everyday words used by both scientists and the public (Flynn 2000). How scientists define words like risk, exposure, uncertainty, screening, etc. may differ from how lay people or even other scientists may define those words. For example, what does risk mean? Even if risk is confined to human mortality, there are numerous ways it can be expressed (Slovic 1998; Sandman 1987). In most situations, scientists believe that risk should be conveyed numerically (e.g., percentages, probabilities, ranges, etc.). However, research indicates that numerical probabilities are often meaningless to lay people. The dilemma with verbal expressions of probability is that while people usually feel they understand the information better, it is difficult to get consensus on what that information actually means (Slovic 1996; Mertz et al. 1998; MacGregor et al. 1999; Lipkus and Hollands 1999).

The specific challenge of estimating doses and potential health risks to the American public from exposure to NTS and global fallout adds another layer of complexity. Dose estimates from this research will not be able to account for all the factors that contribute to individual differences in exposure over time for any single person. Therefore, risk estimates developed from these estimated fallout exposures will only represent the average risk for a population group who shares common characteristics such as age, place of residence, dietary factors, etc. Meaningful estimates of the actual risk to a particular individual will be unobtainable because one cannot account for all the factors that may influence individual risk. This means it will be exceedingly important to develop messages that clearly emphasize that risk estimates generated for NTS and global fallout exposures are average risks and that a person’s actual, individual risk may vary greatly from this average. One approach to meeting this communication challenge would be to use hypothetical exposure scenarios in both the exposure and risk assessment. Providing hypothetical individual scenarios that have “characteristics” people can identify with would provide some context for understanding what exposures they may have received and how these exposures may translate into dose and potential disease risk.

As a result, the charge to develop messages to communicate the type of research outlined in this report will be difficult. Partners in this approach must discover how the public, specifically each target audience, uses and responds to risk-related messages. In addition, the complicated issue of trust and credibility must be examined before it is determined how each audience would process and accept risk messages.

Because the scope of fallout related research is much broader than the issues being addressed by the ^{131}I/NTS Communications Project, the consumer research conducted for the ^{131}I/NTS Communications Project would need to be augmented. Further research would allow DHHS to better ascertain each audience’s perceptions of risk, understanding of multiple exposure information and how each audience best receives, understands, responds to and uses risk information. Such research is vital in order to develop messages for audiences that are credible and useful - rather than messages that overwhelm, confuse, cause undue anxiety, or are misinterpreted.

5.4.4.3 Include Public Health Recommendations in Messages

Informing the public about a health risk without explaining what can be done about that risk can lead to anger and frustration (Arkin 1999). Clearly, recommended actions and other advice would need to be included in messages. In general, these would cover:

- Recommended actions to lessen the consequence of exposure (i.e. regular physicals, early detection, lifestyle changes, etc.); and
- Sources of additional information or assistance (i.e., toll free hotline; Federal agencies or organizations; state, regional or local information resource centers).

Identifying discrepancies in medical recommendations and developing consistent public health messages

Before any health communication and education project is launched, it is important to develop consistent messages for all audiences - specifically for messages that make recommendations concerning visits to health care providers. This would require identifying and examining the inconsistencies in current medical and public health recommendations specific to any health outcomes of concern. There are many differences in scientific and public health policy opinions surrounding what is known (and what is not known) about the potential health consequences from the nation's nuclear weapons legacy as well as the potential health impacts from exposure to fallout from NTS and global nuclear weapons testing. In addition, there are many viewpoints concerning appropriate medical interventions to deal with any potential health impacts from these exposures. An expert panel may need to be convened to explore and evaluate the scientific basis of these differing opinions and recommendations in order to develop consistent public health recommendations for inclusion in messages. This panel could include relevant scientific, medical and public health organizations and advocates, such as the Agency for Healthcare Research and Quality (AHRQ) and members of the United States Preventive Services Task Force. DHHS has already begun to address public requests and opinions regarding government-sponsored screening opportunities for thyroid cancer as well as for other (noncancerous) thyroid diseases in the wake of NCI's ^{131}I NTS Fallout report (NCI 1997) at a thyroid disease screening workshop sponsored by ACERER in June, 2000.

5.5 Developing Working Partnerships

Working partnerships would need to be developed with various stakeholder groups for both the planning and implementation phases of any proposed communications and education plan. The NCI Communications Development Group used to plan NCI's ^{131}I/NTS Communications Project provides an example of the utility of bringing together representatives of various constituencies to assist in communications planning. Because of the added breadth and scope of the potential health consequences of exposure to global fallout and other radionuclides from NTS, partners from the following areas would need to be included in any working partnership that is developed:

- Federal agencies;
- State and local health departments,
- Public Health and environmental advocates,
- National, regional, state and local grass roots organizations (public health and environmental),
- Medical and public health professionals and professional organizations;
- Tribal leaders and organizations;
- Religious organizations;
- National citizen and consumer organizations; and
- Managed care organizations.

As with other national health communications campaigns, partners are essential because they are the ones "in the field." The partners sought should be those who promote collaboration, possess the ability to problem-solve and possess skills needed in garnering additional resources -- volunteers, mailing lists, service networks, web sites, conference venues, printing, etc. (CDC 1998). These partners may be needed to: gather the necessary data to develop the communications plan; establish and maintain access to target audiences; and /or develop and pre-test messages and materials. Or they may be needed in the implementation phase to: participate in special events (i.e., campaign kick-off); disseminate messages and materials; foster the credibility of messages and the program; keep other concerned groups and organizations up to date; and/or evaluate and revise program activities.

5.5.1 Providing Technical Assistance and Resources

For a national communications and education plan to be effective, provisions must be made to coordinate and provide technical assistance and resources to state and local health departments to ensure that communication and educational programs, materials, and methodologies can be successfully planned for and applied. During the planning phase, federal agencies may have to provide technical assistance and/or resources to enlist assistance from various partners to define and access target audiences, develop and pre-test messages and conduct material field testing. For the implementation phase, it may be necessary for these agencies to provide technical assistance and/or resources to guide and train external partners’ staff on how to integrate effective public education into local programs and services.

Examples of the types of technical assistance and resource support typically necessary for a nationwide communications and education campaign are:

- Disseminating research results and model educational protocols to state and local health agencies;
- Developing and maintaining a clearinghouse for partners and other individuals, groups and organizations to identify and retrieve resources and expertise currently existing in medical organizations, universities, archival projects, grassroots organizations, government agencies and the private sector. Such an effort could help to better ensure consistency in all communication and educational materials;
- Increasing the resources needed at the state and/or local level to implement the communications and education campaign as well as to evaluate its reach and success;
- Providing technical assistance, resources and training on risk factors for disease to public health workers at Federal, state and local levels;
- Providing informational materials to leading managed care providers to disseminate with nationwide benefit mailings; and/or
- Developing and providing static and interactive information materials (i.e., fact sheets, decision aids for primary care providers to promote discussion and patient education, websites, CD-ROMs, information kiosks).

5.6 Coordinating with Other Programs

There is a growing accumulation of information on the history of the United States Nuclear Weapons Program and the potential health effects from exposure to radioactive substances. As a result, it is important to identify messages that the American public has already received through other national, regional or local communication and education programs concerning potential health effects from exposure to radionuclides.

This would require coordination with other relevant public and health care provider education efforts to ensure that messages contained in both the ^{131}I/NTS Communications Project and in the potential communication and education plan associated with any future in-depth assessment of global and NTS fallout are consistent and accurate. This would probably be most applicable for messages and educational materials containing information on the history and legacy of nuclear weapons production and testing as well as the potential health consequences associated with any radionuclides of concern. In all communication efforts, partners would have to decide how to manage and address errors in fact, discrepancies or contrasting scientific results and opinions.

Some examples of proposed, ongoing, or recently discontinued programs that are relevant to the issues discussed in this report are provided in the following section.

5.6.1 The Hanford Community Health Project

In response to community concerns about health problems, the Agency for Toxic Substances and Disease Registry (ATSDR) is developing a project to provide outreach and education to Hanford Downwinders and their primary care providers. The focus of this work is on radioactive iodine exposures and thyroid disease. As an initial step, ATSDR has contracted with the National Opinion Research Center (NORC) to conduct a review of health care utilization patterns, issues related to access to health care and informational needs related to thyroid disease among Hanford Downwinders.

5.6.2 The Hanford Thyroid Disease Study (HTDS)

CDC and the Fred Hutchinson Cancer Research Center conducted the HTDS as a retrospective cohort study. The primary purpose of the study was to determine whether thyroid disease in the population surrounding Hanford is associated with exposure to I-131 released from Hanford between 1944 and 1957, the years when the greatest releases of I-131 occurred. The draft report for the study was released in January 1999. Since then, it has undergone extensive peer review by the National Academy of Sciences and the public and the final report is scheduled for completion in 2001.

5.6.3 Case Study in Environmental Medicine on ^{131}I

The Agency for Toxic Substances and Disease Registry in a cooperative agreement with the American College of Medical Toxicologists (ACMT) is working to develop a Case Study in Environmental Medicine (CSEM) on ^{131}I. This CSEM is a self-study guide for PHC professionals about the impact of ^{131}I on the thyroid gland. It includes a review of the exposures of the American public to ^{131}I from nuclear weapons production and testing, and also discusses pathways of exposure, who is at risk, potential health effects, diagnosis and management. It addresses both cancerous and non-cancerous thyroid and parathyroid gland disease, and provides information about prevention of health effects on the thyroid gland in case of nuclear accidents.

This CSEM is expected to be available by the late summer of 2001. It will be available as a booklet and web-based interactive learning tool.

5.6.4 The Hanford Individual Dose Assessment (Hanford IDA) Project

The Hanford Individual Dose Assessment (Hanford IDA) Project was a public service to provide individual thyroid dose estimates for people who lived or spent time in the Hanford Environmental Dose Reconstruction (HEDR) study area between 26 December 1944 and 31 December 1957. The individual radiation dose estimates were for ^{131}I released to the air from the Hanford facility. Along with the individual dose estimates, the Hanford IDA Project provided information to help people understand their thyroid dose estimates and what it might mean for their health. The Hanford IDA Project was operated jointly by the state health agencies of Idaho, Oregon and Washington, and was funded by CDC. This project closed on 31 December 2000. Copies of informational material developed by the project are on file at CDC.

5.6.5 The Hanford Health Information Network (HHIN) and Hanford Health Information Archives

The Hanford Health Information Network (HHIN) was funded by ATSDR and was managed by the state health agencies of Idaho, Oregon and Washington, and nine Pacific Northwest Indian Nations. HHIN closed on June 30, 2000. However, over the years, individuals were able to call toll-free to speak with a health educator and request free educational materials on Hanford's releases between 1944 and 1972 and the potential health effects from those releases. The Network also offered a self-study guide for health care professionals. HHIN-generated materials, procedures and data will be an important source of information to the American public for years to come. In addition, HHIN operating procedures and management principles may serve as an excellent framework to follow if a similar program is funded in the future. Currently, HHIN publications are available through the Washington Department of Health (www.doh.wa.gov/hanford) and select publications are available through ATSDR.

The Hanford Health Information Archives collects and makes available the personal records and health information of Hanford-exposed people who choose to participate. It is housed at Gonzaga University in Spokane, Washington.

5.6.6 Citizen-Based and Professional Education Programs

Numerous educational materials concerning potential health risks associated with exposure to fallout from nuclear testing at the NTS and from the nuclear weapons program have been developed by citizen and professional advocacy groups (e.g. Alliance for Nuclear Accountability (ANA 1998); Physicians for Social Responsibility (PSR 1998)). These materials have been disseminated on a national, state and local level.

5.7 Implementation

Should additional work as outlined in this feasibility report be approved and sufficient resources be made available, communications should be built on the tremendous advances in health education theory, social marketing, communication techniques and on grassroots expertise. Moreover, as time progresses, ever changing and improving communication technologies and methods may allow DHHS to consider more direct and cost-effective communication channels. Whatever communication strategies are selected, community members should be involved in all phases of the communication plan to help provide information materials and activities that are compatible with audience need.

5.7.1 Development of Education Materials

Before developing any education materials, an information database to promote a nationally and regionally coordinated approach to public and health care provider education should be developed. Thus, the nature and extent of existing educational materials regarding the history of the United States nuclear weapons program, global testing programs, radionuclides of concern, and information on the potential health consequences of exposures to those radionuclides can be determined. This will ensure:

- Consistency in the information the public receives;
- Prompt development and dissemination of general informational materials - eliminating time needed on to “start-from-scratch”; and
- Holistic review of materials to identify gaps and needs.

After existing health education materials have been collected from both local and national resources, review and pre-tests of the materials collected would need to be conducted in order to decide if they are appropriate for use. Pre-testing methods should be utilized to ensure that concepts and resulting materials are appropriate and relevant for the intended audiences. This will help DHHS obtain insight into the perceptions, beliefs and languages of the intended audience(s). This approach will ultimately save resources, but will take more time and effort initially.

5.7.2 Determining Communication Channels

Developing and implementing innovative and effective methods for communicating with this project’s defined target audiences will be necessary. Table 5.1, shown earlier in this chapter, provides examples of the wide-range of communication channels and activities that would have to be considered-- from interpersonal and small group to organizational, community and mass reach media. To be successful in such a communications effort, these channels and activities would be defined for each target audience and subgroup(s) as more research is conducted. And as the focus turns to specific audience subgroups, priority consideration should be made to identify effective interventions (e.g., nontraditional media and interpersonal communications)-- for those audience groups who are low-literacy, minority, under- (or not) insured, oral-cultures and non-English-speaking groups.

To determine communication channels, the sources of health information among targeted audiences and their various subgroups would need to be analyzed and a broad range of communication channels and activities, such as, libraries and resource centers, the Internet, print materials, advertising, video news releases, toll-free telephone information services, commercial tie-ins, training classes, and community partnerships would need to be considered. Extensive time and resources may be needed to adapt messages, communication channels and communication activities to audience needs and perceptions, cultural norms and linguistic variations to increase the understanding and reception of those messages.

The communications and education plan envisioned would be designed to include an array of mass media and interpersonal communication activities. Multiple mass media strategies can include public service announcements (PSAs), radio and television programs, an interactive web site, news coverage, and perhaps even information brochures or CD-ROMs mailed directly to homes. Interpersonal communication activities can include such channels as physician-patient counseling, presentations to high-risk individuals, a “speakers’ bureau,” and assistance of local grass root organizations to provide for more personal support and message reinforcement.

For example purposes only, four mass-reach mediums that could likely be considered for this proposed communications and education plan are highlighted below:

5.7.2.1 Interactive Technology – The Internet and Electronic Media

Today’s consumers do not just rely on their doctors – they look to the media and the Internet for health care advice. Last year alone, more than 20 million adults used the

Internet to get health information – and that number is growing every day. As a result, the health care environment has changed – forever (Porter Novelli 2000). The Internet brings health information, simultaneously, to both the public and to health care professionals. Interactive technology can be used to relay health information on demand; enable informed decision-making; promote interaction between the public and health professionals; and even allow for peer information exchange and emotional support. Interactive technology also allows for the presentation of more in-depth information.

For example, both the public and health care providers would benefit from a final study report and associated reference materials in electronic media format and on the Internet. Users could instantly "jump" to the report's glossary, appendices, tables and graphs, supporting data, and references as they read. Alternatively, through an Internet site or other electronic media, users could link to related websites, other government databases, professional or grass root organizations, or library/resource centers.

Additionally, a website could be designed along similar lines as was done by NCI for its 1997 ^{131}I/NTS report. A key component of NCI's website has been its dose calculator. Since NCI first launched this dose calculator, they have received consumer feedback regarding its usefulness and readability. As a result, they are currently conducting usability testing to provide insight into how best to modify the website design to improve its ease of use and understandability. The feedback they have received and "lessons learned" can be incorporated into any new website developed if a more detailed dose and risk study is conducted.

5.7.2.2 Toll-Free Information Services

As part of its communication strategy, toll-free telephone information services could be considered. Three options in this area are to provide the public with access to an automated toll-free voice/fax information system, a staffed toll-free information clearinghouse and "hotline," or a combination of the two. It would be relatively cost-friendly to provide an automated toll-free information service, if it is included as part of an existing Toll-Free Voice/Fax Information System. For example, CDC has a system that provides CDC-supplied voice recordings and fax-on demand services to the public and health-care or public health workers through a toll-free telephone number. Users hear a menu of items about which they can receive information. The system also captures address information in order to facilitate on-demand mailings as well as provide mailing lists for mass-mailing campaigns.

The automated system is less costly than a staffed "hot line," and it does provide accurate and timely delivery of materials. However, due to the social and political context framing the issues discussed in this report, this communications effort may be best served by a combination of an automated toll-free service and a staffed (at least part-time) information clearinghouse and toll-free telephone service. In addition, a pilot program to monitor public usage of the staffed hotline in order to forecast extended need would be necessary.

5.7.2.3 Education for Public Health Professionals

The CDC has been a central source of practice based, job relevant, high priority training for public health professionals in state and local health departments since its beginning in 1946. For many years, this training was primarily delivered in the classroom or laboratory. But fundamental changes in the American health care system increased both the number of persons who needed training and the number of content and skill areas they needed training in, and in recent years CDC found itself unable to meet the increased demand using traditional methods. In June 1993, CDC launched the Public Health Training Network (PHTN) (CDC 2000). This network could be used as the main communication channel to educate and train physicians/health care providers on the potential health consequences of exposure to NTS and global radioactive fallout.

PHTN is a distance learning system that uses a variety of instructional media: print-based self-instruction, interactive multimedia, videotapes, two-way audio conferences, and interactive satellite videoconferences. Since 1993, PHTN has delivered nearly 1,000,000 training opportunities to professionals in public health settings and, increasingly, in healthcare and related settings. PHTN's success has stimulated state and federal health agencies to produce training programs and to build their own capacity to meet training needs through distance learning. State health departments are expanding their own capacity, supporting field operations, and developing new courses that address their audiences' unique needs.

PHTN successful in the past

Evaluation studies demonstrate that PHTN programs, and distance learning as a medium, are effective ways to update and enhance professional competencies. In particular, CDC has successfully used PHTN to educate health care providers about potential health effects from exposure to ionizing radiation. CDC used the PHTN in its nationwide public health awareness campaign to alert physicians to the potential adverse health effects associated with past nasopharyngeal radium irradiation treatment. This project altered the policy of the Department of Veterans' Affairs (VA) and the Department of Defense (DOD) concerning head and neck exams for veterans and military personnel who received the treatment in the early 1940s and 50s. It was also the impetus behind DOD's notification project to alert veteran service personnel to the treatment's possible health risks.

Using PHTN technology, in 1996, CDC convened a live satellite videoconference to address the history and potential health consequences of nasopharyngeal radium irradiation treatments. This conference linked CDC with more than 250 VA and DOD medical facilities throughout the country. Its target audience was physicians in general practice, family practice, internal medicine, otolaryngology, radiology, and nuclear medicine, nurse practitioners and physician assistants in the same fields. The program served as a continuing medical education program for physicians and other health care providers about the potential adverse health effects of this treatment, and included a demonstration of a thorough head and neck examination. Moreover, to capture attention in the public health community, the program offered CME, CEU, American Academy of Family Practice elective credits and Continuing Nursing Education Credits.

Since then, CDC has provided the videotaped version to the VA for use in more than 200 VA medical centers, to more than 50 public and private hospitals in Connecticut and Rhode Island, the media, and interested citizens. This effort, in combination with publishing information in medical journals (i.e., CDC's Morbidity and Mortality Weekly Report, the Journal of the American Medical Association and Otolaryngology - Head and Neck Surgery), was a successful and far-reaching effort to educate public health care providers on this issue.

5.7.2.4 Public Service Announcements (PSAs)

Within the context of a large communications program, PSAs are most useful for creating public awareness or heightening the public's sensitivity to a health problem or issue, or transmitting specific information to the public. They are also appropriate for increasing recognition of a health program, generating requests for health information or recruiting volunteers (NCI 1996). The use of PSAs may or may not be useful during the initial "launch" of a plan to create nationwide public awareness for fallout issues. The benefits of using PSAs would have to be further explored. However, if PSAs are developed, they must be carefully crafted and their delivery carefully planned before launch, so that all messages, partner support structures, and media planning (at the Federal, state and local levels) are in place to respond to the public's health concerns and potential outrage emotional issues.

5.8 Additional Work Outside the Scope of this Report

A public awareness and education effort dealing with fallout would be perceived by the public as just one part of the big picture of potential health impacts from environmental radiation exposure from the NTS, global, and individual emissions from nuclear weapons production facilities. Therefore, in order for this communications effort to be considered credible by the American public, all issues must be acknowledged, though some are beyond the scope of the proposed research and communication efforts.

With that premise in mind, any proposed communication and education plan should contain communications strategies that speak to outstanding public concerns and issues. The following outstanding public concerns and issues have been raised by stakeholders:

- Concern over multiple and cumulative exposures from all phases of the United States Nuclear Weapons Program - including weapons testing and operational and cleanup activities related to research laboratories and weapons production facilities;
- Diverse opinions from the scientific community regarding health consequences of radiation exposures;
- The provision of follow-up medical services for those in high risk groups and/or for those underinsured;
- Government accountability for past actions;
- Government acknowledgement of health impacts;
- Government compensation;
- The desire to receive formal promises at upper Administration levels that prove the Federal Government's commitment not to harm its public again in the name of National Security.
- The need for dose and risk estimates specific for Native American diets and migratory patterns;
- The need for dose and risk estimates for workers and military participants

As some of these are policy issues, an intergovernmental task force would be needed to address these issues.

5.9 Conclusion

Development and implementation of a nationwide communications project would require careful planning to provide appropriate, effective and credible messages and educational materials to the American public and to the nation's health care providers about the potential health risks associated with fallout from atmospheric nuclear weapons tests conducted in the 1950s and early 1960s by the United States and other countries. This public awareness and educational effort would be a necessary step in providing United

States citizens and residents with the information they need to evaluate their potential risk from the United States and global nuclear weapons legacy.

Because the research concerning the health consequences of radioactive fallout from the NTS and global sources is not complete, it is too early to provide a communications and education plan for communicating those results to the American public. Instead, it is recommended that the American public receive information on the potential health consequences from nuclear test fallout in a staggered approach. The DHHS can draw on the strategic planning efforts already underway for NCI's ^{131}I/NTS Communications Project. This effort, led by NCI and advocated by CDC, began in 1999 in response to public interest and the IOM's review of NCI's 1997 report, *Estimated Exposures and Thyroid Doses Received by the American People from Iodine-131 In Fallout Following Nevada Atmospheric Nuclear Bomb Tests (NCI 1997)*. Because a great deal of work has already been accomplished by NCI to structure its existing ^{131}I/NTS Communications Project to ensure ongoing public involvement in plan development and implementation, it may be appropriate to use a similar approach for future communication planning efforts associated with a more in-depth analysis of the research discussed in this feasibility report. The effectiveness of NCI's approach should, however, be formally evaluated before it is adopted for this potentially much larger communications project.

In this chapter, the numerous steps and challenges associated with communicating information of NTS and global nuclear weapons fallout were discussed. Also discussed were the two major components of such a proposed national education and public awareness campaign: public communication and education and health care provider education. The first component addresses "right-to-know" issues and educates the American public on scientifically determined risk factors for disease for each of the radionuclides of concern, so that they can self-identify whether or not they are in a “high-exposure” and/or “high risk” group. The second component serves the premise that the nation’s health care providers will have the greatest impact on improving the health status of persons who may have been adversely affected by radioactive fallout. Physicians and health care providers could be educated on risk factors for disease, risks and uncertainties of exposure to the radionuclides of concern and their potential health consequences, and recommended testing and screening procedures so they can make good decisions for their patients -to not only serve as a source of information to public, but also help with the decision process when a concerned patient comes in.

Additionally, recruiting working partners would be extremely important for both the planning and implementation phases of a communications and education project. The goal in establishing these partnerships is to ensure that the proposed communication project meets the needs of the intended audiences, and that the materials and activities developed are compatible with each audience’s needs.

Finally, it is important to consider a broad range of communication channels and activities, such as libraries and resource centers, the Internet, print materials, advertising, video news releases, toll-free telephone information services, commercial tie-ins, training classes, and community partnerships to meet these needs.

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Chapter 6

Conclusions and Options for Future Work

Contents: *This chapter provides a brief summary of five options that could be considered for future work on assessing the health impacts to people in the United States from exposure to radioactive fallout from nuclear weapons testing. The Department of Health and Human Services will make no formal recommendations concerning future work until peer review of this report has been completed.*

6.1 Introduction

The purpose of this report is to provide an initial assessment of the feasibility and public health implications of a detailed study of the health consequences to people in the United States of nuclear weapons testing. The preliminary findings of this feasibility study demonstrate that conducting a detailed study of the health impact on American people as a result of exposure to radioactive fallout from the testing of nuclear weapons in the United States and abroad is technically possible. However, significant resources would be required to implement this detailed study, and careful consideration should be given to public health priorities, as well as to concerns that some stakeholders have expressed to DHHS about national and global nuclear weapons testing fallout.

To assist in the process of making a decision about future fallout-related work, five different options have been developed for consideration. Each of these options is briefly described below. Detailed estimates of the resources needed to complete each option considered have not been developed. However, the actual cost of some past projects is presented for purposes of illustration only.

6.2 Options for Future Work

Option 1. No additional fallout-related work

Rationale: The dose and risk estimates presented in this report are very preliminary. Estimates of uncertainty have not been quantified for many of these estimates, they are subject to a variety of errors, and they are incomplete, e.g. estimates are not provided for the States of Alaska and Hawaii.

On the basis of these preliminary estimates of dose and risk, fallout radiation appears to have the greatest impact on risks of thyroid tumors. The National Cancer Institute (NCI) is undertaking a communications program to inform people in the United States about thyroid disease and radionuclide fallout as a follow up to their dose reconstruction of ^{131}I releases from the Nevada Test Site (NTS) (NCI 1997). Both the American Thyroid Association (Ladenson et al. 2000) and the American Association of Clinical Endocrinologists (AACE 1999) are urging people in the United States to get regular thyroid examinations as part of good preventive medicine practices. Supporting these public health activities may be more appropriate than performing a more detailed dose reconstruction and risk assessment for fallout from nuclear weapons testing.

An important factor for conducting this feasibility study was the public's concern over their right-to-know about the health impact of weapons testing. In addition, as a result of the NCI study on the impact of ^{131}I released from the NTS, people became interested in information concerning other radionuclides released from NTS and by nuclear weapons testing worldwide. This interest was formally supported by the Department's Advisory Committee for Energy-Related Epidemiologic Research (ACERER), and was expressed by participants at the January 2000 workshop held by NCI and the Centers for Disease Control and Prevention (CDC) to devise a ^{131}I communications plan. Therefore, while the dose and risk estimates presented in this report are preliminary and contain large uncertainties, they may be sufficient to address the public's need for information on the public health impact of radioactive fallout.

Option 2. Retrieve and archive the historic documentation related to radioactive fallout from nuclear weapons testing conducted by the United States and other nations.

Rationale: Although a large number of summary reports related to nuclear weapons fallout have been published, many of the primary documents upon which these summary reports are based will be lost forever if they are not protected soon. Documents related to nuclear weapons testing will always be valuable to the scientific and health community. Hence, documents could be collected and protected immediately from further loss. Implementing this option would preserve the possibility of conducting a meaningful study of the health consequences of nuclear weapons testing in the future. This option could be implemented alone or in conjunction with one of the other three options discussed below.

The National Center for Environmental Health of the CDC has been actively involved in document retrieval and document data base development since 1992. Such projects have been an integral part of dose reconstruction activities conducted by CDC for the Idaho National Engineering and Environmental Laboratory, the Savannah River Site, and the Los Alamos National Laboratory. These document location, retrieval, and data base development projects have cost between \$3 million and \$5 million and taken 2-4 years to complete at each of these nuclear weapons research and development sites.

Option 3. Conduct a more detailed dose reconstruction of radioactive fallout from global nuclear weapons testing for Iodine-131, the most significant radionuclide identified in this study.

Rationale: As noted earlier, these preliminary dose and risk analyses indicate that fallout radiation has the greatest impact on risks of thyroid tumors. The NCI has previously completed an extensive dose reconstruction and basic risk analysis for ^{131}I fallout received from the NTS (NCI 1997; IOM 1999). This project cost approximately \$5 million and it took many years to complete. Follow up activities include development of an Internet site where individuals may obtain an estimate of their individual dose, and implementation of a communications project to inform people in the United States about the results of this study and its potential public health implications.

The estimates presented in this report of ^{131}I doses from global fallout are crude as they only refer to an average over the entire population of the United States, and they do not include a quantitative estimate of uncertainty. On average over the population of the United States, consideration of global fallout would likely increase the dose and risk estimates previously developed for ^{131}I from NTS fallout by about 10%. However, the distribution of doses over the population of the United States is likely to be very different for global fallout than for fallout received from NTS because deposition of global fallout is closely dependent on thunderstorm activity. As a result, some people received higher doses from global fallout than from NTS fallout while other people received much less. Therefore, it might be desirable to perform a detailed dose reconstruction and basic risk analysis for ^{131}I in global fallout, and incorporate that information into the NCI Internet site and communications plan.

The States of Alaska and Hawaii could be included in this effort, too. This effort should also include collecting and protecting primary documents related to nuclear weapons testing (Option 2).

Option 4. Conduct a more detailed dose reconstruction for multiple radionuclides in radioactive fallout from both Nevada Test Site and global nuclear weapons testing.

Rationale: The work that has now been completed demonstrates that conducting a more detailed study of the health impact on American people of exposure to radioactive fallout from the testing of nuclear weapons in the United States and abroad is technically possible. There are numerous possible subject areas that can be researched for the purpose of improving the preliminary dose estimates provided in this report and to provide a more complete historical record of the nature of the releases from the weapons testing and the resulting exposures received by Americans from NTS and global fallout. These recommendations primarily have emerged from noting the limitations of the input data and available models to conduct the work reported here. The research options provided in Chapter 3 of this report can generally be categorized as those related to (1) availability of nuclear test data, (2) improvement in models, (3) inclusion of specific locations, and (4) public health. However, despite the improvements that are possible, inherent and unavoidable limitations in knowledge about the lifestyle of individual Americans will prohibit ever determining precise doses to specific persons.

As a result of these technical considerations and the results presented in this report, it might be desirable to expand on Option 3, above, and perform a detailed dose reconstruction and basic risk analysis not only for ^{131}I in global fallout but also for other radionuclides found in both NTS and global fallout. As described in Option 3, the results of this dose reconstruction and risk analysis could then be incorporated, for example, into the existing NCI Internet site and communications plan. The States of Alaska and Hawaii could be included in this effort, too. This effort should also include collecting and protecting primary documents related to nuclear weapons testing (Option 2).

The cost and staffing requirements for implementing Option 4 would depend on the level of detail desired beyond that presented in the Report. For example, CDC's National Center for Environmental Health has been involved in a comprehensive dose reconstruction for the Department of Energy's nuclear weapons production site at Hanford, Washington, since 1992. This project involves portions of the States of Washington, Oregon, and Idaho, and it includes nine Native American nations. The Hanford project has cost approximately $30 million to date. Option 4 would, of course, involve 50 States and it could include numerous population subgroups.

Option 5. Conduct a detailed study of the health effects of nuclear weapons testing fallout including, in a single project, dose estimation, risk analysis, and communication of the results to interested parties.

Rationale: As noted previously in Option 4, above, the work that is presented in this report demonstrates that conducting a more detailed study of the health impact on American people of exposure to radioactive fallout from the testing of nuclear weapons in the United States and abroad is technically possible. The estimates of dose from nuclear weapons testing fallout developed in this project could be refined to make them more suitable for use in evaluating health consequences to American population groups.

This option differs from Option 4 primarily in the type of communication campaign and risk analysis that would be undertaken. Option 4 proposes to perform a limited risk analysis and to utilize existing communication planning being undertaken by the NCI. This option would include a more detail risk analysis for American population subgroups and expand NCI's effort to include more of the communication options discussed in Chapter 5.

Costs and staffing requirements for communications efforts are dependent on the results of the dose reconstruction and the risk assessment work and what public health implications are learned through that research. However, other issues will also need to be considered. For example, even if results from the dose reconstruction and risk analysis do not provide a risk-based rationale for conducting a large-scale, nationwide communications campaign, public right-to-know and social justice issues may affect the scale and reach of the campaign. In addition, other factors must also be considered in developing resource estimates. Some of these factors include:

- Planning and implementing a campaign with public involvement. To plan, design and conduct a campaign in a public and participatory manner takes more time, requires more staff and requires more funding (i.e., establishing and providing logistical support for an advisory group, for public meetings, workshops, and consensus decision-making).
- Conducting formative research. The more segmented the affected audiences and populations are (e.g., there are over 500 recognized Native American tribes), the more complex the campaign becomes, requiring additional funds and staffing resources to conduct formative research for audience profiling, message development and dissemination strategies.
- The communication channels chosen to disseminate campaign messages and materials. Associated costs and staffing resources could range from low-end (internet and automated toll-free phone/fax system) to high-end (mass mailings and print and television publicity).

- The scale of health care provider training. Associated costs and staffing resources vary greatly when comparing a passive education program (fact sheets available through the internet) to an active education program (for example, Continuing Medical Education provided through satellite training).
- Building capacity within state and local health departments and/or other partners. This may entail low-end efforts of merely disseminating research results and information materials to state and local health agencies. Or it may be on the higher end and entail such activities as developing and disseminating model educational protocols; increasing the resources and infrastructure needed at the state and/or local level to implement the communications and education campaign as well as to evaluate its reach and success; of providing technical assistance, resources and training on risk factors for disease to public health workers at state and local levels.

For example, for CDC and NCI's diethylstilbestrol (DES) National Education Campaign (a smaller scale national campaign specific to individuals exposed to DES in utero and their health care providers) it is estimated that the planning phase alone will cost $3 - $5 million. Funding and resource needs for the implementation phase for the DES campaign are expected to increase exponentially during the implementation and distribution phase. In another example, in the late 1980's, CDC mailed information on Acquired Immune Deficiency Syndrome (AIDS) to every household in the United States. This mailing cost over $30 million. Planning for the NCI ^{131}I/NTS Communications Project has cost approximately $1 million dollars to date.

Public involvement is a significant component of all DHHS projects associated with the historic development, production, and testing of nuclear weapons. ACERER has provided advice to DHHS during the course of this feasibility study. However, there are many issues that have been raised by stakeholders that transcend the mandate of DHHS. For example, the Department of Energy is responsible for maintaining many of the environmental monitoring records that are needed for a detailed study; only the Department of Defense can grant access to classified records that would allow improvement of some of the dose estimates. Therefore, if this option is mandated, a project-specific, trans-Federal advisory committee should be established to provide advice on the conduct of additional activities related to the health effects of nuclear weapons testing fallout. This committee of 10-15 people could be composed of representatives from State public health agencies and various public stakeholder groups, and independent scientists familiar with technical aspects of the proposed activities. In addition, there would be ex-officio members representing appropriate Federal agencies.

For the past 8 years, CDC's National Center for Environmental Health has been actively working with committees chartered in accordance with the Federal Advisory Committee Act, including ACERER. The annual cost of each of these advisory committees is approximately $500,000. In addition, the equivalent of two full-time professional staff and one or two support staff are required to support the activities of each advisory committee.

6.3 Conclusions

The preliminary findings of this feasibility study suggest that the health risks from exposure to fallout from past nuclear weapons tests may be small, but this study also demonstrates that conducting a detailed study of the health impact on American people as a result of exposure to radioactive fallout from the testing of nuclear weapons in the United States and abroad is technically possible. This chapter briefly describes five options for future fallout-related work that might be undertaken on the basis of the results of this feasibility report. These options are presented for consideration during the peer review process for this Technical Report. DHHS will make no formal recommendations for future work until the peer review has been completed.

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Glossary

Term	Description
Absorbed dose	The amount of energy deposited by ionizing radiation in a unit mass of tissue. Expressed in units of joule per kilogram (J/kg), which is given the special name 'gray' (Gy). The traditional unit of absorbed dose is the rad (100 rad equal 1 Gy).
ACERER	DHHS Advisory Committee on Energy-Related Epidemiologic Research
Activities	Methods used within a communications channel to deliver a message (e.g., the activity of holding training classes to help seniors start their own walking clubs is an example of using a community channel).
Activity	The rate of decay of radioactive material expressed as the number of nuclear disintegrations per second (See Becquerel).
AEC	Atomic Energy Commission, predecessor of the Department of Energy.
Airdrop	A nuclear device dropped from an aircraft and exploded in the atmosphere.
Alpha particle	A particle emitted from the nucleus of some radioactive atoms when they decay. An alpha particle is essentially a helium atom nucleus. It generally carries more energy than gamma or beta radiation, and deposits that energy very quickly while passing through tissue. Alpha particles cannot penetrate the outer, dead layer of skin. Therefore, they do not cause damage to living tissue when outside the body. When inhaled or ingested, however, alpha particles are especially damaging because they transfer relatively large amounts of ionizing energy to living cells.
AM	Arithmetic Mean
Atom	The smallest particle of an element that is capable of entering into a chemical reaction.
Atomic mass	The mass of an atom relative to other atoms. The atomic mass of any element is approximately equal to the total number of protons and neutrons in its nucleus.
Attitudes	An individual's predispositions toward an object, person, or group, that influences his or her response to be positive or negative, favorable or unfavorable.
Audience	See primary target audience and secondary target audience.

Term	Description
Audience profile	A formal description of the characteristics of the people who make up a target audience. Some typical characteristics useful in describing segments include media habits (magazines, TV, newspaper, radio, and Internet), family size, residential location, education, income, lifestyle preferences, leisure activities, religious and political beliefs, level of acculturation, ethnicity, ancestral heritage, consumer purchases, psychographics.
Audience segment(s)	A group of people who are enough alike on a set of predictors that one can develop program elements and communication activities that will likely be equally successful with all members of the segment.
Background Radiation	The amount of ionizing radiation to which a person is exposed from natural sources, such as terrestrial radiation due to naturally occurring radionuclides in the soil or cosmic radiation originating in outer space.
Balloon	A nuclear device suspended from a balloon and exploded in the atmosphere.
Barge	A nuclear device exploded from a barge moored in the lagoon of Enewetak or Bikini.
Barriers	Hindrances to desired change. These may be factors external or internal to audience members themselves (e.g., lack of proper health care facilities, the belief that fate causes illness and one cannot alter fate).
Baseline study	The collection and analysis of data regarding a target audience or situation prior to intervention. Generally, baseline data are collected in order to provide a point of comparison for an evaluation.
Becquerel (Bq)	A measure of the rate of radioactive decay: The Bq corresponds to one decay (disintegration) per second. It replaces the traditional unit activity, the Curie (Ci).
Beta Particle	An electron (or positron) ejected from the nucleus of a decaying atom. Beta particles penetrate the dead skin layer. The beta particle is not stopped in tissue as quickly as an alpha particle, producing less damage per living cell. Beta particles may interact with living tissue by entering from the outside or by ingestion or inhalation.
Biological half-life	The time required for a biological system, such as a person, to eliminate by natural processes, other than radioactive decay, one-half of the amount of a substance, such as a radionuclide, that has entered it.

Term	Description
Cancer	A collective term for malignant tumors. A malignant tumor generally is unencapsulated, grows by invasion, and is able to metastasize via lymphatic and blood systems to distant tissue sites.
CDB	County Data Base
CDC	Centers for Disease Control and Prevention: The CDC has 11 centers, offices and an institute. It is an agency of the Department of Health and Human Services. The CDC is a non-regulatory agency - its mission is to promote health and quality of life by preventing and controlling disease, injury and disability.
CIC	Coordination and Information Center
Coefficient of variation	The standard deviation divided by the value of the parameter considered.
Collective Dose	The estimated dose for an area of the country multiplied by the estimated population in that area of the country.
Communication (or creative) concepts	Central themes of a communication effort to which all messages are relate. Concepts represent the "hooks" to which an audience can connect or relate.
Communication objectives	A quantifiable statement of a desired program achievement necessary to reach a goal.
Community channel	A communication channel in which messages are disseminated at the community level (e.g., library, supermarket, local swimming pool).
Comprehension	A measure to determine whether messages are clearly understood.
Concept testing	The process of learning about the target audience's responses to possible concepts on which you might base your message. This process usually requires qualitative research, such as focus groups.
Contributing factors	Determinants that directly or indirectly cause the problem. A contributing factor can be biological, behavioral, or attitudinal; or an element of the physical or social environment; or the result of policies related to the problem.
Cost/benefit evaluation	Examines the overall cost of a program compared to the dollar value of the effects that can be attributed to the program. These two values yield a cost-benefit ratio.
Crater	The result of a nuclear device placed shallow enough underground to produce a movement of earth when exploded.
Credibility	A quality that contributes to the ability of a message source to influence the target audience. Some components of credibility include whether the message source is trustworthy, believable, reputable, competent, and knowledgeable.

Term	Description
Curie (Ci)	The traditional unit of measure used to express the amount of radioactive material present. One curie is 37 billion atoms undergoing radioactive decay each second.
Decay constant	The fraction of a number of atoms of a radioactive nuclide that decays in unit time.
Decay product (or Daughter product)	A nuclide resulting from the radioactive disintegration of a radionuclide, being formed either directly or as a result of successive transformations in a radioactive series. A decay product may be either radioactive or stable.
Delivery/ implementation evaluation	Studies of the functioning of components of program implementation; includes assessments of whether materials are being distributed to the right people and in the correct quantities, the extent to which program activities are being carried out a planned and modified if needed, and other measures of how and how well the program is working. Sometimes referred to as process evaluation.
Demographics	Data such as gender, age, ethnicity, income, or education that can be collected from a target audience, and can be useful for defining the target audience and understanding how to communicate more effectively with the target audience.
Deposition density	The activity of a radionuclide deposited per unit area of ground. Reported as Bq m^{-2}.
Detonation	A single nuclear device explosion; one or more may comprise a test and several tests comprise a series.
DHHS	Department of Health and Human Services
DOE	Department of Energy, successor of the Atomic Energy Commission

Term	Description
Dose	When radiation enters a person's body, that person receives a radiation dose. Several different terms describe these radiation doses. The rad or gray expresses the concentration (amount of energy divided by the tissue mass) of energy deposited by radiation in the body. The rad is the most basic unit of radiation dose, but its use is limited because different types of radiation have different effects on the cells in the body. The rem or sievert (Sv) is a unit of radiation dose that takes these different effects into account. It puts different types of radiation on an equivalent basis in terms of their potential impact on human cells. A third measure of dose, effective dose is used to account for the fact that a rem of radiation dose to one part of the body does not have the same potential health effect as a rem to another part. The effective dose allows estimation of dose to the entire body from individual organ doses. To help people interpret these radiation doses, it may be helpful to compare them with other radiation doses people typically receive in daily life. This is called background radiation. Each year the average American receives an effective dose of about 3 mSv (300 millirem or 0.3 rem) from background radiation. This radiation is from naturally occurring sources, such as the sun, air, soil and radon gas. Manmade sources such as medical x-rays add about 60 millirem per year to the average person's dose.
Dose coefficient	A factor used to convert radionuclide intake by members of the general public to dose. Usually expressed as dose per unit intake (e.g., $Sv\ Bq^{-1}$)

Term	Description
Dose Reconstruction	A scientific study that estimates doses to people from releases of radioactivity or other pollutants. The reconstruction is done by determining how much material was released, how people came in contact with it and the amount absorbed by their bodies.
Dosimetric	Methods developed to estimate the radiation doses to people or their environment exposed to ionizing radiation. Such methods rely heavily on dose reconstruction techniques (see Dose Reconstruction)
Effective dose	A single dosimetric quantity useful for comparing the overall health detriment associated with irradiation of the whole body. It takes into account the absorbed doses received by the various organs and tissues of the body, and weighs them according to present knowledge of the radiosensitivity of each organ as well as accounts for the type of radiation and the potential of each type to inflict biological damage. The effective dose is used, for example, to compare the overall health detriments of different radionuclides in a given mix. The unit of effective dose is the sievert (Sv); 1 Sv = 1 Joule kg^{-1}
Effective half-life	The time required for the amount of a radionuclide deposited in a living organism to be diminished 50 percent as a result of the combined action of radioactive decay and biological elimination.
Effects evaluation	A measure of the extent to which a program accomplished its stated goals and objectives. Also called impact, outcome, or summative evaluation.
Electron	An elementary particle with a unit negative electrical charge and a mass 1/1837 that of the proton. Electrons surround the positively charged nucleus and determine the chemical properties of the atom.
Electron-volt	A unit of energy equivalent to the amount of energy gained by an electron in passing through a potential difference of one volt, abbreviated eV
EML	Environmental Measurements Laboratory
Environmental factor	A component of the social, biological, or physical environment that can be casually linked to the health problem.
EPA	Environmental Protection Agency

Term	Description
Epidemiology/ Epidemioligic/ Epidemiological	The study of the determinants of disease in people. Two basic types of epidemiologic studies are the follow-up or cohort study and the case-control study. In follow-up studies, groups are identified with regard to the presence or absence of some exposure and are followed through time to assess and compare disease rates in each group. In case-control studies, people with disease are compared with those without disease and the frequency of prior exposure histories compared.
Equivalent Dose	A quantity used in radiation protection to place all radiation on a common scale for calculating tissue damage. Equivalent dose is the product of the absorbed dose in grays and the radiation weighting factor. The radiation weighting factor accounts for differences in radiation effects caused by different types of ionizing radiation. Some radiation, including alpha particles, cause a greater amount of damage per unit absorbed dose than other radiation. The sievert (Sv) is the unit used to measure equivalent dose. The sievert replaces the rem, the traditional unit (1 Sv equals 100 rem).
Euthyroid	A thyroid that functions normally.
Evaluation plan	Written plan that documents all tasks related to evaluation (e.g., designing surveys, planning data collection and analysis, reporting on findings).
Expert review	Examination and critique of program plans or materials by selected people who are knowledgeable in a relevant content area.
Exposure	1) A term generally used to mean subjected to or being in the presence of radioactivity or radiation. 2) A measure of the ionization produced in air by x or gamma radiation. It is the sum of the electrical charges of all ions of one sign produced in air when all electrons liberated by photons in a volume element of air are completely stopped in air, divided by the mass of the air in the volume element. The unit of exposure frequently used is the roentgen, R. In the SI system of units, the unit of exposure is the coulomb per kilogram, C kg^{-1}; 1 R = 2.58 x 10^{-4} C kg^{-1}.
Exposure Rate	A measure of the ionization produced in air by x or gamma radiation per unit of time (frequently expressed in R hr^{-1} or mR hr^{-1}).
Exposure route	A pathway by which a radionuclide or other toxic material can enter the body. The main exposure routes are inhalation, ingestion, absorption through the skin, and entry through a cut or wound in the skin.

Term	Description
Exposure/reach evaluation	Measures the extent to which a message was disseminated (e.g., how many members of the target audience encountered the message). However, this type of evaluation does not measure whether audience members paid attention to the message or whether they understood, believed, or were motivated by it. Also referred to as process evaluation.
External dose	The dose received from radiation sources outside of the body.
Factor-specific strategy	A strategy (health communication, health policy, engineering, and/or health service intervention) that is designed to cause change in a specific factor that contributes to the health problem.
Fallout	The radioactive debris, once having been airborne, following a nuclear detonation, that has been deposited on the earth. Special forms of fallout include "local", "intermediate", and global.
Femtocurie	One billionth of a microcurie, $3.7\ 10^{-5}$ disintegration per second, abbreviated fCi.
FIPS	Federal Information Processing Standard. The code system used to number counties within each state of the United States. The first and second digits are the two-digit state/equivalent territory identifier; the last three digits are the county or equivalent area identifier.
Fission	A nuclear transformation characterized by the splitting of a nucleus into at least two other nuclei and the release of a relatively large amount of energy.
Fission yield (or yield)	The percentage of fissions leading to a particular nuclide by direct formation and by decay of precursors.
Focus group interviews	A type of qualitative research in which an experienced moderator leads about 8-10 respondents through a discussion of a selected topic, allowing them to talk freely and spontaneously.
Formative evaluation	Evaluation conducted during program development. Formative evaluation measures the extent to which to concepts, messages, materials, activities and channels meet researchers' expectations with the target audience.
Fusion	A nuclear transformation characterized by the joining together of two light nuclei (usually hydrogen) under extreme pressure and heat that results in a release of a substantially larger amount of energy than that from fission.
Gamma	A high-energy electromagnetic radiation emitted from a decaying atomic nucleus. Gamma rays are similar to medical x-rays, but are emitted at very specific energies characteristic of their decaying atoms. They penetrate tissue farther than beta or alpha particles, but leave a lower concentration of ions in their path to potentially cause cell damage.

Term	Description
Gatekeeper	Someone with whom you must work before you can reach a target audience (e.g., a schoolteacher) or accomplish a task (e.g., a television public service director).
Geodemographics	Geographic factors and trends in a specific locale (e.g., where people live, population density, health care, climate, eating patterns, spending patterns, leisure activities, local industry, and outdoor activities) that can help with location decisions (e.g., selecting a clinic site) or local contact interventions.
GM	Geometric Mean
GMT	Greenwich Mean Time
Goal	The overall improvement in the health problem the health communication effort will strive to create.
GSD	Geometric Standard Deviation
H Hour	Detonation time (zero hour), the time the device was detonated.
Half-life	The length of time in which any radioactive substance will lose one half of its radioactivity. The half-life determines how long a substance will remain radioactive.
HASL	Health and Safety Laboratory
Health behavior	An action performed by an individual that can negatively or positively affect his or her health (e.g., smoking, exercising)
Health communication	The study and use of communication strategies to inform and influence individual and community decisions that enhance health.
ICRP	International Commission on Radiological Protection
Implementation plan	Written plan that documents all tasks related to program implementation from "rollout" forward (e.g., kickoff event, newsletter mailings, conferences). This plan differs from a research or development plan that documents tasks prior to rollout (e.g., researching the target audience, concept testing, getting buy-in from stakeholders).
In-depth personal interviews	A qualitative research method that involves a one-on-one discussion between an interviewer and a respondent about selected topics. The structure and interviewing style are less rigid than in quantitative, interviewer-administered surveys.
Integrated Intake	The intake of a radionuclide over time in an area having a specific deposition density. Reported as Bq per Bq m^{-2}.
Intermediate	The nomenclature for test yields varied according to information policy governing specific years. From 1945 through 1963, "Intermediate" referred to test yields from 20 to 200 kt.
Internal dose	The dose received from radioactive material taken into the body.

Term	Description
Interpersonal channel	A communication channel that involves dissemination messages through one-on-one communication (e.g., mentor to student, friend to friend, pharmacist to customer).
IOM	Institute of Medicine
Isotopes	Forms of the same element having the same number of protons, but different numbers of neutrons.
Key informants	Persons or organizations whose opinions can be seen as representative of a community or target audience because of their experience or expertise with the target audience.
Kickoff	Start date for the public portion of a health communication effort, after the internal, preparatory work is complete, that often includes an announcement or event such as a news conference, health fair publicity, or program registration drive.
Kilocurie	One thousand curies, 3.7×10^{13} disintegrations per second, abbreviated kCi.
Kriging procedure	Interpolation technique used to estimate the ^{131}I deposition densities in counties where measurements were not available.
kt	A kiloton. The energy of a nuclear explosion that is equivalent to an explosion of 1,000 tons of TNT.
LLI	Lower Large Intestine
LLNL	Lawrence Livermore National Laboratory
Low Test Yield	The nomenclature for test yields varied according to information policy governing specific years. From 1945 through 1963, "Low" referred to test yields less than 20 kt.
Mass-reach media channel	A channel in which messages disseminated to a large number of people simultaneously using various media (e.g., radio, TV, newspapers, billboards).
Materials	Tangible products that contain the message to be delivered to the target audience (e.g., a brochure, a PSA tape, or a script for an oral presentation).
Megacurie	One million curies, 3.7×10^{16} disintegrations per second, abbreviated MCi.
Microcurie	One millionth of a curie, 3.7×10^{4} disintegrations per second, abbreviated mCi.
Millicurie	One thousandth of a curie, 3.7×10^{7} disintegrations per second, abbreviated mCi.
Milliroentgen (mR)	One-thousandth of a roentgen.
MSL	Mean Sea Level

Term	Description
Mt	A megaton. The energy of a nuclear explosion that is equivalent to an explosion of one million tons of TNT.
Nanocurie	One billionth of a curie, 37 disintegration per second, abbreviated nCi.
NCEH	National Center for Environmental Health, CDC
NCI	National Cancer Institute
NCRP	National Council on Radiation Protection and Measurements
Neoplastic	Pertaining to the pathologic process resulting in the formation and growth of an abnormal mass of tissue.
Neutron	Neutrons are part of the nucleus of an atom. Neutrons are, as the name implies, neutral in their charge. That is, they have neither a positive nor a negative charge. Neutrons are about the same size as protons.
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council
NRL	Naval Research Laboratory
NTS	Nevada Test Site
Nuclide	A species of atom characterized by the constitution of its nucleus. The nuclear composition is specified by the number of protons Z, the number of neutrons N, and energy content; or alternatively, by the atomic number Z, the mass number = N + Z, and the atomic mass. To be regarded as a distinct nuclide, the atom must also be capable of existing for a measurable time; thus nuclear isomers are separate nuclides, whereas promptly decaying excited nuclear states and unstable intermediates in nuclear reactions are not so considered.
Offsite	The detection of radioactivity offsite is defined as detected outside the boundary of the test site.
Onsite	A notation that radioactivity was detected onsite only is made for tests from which there was a release of radioactivity into the atmosphere that was not detected beyond the boundaries of the test site.
ORERP	Offsite Radiation Exposure Review Project
PHS	Public Health Service
Picocurie	One millionth of a microcurie, 0.037 disintegration per second, abbreviated pCi.
Plowshare	Name of nuclear tests carried out in the United States for civilian purposes, e.g., excavation.
PPG	Pacific Proving Ground

Term	**Description**
Proton	Protons, along with neutrons, make up the nucleus of an atom. Protons have a single positive charge. While protons and neutrons are about 2,000 times heavier than electrons, they are still very small particles.
Rad	A measure of the amount of energy absorbed by the body: The rad is the traditional unit of absorbed dose, equal to 100 ergs/gram in any medium; now replaced by the gray (1 gray equals 100 rad).
Radiation	Energy moving in a form of particles or waves. Familiar radiations are heat, light, radio waves and microwaves. Ionizing radiation is a very high-energy form of electromagnetic radiation. It is invisible and cannot be sensed without the use of detection equipment. Ionizing radiation creates ionization within tissue; these ions can cause cell damage.
Radioactive decay	Spontaneous disintegration of the nucleus of a radionuclide.
Radioactive equilibrium	Establishment of a radionuclide parent-daughter relationship where by the activity of the daughter radionuclide is approximately the same as that of the parent radionuclide.
Radioactivity	Spontaneous transformation of an unstable atom, often resulting in the emission of radiation. This process is referred to as decay or disintegration of an atom.
Radionuclide	A radioactive, unstable nuclide.
Rem	Roentgen equivalent, man: The traditional unit of equivalent dose; replaced by the sievert (Sv) (1Sv = 100 rem). The rem measures the damage to a human from radiation exposure. It is determined by multiplying the number of rads by a number reflecting the potential damage caused by the particular type of radiation.
Risk	The probability of developing a given disease over a specified time period. Risk can be influenced by several factors: personal behavior or lifestyle, environmental exposure to other material, or inborn or inherited characteristic that is known from scientific evidence to be associated with a health effect. Because many risk factors are not exactly measurable, risk estimates will be uncertain.
Roentgen (R)	A special unit of exposure to ionizing radiation. It is that amount of gamma or x-rays required to produce one electrostatic unit of charge of either sign per cubic centimeter of air at standard temperature and pressure.
S.I. units	The *Systeme International* (or International System) of units and measurements. This system of units officially came into being in October 1960 and has been adopted by nearly all countries, though the amount of actual usage varies considerably. Units used throughout this report are listed as S.I. units with traditional unit comparisons given periodically.

Term	Description
Safety Experiment	Experiment designed to confirm that a nuclear explosion would not occur in case of an accidental detonation of the explosive associated with the device.
Surface	A nuclear device placed on or close to the earth's surface.
Sv	The unit of equivalent dose of any ionizing radiation that produces the same biological effect as a unit of absorbed dose of ordinary x-rays (1 sievert = 100 rem).
TDB	Town Data Base
Test	A test is defined in the Threshold Test Ban Treaty as either a single underground nuclear explosion conducted at a test site, or two or more underground nuclear explosions conducted within an area delineated by a circle having a diameter of two kilometers and conducted within a total period of time not to exceed 0.1 second.
Thermonuclear Device	A 'hydrogen bomb.' A device whose explosive energy comes from fusion of hydrogen nuclei as well as fission.
TOA	Time of Arrival
Tower	A nuclear device mounted at the top of a steel or wooden tower and exploded in the atmosphere.
ULI	Upper Large Intestine
Uncertainty	The term used to describe the lack of precise knowledge in a given estimate based on the amount and quality of the evidence or data available. All estimates contain uncertainty. In this report, uncertainty exists because of a lack of precise knowledge about factors that are important in estimating a person's dose or risk.
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
Weapons Effects	A nuclear test to evaluate the civil or military effects of a nuclear detonation on various targets, such as military hardware.
X-ray	X-rays are an example of electromagnetic radiation that arises as electrons are deflected from their original paths or inner orbital electrons change their orbital levels around the atomic nucleus. X-rays, like gamma rays are capable of traveling long distances through air and most other materials. Like gamma rays, X-rays require more shielding to reduce their intensity than do beta or alpha particles. X- and gamma rays differ primarily in their origin: x-rays originate in the electronic shell; gamma rays originate in the nucleus.

A FEASIBILITY STUDY OF THE HEALTH CONSEQUENCES TO THE AMERICAN POPULATION FROM NUCLEAR WEAPONS TESTS CONDUCTED BY THE UNITED STATES AND OTHER NATIONS

Volume 2
Technical Report

Prepared for the U.S. Congress
by the

Department of Health and Human Services
Centers for Disease Control & Prevention
and the
National Cancer Institute

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Charles Miller, Ph.D.
Co-Principal Investigator
Radiation Studies Branch
National Center for Environmental Health
Centers for Disease Control & Prevention

Andre Bouville, Ph.D.
Co-Principal Investigator
Radiation Effects Branch
Division of Cancer Epidemiology and Genetics
National Cancer Institute

Inquiries and requests for copies should be directed to:

Charles Miller, PhD
Radiation Studies Branch
National Center for Environmental Health
Centers for Disease Control and Prevention
Mail Stop E39
1600 Clifton Road NE
Atlanta, GA 30333

List of Contributors

Centers for Disease Control and Prevention

Paul Garbe
Charles W. Miller
Joan Morrissey
Claudia Parvanta
Judy Qualters
J. Felix Rogers
James M. Smith
Diana Swindel
Robert C. Whitcomb, Jr.
Charles M. Wood

National Cancer Institute

Andre Bouville
Clare Collins
Betsy Duane
Ethel Gilbert
Charles Land
Anne Lubenow
Nick Luckyanov
Kiyohiko Mabuchi
Elane Ron
Susan Sieber
Steven L. Simon
Bob Weinstock

Consultants

Lynn Anspaugh
Harold Beck

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Appendix A

Summary of the National Cancer Institute Report

Contents: *This appendix provides a summary of the NCI report on ^{131}I doses and risks to the American people as a result of fallout from nuclear weapons testing at the Nevada Test Site. It also includes a brief summary of the review of that report by the Institute of Medicine.*

A.1 The National Cancer Institute Report

In response to a Congressional mandate, the National Cancer Institute published in 1997 a report (NCI 1997) in which estimates of human exposure to and thyroid radiation doses from ^{131}I resulting from individual nuclear tests conducted at the Nevada Test Site (NTS) are provided. The report is available in printed form and on the world wide web (http://rex.nci.nih.gov ;click on “What’s New”, then on “About Radiation Fallout”). The legislation also called for the assessment of the risk of thyroid cancer associated with radiation thyroid doses due to ^{131}I: other studies address this requirement; they are summarized in this chapter for the sake of completeness. Most of what follows is based on a recently published summary of the NCI report (Bouville et al. 1999).

Low-yield nuclear tests were conducted at the NTS between 1951 and 1992. From January 1951 through October 1958, 119 tests were conducted, most of them above ground. Nuclear testing was discontinued between November 1958 and September 1961, but from September 1961 until September 1992 more than 800 tests were conducted; with very few exceptions, these tests were detonated underground, under conditions that were designed for containment of radioactive debris. Only 38 of these underground tests resulted in the detection off-site of radioactive materials; the last occurrence of substantial radioactive contamination of the environment took place in December 1970. On 2 October 1992, the United States entered into another moratorium on nuclear weapons testing (DOE 1994).

Ninety of the nuclear tests released almost 99% of the total ^{131}I entering the atmosphere from all bomb tests conducted at the NTS. These ninety tests released about 6 x 10^{18} Bq of ^{131}I, mainly in the years 1952, 1953, and 1957. Some radioiodine was deposited everywhere in the United States; highest deposition densities were immediately downwind of the NTS and lowest deposition densities were on the west coast. In the eastern part of the country, most of the deposited ^{131}I was associated with rain, while in the more arid west, dry deposition prevailed. Because ^{131}I decays with an 8-day half-life, exposure from the released ^{131}I occurred primarily during the first month following a test.

A.2 Estimating Exposures and Thyroid Doses

For most people, the major exposure route was the ingestion of cows' milk contaminated as the result of ^{131}I deposited on pasture grasses; other exposure routes such as the inhalation of contaminated air and the ingestion of contaminated leafy vegetables, goats' milk, cottage cheese, and eggs also were considered. Historical measurements of the amounts of radioactivity deposited and of daily rainfall were used as the basis for the dose calculations whenever feasible. Nationwide deposition data were available for all but nine of the ninety tests that were studied in detail; for those nine tests, a mathematical model was used to estimate the atmospheric transport and ground deposition of the ^{131}I.

Data on the transfer to milk of ^{131}I deposited on pasture and on regional pasture consumption by cows were used to estimate concentrations of ^{131}I in milk fresh from cows. These concentrations, together with milk distribution patterns in the 1950s, were used to estimate local concentrations of ^{131}I in the cows' milk available for human consumption throughout the country. The categories of fresh cows' milk that were considered include the milk obtained directly from dairy farms, milk purchased in stores, either provided from local or from distant farms, and milk obtained from family cows. Finally, cows' milk consumption rates, based upon diet surveys, were used to estimate the amounts of ^{131}I ingested by humans by age group and by gender. The transfer of ^{131}I to people through other exposure routes (ingestion of leafy vegetables, goats' milk, mother's milk, eggs, and cottage cheese contaminated by ^{131}I, as well as inhalation of air contaminated by ^{131}I) was similarly analyzed.

Thyroid doses from ^{131}I were estimated for 13 age groups, including the fetus, and adults of both genders, in each county of the contiguous United States and for all periods of exposure. The overall average thyroid dose to the approximately 160 million people in the country during the 1950s was 20 mGy. The uncertainty in this per capita dose is estimated to be a factor of 2; that is, the overall average thyroid dose may have been as small as 10 mGy or as large as 40 mGy, but 20 mGy is the best estimate. The study also demonstrated that there were large variations in thyroid dose from one individual to another. The primary factors contributing to this variation are county of residence, age at the time of exposure, and milk consumption patterns.

A.2.1 Geography

The geographical location where people lived is very important. In counties east of the NTS in Nevada and Utah, and in some counties in Idaho, Montana, New Mexico, Colorado, and Missouri, the estimated per capita thyroid doses from all tests were highest, in the range of 50 to 160 mGy. In many counties on or near the west coast, the border with Mexico, and parts of Texas and Florida, the estimated per capita thyroid doses were lowest, in the range of 0.01 to 5 mGy. Intermediate values were obtained in the remainder of the country.

A.2.2 Age

The thyroid doses to individuals at a particular location were strongly dependent upon age at the time of exposure. Thyroid dose estimates resulting from milk consumption were uniformly higher for young children than for adults, assuming that individuals consumed milk at average rates for each age group from the same source. At any particular time, the average thyroid doses resulting from milk consumption for children between 3 months and 5 years of age exceeded the thyroid doses received by adults by at least a factor of ten.

The date of birth and geographic residence of individuals also are strong determinants of the cumulative dose received from all tests (from 1951 to 1970). The variation in cumulative thyroid doses to individuals born at different times, each of whom lived in a single county and consumed cows' milk from local sources at average rates, is illustrated in Table A.1. This can be considered a dose table for six typical families located in the identified cities throughout the testing period. The factors affecting the doses to parents are approximately independent of birth dates up to 1930; doses to adult men and women born prior to this time were nearly the same. Thyroid doses to children born about six months prior to the three major test series (1952, 1953, and 1957) were substantially higher than the adult doses, as shown in the three central columns. The last column shows doses to children born in 1958, which is the year when the last test series in the atmosphere took place at the NTS. Cumulative thyroid doses to most of the children born in later years are estimated to be less than 1 mGy.

Table A.1 Example calculations showing the variation of the thyroid dose according to date of birth and place of residence of the individual considered.

	Thyroid dose estimates (mGy)					
Place of residence	Father, born 9/15/27	Mother, born 10/10/29	Child, born 10/1/51	Child, born 9/15/52	Child, born 11/28/56	Child, born 9/5/58
Los Angeles, CA	0.3	0.4	3	0.8	0.2	0
Salt Lake City, UT	17	18	130	96	56	1
Denver, CO	15	16	120	100	65	2
Chicago, IL	6	7	76	62	20	0.3
Tampa, FL	3	4	18	19	22	0.03
New York, NY	8	9	73	49	21	0.1

A.2.3 Diet, particularly milk consumption

For individuals within a particular age range, milk consumption can vary substantially. For example, surveys have shown that 10-20% of children between ages 1 and 5 do not consume cows' milk. Their doses were only about one tenth of those received by children who consumed milk at average rates for their age. Conversely, the milk consumption of 5 to 10% of individuals in the same age range was 2-3 times greater than the average and their thyroid doses were therefore proportionally larger. The type of milk consumed also is important. It is estimated that about 20,000 individuals in the United States population consumed goats' milk during the time of the bomb tests. Thyroid doses to those individuals could have been 10 to 20 times greater than those to other residents of the same county who were the same age and gender and drank the same amount of cows' milk. On the other hand, thyroid doses received during infancy (0 to 1 y) were much smaller for the infants who consumed mother’s milk or formula than for the infants who consumed cows’ milk.

A.2.4 Estimating thyroid doses for specific individuals

The foregoing examples illustrate that the thyroid dose received by any particular individual depends on his/her source of milk and dietary habits and thus may differ considerably from the group dose estimates. Furthermore, the person's total thyroid dose from all tests depends upon place of residence and age at the time of each test. Because of the very large number of variations in residence location, age, and dietary habits, it is not feasible to provide estimates of cumulative doses for specific individuals. However, detailed instructions and examples are provided in the report to permit individuals to estimate their cumulative dose using personal residence and dietary data. In addition, the information available on the world wide web enables the reader to enter a date and county of birth, as well as gender, in order to obtain estimates of thyroid dose applicable to the individuals with those characteristics for each test series and for all tests for a range of milk consumption rates and for various types of milk (including mother’s milk, cow’s milk, and goat’s milk). In these calculations, it is assumed that the individuals did not change their dietary habits or their county of residence during the time period when atmospheric weapons testing took place at the Nevada Test Site.

A.2.5 Uncertainties and model validation

There are large uncertainties in the estimated thyroid doses given in the NCI report because it is impossible to know all the information needed to determine exact doses. These uncertainties were assessed in two ways. First, calculated concentrations of ^{131}I were compared with historical measurements of ^{131}I in people and the environment. Second, the uncertainties in the historical measurements and in each of the factors used to estimate the transfer of ^{131}I to people's thyroids through the various exposure routes yielded an estimate of the total uncertainty. The uncertainty in the thyroid dose estimated for an individual is greater than the uncertainty in the overall average thyroid to the entire United States population. Under the best circumstances, the uncertainty of an individual's thyroid dose from NTS ^{131}I is about a factor of 3, e.g., if the thyroid dose estimate for an individual is 30 mGy, it will likely lie between 10 and 90 mGy, compared with a factor of 2 for the entire United States population.

A.3 Estimating Risks

Thyroid cancer risk associated with external irradiation by gamma rays and x rays is well quantified. However, information is limited regarding the risk associated with thyroid exposure from ingested or inhaled ^{131}I and precise dose-response estimates are not available. To estimate the thyroid cancer risk from the ^{131}I exposure, it was necessary to extrapolate from what is known about external radiation, taking into account an appropriate value for the relative biological effectiveness (RBE) of ^{131}I compared to gamma rays or x rays. RBE values ranging from 0.1 to 1.0 have been suggested based on experimental data (Lee et al. 1982; NCRP 1985; Walinder 1972) or a comparison of animal and human data (Laird 1987).

The risk of induction of thyroid cancer following external irradiation by gamma rays or x-rays is derived from studies of the Hiroshima-Nagasaki survivors and of several medically exposed populations. Findings are summarized in a pooled analysis of seven studies (Ron et al. 1995). The evidence for a radiation-related risk is strong for childhood exposure, and weak or non-existent for adult exposure. The pooled analysis also demonstrated a linear dose-response relationship with no significant difference in risk by gender. The excess relative risk (ERR) decreased sharply with increasing age at exposure. The age-specific excess relative risks are shown in Table A.2. Ron et al. (1995) estimated an ERR of 7.7 per Gy (95% confidence interval = 2.1-28.7), for childhood exposure at ages younger than 15. The radiation-associated risk persisted for at least four decades and although there was evidence of variation in radiation-related relative risk over time following exposure, there was no evidence of a trend.

Table A.2 Excess relative risk by age at exposure (Ron et al. 1995).

Age at exposure, y	ERR at 1 Gy
0 – 4	9.0
5 – 9	5.4
10 - 14	1.8

Land (1997) estimated the lifetime excess thyroid cancer cases based on the following assumptions: (a) there is a significant excess risk following exposure before age 20 years, but no risk after age 20 years; (b) there is a linear dose response with age-specific risk coefficients estimated from modifying factors provided in Ron et al (1995); (c) ERR remains constant over lifetime; (d) ERR is the same for males and females; (e) RBE could range from 0.1 to 1.0; and (f) the estimated lifetime risk of developing thyroid cancer is 0.25% for males and 0.64% for females (SEER 1973-92). Land's estimates and 95% uncertainty intervals are given in Table A.3 for various assumed values of RBE. Assuming that the RBE is 0.66, an estimate of 49,000 lifetime excess cases is predicted, with a 95% uncertainty interval ranging from 11,300 to 212,000.

Table A.3 Estimated numbers of lifetime excess thyroid cancer cases for a range of RBE values (Land 1997).

Assumed RBE	Estimated number of lifetime excess cancer cases	95% uncertainty interval
1.0	75,000	17,000 – 324,000
0.66	49,000	11,300 – 212,000
0.3	22,000	5,100 – 95,000
0.1	7,500	1,700 – 32,000

Hoffman (1997) used a somewhat different method to predict lifetime risk. A probabilistic distribution of RBE values was selected, with discrete values of 1.0, 0.66, 0.5, 0.33, and 0.2 assigned with probabilities of 35%, 40%, 15%, 7%, and 3%, respectively. The uncertainty associated with the Ron et al. (1995) risk coefficient was also taken into account. A central estimate of 46,000 lifetime excess thyroid cancer cases, with 95% uncertainty limits from 8,000 to 208,000, was obtained by means of a Monte-Carlo simulation analysis (Table A.4).

Table A.4 Predicted numbers of excess thyroid cancer cases, by gender (Hoffman 1997). The lower and upper limits correspond to a subjective 95% confidence interval.

Gender	Lower limit	Central value	Upper limit
Females	6,700	37,000	184,000
Males	1,200	7,400	38,000
Total	8,000	46,000	208,000

A.4 Subsequent Activities

In order to ensure that the results presented in the NCI report are credible, that the predicted lifetime excess thyroid cancer cases are reasonable, and that their public health implications are understood, the NCI requested the National Academy of Sciences – Institute of

Medicine (IOM) to assess the soundness of the dose reconstruction, to provide a preliminary assessment of the public health implications, and to provide guidance to the Department of Health and Human Services for educating and informing members of the public and the medical profession about public health issues related to the thyroid dose estimated which was presented in the NCI report. Regarding the estimation of the thyroid doses, the conclusions of the IOM report (IOM 1999) were that "the NCI report reflects an intensive effort to collect or generate the data needed for a complicated series of analyses, although documentation of methods, analyses, or results was insufficient in a few places. The committee concluded that the NCI was unlikely to have grossly over- or underestimated the collective I-131 dose, but it was less confident that the NCI had realistically determined the uncertainty associated with the estimate." With respect to the NCI estimates of cancer risk, it is indicated in the IOM report (1999) that "the committee considered the NCI approach to developing estimates of excess cancer cases due to ^{131}I exposure generally reasonable, but the committee did raise questions about certain assumptions. In particular, it noted that there is disagreement within the scientific community about the assumption of dose-response linearity, that is, the assumption that the smallest dose of ^{131}I to the thyroid results in some excess risk of cancer. Most exposure to ^{131}I following the Nevada tests was low-level exposure for which evidence of cancer risk is very limited."

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Appendix B

ACERER Issues

***Contents**: This section provides a list of recommendations made by the Advisory Committee on Energy-Related Epidemiologic Research and the status of the Department of Health and Human Services' response to those recommendations.*

In the fall of 1998, the Advisory Committee on Energy-Related Epidemiologic Research (ACERER) provided a set of formal recommendations to Department of Health and Human Services (DHHS) concerning its research into the occupational and public health consequences of the nation's nuclear weapons production and testing activities. These recommendations (and the status of our response actions) are as follows (ACERER 1998)[1]:

- **"Fulfill the legislative intent of Public Law 97-414."**

  The NCI (NIH 2000) has recently updated the Radioepidemiological Tables that were published in 1985 (NIH 1985). This revision required developing risk models for more than 20 specific cancers, including those organs and tissues that are of interest following exposures to radioactive fallout. Although the tables are being developed to estimate the "probability of causation", that is, the probability that a cancer that has been diagnosed in an individual is the result of some previous exposure to radiation, the models could be used to estimate the lifetime risk of developing cancer, a more useful quantity for those exposed to fallout and who as yet have no observable health effects. Additionally, the NCI is developing the ^{131}I/NTS Communications Plan that will provide the American public and the nation's health care providers with accurate, yet understandable, information regarding the potential risks of thyroid disease associated

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[1] Advisory Committee for Energy-Related Epidemiologic Research (ACERER), (1998). Resolution containing sic recommendations concerning the Department of Health and Human Service's Follow-up to the NCI study, October, 1998.

with exposure to ^{131}I released during nuclear bomb tests in the 1950s and 1960s at the NTS.

- **"Complete a comprehensive dose reconstruction project for NTS fallout."**

This feasibility report provides DHHS's initial work to provide dose estimates beyond ^{131}I to include all of the biologically significant radionuclides from NTS and global testing. The options for future work discussed in Chapter 6 address this ACERER recommendation.

- **"Notify Americans of the factors that might help them to determine whether they received significant radiation doses from NTS fallout."**

NCI has taken the lead in communicating information to people exposed to ^{131}I fallout from the Nevada Test Site as well as the potential health implications of these exposures. The communications plan developed by NCI for the ^{131}I/NTS Communications Campaign may prove to be a useful model for communicating information about exposure and risk from *other* radionuclides from NTS as well as global fallout. If a detailed study is conducted and sufficient resources are provided, a comprehensive, nationwide public awareness and provider education campaign could be implemented.

- **"Create a public and health care provider information service on NTS exposures and resulting public health concerns."**

A major component of the communications and education approach discussed in this feasibility report calls for the development of education strategies, plans and resources to guide health care practitioners through patient education, diagnosis, treatment, and the surveillance of illness in persons exposed to radioactive fallout. This report also discusses the need to explore and evaluate existing inconsistent health care recommendations and guidelines in order to develop consistent messages for health care providers. Also, the establishment of a national resource center to provide information and education to both concerned public and health care providers is outlined as a potential mechanism for addressing the public's needs and concerns.

- **"Support archival projects to document experiences of exposed peoples."**

CDC agrees with ACERER that the citizen input they have received throughout their energy-related work at nuclear weapons production sites can provide helpful information on records recovery, past exposures and exposure pathways. In the communications and education approach presented in this feasibility report, archival projects are discussed as a useful source to not only measure the level of public awareness, concern, and familiarity with the issues, but also as potential partners during the planning and implementation phases of a communications effort to assist in defining target audiences and disseminating information. If additional fallout-related work is funded, it may be possible to assist national, regional and local efforts devoted to recording and preserving the histories of peoples exposed to radiation from nuclear testing and nuclear weapons materials production. It would be important to identify and protect existing data archives (such as, historical reports, monitoring data, institutional memories, etc.) in order to facilitate any future scientific work.

- **"Further evaluate screening opportunities for thyroid cancer. It is urgent, in the meantime, to evaluate the advisability and feasibility of screening for other (noncancerous) thyroid and parathyroid diseases, with a priority to evaluate this service for those at highest risk due to their exposures."**

ACERER with planning and logistical support from NCI and CDC, held a discussion of screening issues with invited experts on June 8, 2000. This is a very complex public health issue that has been considered by the Institute of Medicine and others. Though, ACERER has not made formal recommendations to DHHS regarding targeted screening of higher exposure groups, DHHS has been proactive in investigating current thyroid screening recommendations by groups such as the Preventive Services Task Force and the American Thyroid Association. Additionally, it has explored existing coverage of thyroid disease screening procedures by programs under its purview such as Medicare and the Indian Health Service.

Since ACERER first submitted these recommendations to DHHS, they have been updated on the progress of NCI and CDC on both the ^{131}I/NTS Communications Project and the work being conducted to complete this feasibility report. Specifically, ACERER and other members of the public have been able to review and provide advice and comment on:

- The agenda and draft materials for the ^{131}I/NTS Communications Project January 2000 Workshop;
- The outline of the ^{131}I /NCI Communications Plan;
- Monthly progress reports on the Communications Project's activities;
- Progress reports on CDC and NCI's work to examine the scientific feasibility of estimating the doses and potential risks to the American publics resulting from other radionuclide exposure from NTS fallout and global nuclear weapons testing and the subsequent nationwide communication of this research; and
- They will be provided a draft copy of this feasibility report and they will have an opportunity to comment.

The agencies and DHHS will continue to work with their advisory committee as work progresses on these fallout-related projects.

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NIH. National Institutes of Health. Draft report of the NCI-CDC working group to revise the 1985 NIH radioepidemiological tables. Bethesda, MD; 2000.

Appendix C

Document Preservation and Retrieval: Current and Potential Future Activities

Contents: *Any additional fallout-related work will require an extensive review of fallout monitoring programs. This section describes some of these programs and the need for document identification and preservation.*

C.1 The Need for Original Data

In almost ten years of dose reconstructions, the Centers for Disease Control and Prevention (CDC) has always tried to locate and use original data whenever possible in order to reduce calculation errors and loss of accuracy. In many cases, this has led to substantial revisions to previous release data. For example, at the Savannah River Site and Fernald, CDC's estimates more than doubled the previously reported amounts of some released radioisotopes, and at Hanford CDC determined that the amount of ^{131}I should be increased by 70%. These results were obtained simply by careful evaluations of known sources and activity at those sites, without discovering any previously unknown activities or releases.

In conducting this feasibility study, CDC discovered extensive repositories of data that could be used in this study. However, some of these data have already been destroyed.

Some are being preserved in various repositories, and they may or may not be catalogued. An unknown amount exists in undocumented collections at different government facilities or in private hands. The people who conducted the research and who understand the data will not be available much longer, due to retirement or death. If there is ever going to be a study of the health effects of all nuclear weapons tests using original data, the information collection phase must be done soon.

C.2 Past Research

Measurements and evaluations of fallout dispersal and deposition during the era of nuclear testing were, in the aggregate, probably the largest environmental monitoring program ever undertaken by the United States and other countries. Most of the monitoring programs were classified at the time, and many still are. Future studies will require access to and declassification of documents by the Departments of Energy (DOE) and Defense (DOD). In addition to the specific and extensive monitoring conducted with each test, there were many national or international monitoring programs. For example, the United States Public Health Service (PHS) maintained a nationwide network of gummed film collecting stations and conducted a nationwide milk-sampling program (Devore and Terrill 1982). The United States Atomic Energy Commission's Health and Safety Laboratory in New York City, later renamed the Environmental Measurements Laboratory, also maintained a nationwide sampling program including atmospheric samples, soil samples, and gummed film samples (Bouville and Beck 2000; Friend 1961; Harley 1976; Salter 1965). The Applied Fisheries Laboratory at the University of Washington collected extensive seawater and marine biology samples (Hines 1962).

In addition to the efforts of the PHS and the Atomic Energy Commission, many state agencies, universities, other government agencies, and even some corporations conducted their own monitoring programs. The DOD had its own set of sampling programs that remain classified to this day. Eastman Kodak conducted fallout measurements because fallout was exposing newly manufactured film.

Every nation that conducted atmospheric nuclear weapons tests took similar measurements, and many other nations had significant fallout measurement programs during this period. Japan and India monitored and analyzed Chinese fallout data. New Zealand and Australia collected data on French tests in the South Pacific and British tests in Australia. Finland, Sweden, and Norway collected and analyzed fallout from Russian atmospheric tests on Novaya Zemlya. The United Kingdom conducted an extensive program of atmospheric ^{137}Cs and ^{90}Sr monitoring. There were also some international programs under the auspices of the United Nations.

Since the end of nuclear testing, the United States, several foreign governments, the United Nations, and various non-governmental organizations have conducted studies of the health effects of fallout in various regions of the world. For example, the International Atomic Energy Agency (IAEA) conducted a dose reconstruction on Fangataufa and Mururoa after the French tests there. The United States and the Republic of the Marshall Islands jointly conducted a radiological survey of the Marshall Islands after testing by the United States in the Pacific Ocean. The governments of the countries of the Former Soviet Union are conducting epidemiological and radiological studies around Soviet test sites, and making their data available internationally. The Scientific Committee On Problems of the Environment (SCOPE), part of the International Committee for Science, recently completed an assessment of the environmental and human impacts of nuclear test explosions (Kirchmann 2000).

C.3 Current Status of Document Preservation

Ten years ago the DOE declared a moratorium on the destruction of all energy related documents of epidemiological significance. Since that time DOE documents shipped to a Federal Records Center or the National Archives have indefinite destruction dates if they are in a group of records covered under the moratorium. Many of these records, particularly the older ones, are not cataloged in any detail. A researcher may be able to determine that there are 60 cubic feet of documents about nuclear weapons testing at the Federal Records Center in Maryland, but it is necessary to actually visit the Center and open boxes to determine what the documents are and whether they are needed. Since these records are in a safe place, this effort may be deferred for the time being.

In 1978, the DOE launched a comprehensive effort to gather as much information about United States nuclear weapons testing as possible. This information is held at the Coordination and Information Center (CIC) in Las Vegas, NV. This information is very well catalogued, and researchers can search for documents by title, DOE number, author, or key words via the Internet (http://www.osti.gov/waisgate/opennet.new.html). As long as CIC's funding remains stable, these documents will remain available for researchers.

The DOE has an Internet site listing sites that contain relevant documents (http://tis.eh.doe.gov/workstation/homerep.html). However, this Internet site does not provide enough information for a researcher to determine what is available without an actual visit to the facility. If these documents are to be useful for future research, someone should visit each site and catalog documents actually useful for fallout research. The documents are protected, however, so this could be deferred.

Other agencies in addition to the DOE conducted their own research or measurements programs, such as the PHS (Devore and Terrill 1982) or Eastman Kodak. These documents are not covered by DOE’s moratorium and could be destroyed at any time. The documents at these sites should be copied and catalogued as soon as possible.

Many nations sent reports of their fallout measurements to the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) in Vienna, Austria, beginning in 1958. Many of these research reports are out of print and the copy at UNSCEAR may be the only surviving copy. Since submission of reports to UNSCEAR was voluntary, none of their report series are complete. However, UNSCEAR documents may be useful in two ways. First, the research reports themselves may provide useful scientific data (even if incomplete); and second, while UNSCEAR does not have any raw data it is possible to use UNSCEAR's records to identify countries and laboratories where original data may be found. UNSCEAR has not determined how long they will retain any of these research reports. CDC has borrowed some of the UNSCEAR records relevant to fallout, and is copying them now.

Many scientists with years of experience on fallout studies have unique data in their own offices. Others working for universities, the government, or other organizations took their data with them when they retired. These data are the most fragile of all. They are not catalogued, covered by a moratorium, or available to future researchers. For example, one retired scientist had several thousand measurements of radioactive iodine in animal thyroids from all over the world. Some of the information was contained in hand written notebooks and some of it was stored on antiquated IBM tapes. CDC was able to find a contractor capable of reading old data tapes, retrieved the data, and now has it in a format that modern database software can read. CDC is now making arrangements to borrow the remaining notebooks and have them keyed into a database and appended to the existing data. The government should mount an aggressive effort to identify, copy, and preserve information like this as soon as possible if this information is ever to be used in a new study.

The DOD has never declared a moratorium on destruction of records of epidemiological significance, and they are not under any obligation to share whatever relevant data they may have with the Department of Health and Human Services (DHHS). The Navy was in charge of early weapons testing in the Pacific, including radiological measurements; and the Air Force has been conducting atmospheric measurements for many years. Most of this information remains classified. Immediate steps should be taken to identify, catalogue, protect, and declassify this material (in that order). This requires giving government staff with the appropriate security clearances access to the material, but it will not be necessary to declassify any documents until the time comes to use them.

CDC has not visited any foreign repositories for fallout related information except the UNSCEAR headquarters in Vienna, Austria. CDC’s staff knows with a fairly high degree of confidence what laboratories have conducted measurements, but we do not know what data are still available or how long it will be available. DHHS could identify exactly what kind of data are required from foreign laboratories to fill the holes in available data for calculating health effects on residents of the United States from global fallout and begin negotiating with foreign governments for permission to review, copy, and use their data as necessary.

In the United States, CDC has visited 15 sites to evaluate documents for their relevance to this fallout study. There has been no attempt to catalog these documents, and only a few copies were made as examples of what was there.

- The information at some sites was not useful for future fallout studies. CDC noted that fact and will take no further action.
- Some of the DOE information at Federal Records Centers was useful. This information was covered by the moratorium, so it will not be destroyed. However, it was not very clearly described, so it will eventually be necessary to visit these Centers, open boxes, and enter abstracts of the useful documents into a database if this information is to be useful to future researchers.
- Some of the DOD information at Federal Records Centers was useful. Most of this information was not covered by the moratorium and will be destroyed in the next few years if no action is taken. CDC has not been able to do anything with this material yet.
- Some of the DOD information was not made available to CDC, so it is impossible to tell whether it is useful or not.
- There are large quantities of useful information at national laboratories. This information is often scattered all over the laboratory, not catalogued in any way. While this information fits the description of material covered by the moratorium, the administration of the moratorium only covers groups of boxes in archives, not individual records, so there is no guarantee the material will be preserved. Under a different appropriation and for a different project, CDC is busy searching, copying, and cataloguing relevant documents at the Los Alamos National Laboratory. There are no document retrieval and assessment activities underway at any other national laboratory at this time, due to lack of funding or a mandate to do so.

The Environmental Measurements Laboratory (EML) in New York City is an important source of fallout data. Some of this information is very well preserved and readily available, such as the soil sampling data posted on the Internet. In addition to their own research, the EML has collected published reports from all over the country or the world about fallout measurements. Many of these are out of print. Since they are not DOE reports, but copies of old journal reports, they are not covered by the moratorium, and CDC discovered EML staff was preparing to destroy these reports in order to reduce required office space and save money. Other information, such as gummed film data, was to be stored uncatalogued in boxes in the basement of the building. While this material would not have been lost, it would not be available to future researchers because no one would be aware of the existence of the material. CDC made two more visits to EML, where they segregated fallout relevant material from other material; and made arrangements with EML staff to retain that material. CDC also got permission from DOE to ship the gummed film data to Atlanta, where they are making arrangements to have the data scanned into a computer.

In 1978, the PHS combed its own archives and collected about 11,000 documents about fallout. The 1979 report Effects of Nuclear Weapons Testing on Health: Report of the Panel of Experts (Hulley 1979) describes the contents of this archive. In Hulley (1979), the panel concluded that the PHS archive contained enough information to assess the health effects of fallout. CDC has a copy of this report. All of the documents from the original archive are on microfilm at the DOE's Coordination and Information Center (CIC) in Las Vegas.

During the years of nuclear weapons testing Congress held many hearings on the health effects of fallout and the need for further nuclear weapons testing. The published hearings are out of print now, but CDC has found extensive collections of these hearings in several locations – CIC, university libraries, and the Environmental Measurements Laboratory, to name a few. CDC has a copy of the Hearings before the Special Subcommittee on Radiation of the Joint Committee on Atomic Energy, 85th Congress First Session on the Nature of Radioactive Fallout and its Effects on Man 1957 and will use others as the need arises. These hearings are valuable in two ways. They contain useful information themselves, and they point to locations where more information may be found. As with other documents cited above, DHHS needs to identify Congressional hearings relevant to the fallout study which are not already stored at CIC, find and copy them, and ensure they are stored in a protected archive.

C.4 Possible Future Actions

There is a fundamental need for DHHS to continue the past efforts of itself and other agencies to ensure the preservation and continuing availability of data necessary for future fallout research. Priorities should be:

- Continue the search for documents not held by a government agency; copy them, catalog them, and take steps to ensure their preservation.
- Enroll other government agencies, especially the DOD, in the effort to identify, preserve and publish information.
- Make copies of the documents publicly available in paper form in a library or scan them and make them available over the Internet.
- Specific actions that could be done in the near future:

- Find PHS gummed film and milk data.
- Extend the moratorium to DOD data.
- Review DOD data, especially data on post-test fission product ratios.
- Copy UNSCEAR documents and return the originals to Vienna.
- Scan EML gummed film data into computer readable form if they are not already available in that form.
- Catalog the reports at the EML and establish a reading room or library for them.
- Visit 44 facilities identified by DOE that contain fallout relevant material, and protect and catalog the material if necessary.
- Assemble a list of Congressional hearings relevant to fallout and ensure that a complete collection is preserved somewhere.
- Begin negotiations with foreign laboratories for permission to examine and possibly copy their data.

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Appendix D

External Dose Estimates from NTS Fallout

External Radiation Exposure to the Population of the Continental U.S. from Nevada Weapons Tests and Estimates of Deposition Density of Radionuclides That Could Significantly Contribute to Internal Radiation Exposure Via Ingestion

Harold L. Beck

Report to the National Cancer Institute in fulfillment of
P.O. #263-MQ-909853

June, 30, 1999 (revised Nov. 1, 1999)

Abstract

This report provides estimates of the external radiation exposure and whole body effective dose received by residents of the continental U.S. during the period 1951-1962 from weapons tests carried out at the Nevada test site. Estimates are given on a county by county basis for each test and for each year of testing. The average committed population dose from all NTS tests was about 0.5 mSv, about equivalent to 1-2 years of external radiation exposure from natural background. Residents of the counties immediately downwind from the NTS incurred much higher doses, in excess of 3 mSv, while the residents of the Far West, Pacific NW and SE received lower than average exposures. The tests and radionuclides that contributed the most exposure are discussed as well as the dependence on fallout time of arrival. The most exposed individuals were outdoor workers, the least exposed, persons who spent most of their time indoors in heavily constructed buildings.

The deposition of radionuclides that contribute to internal radiation exposure via the ingestion pathway was also calculated on a county by county and test by test basis. The general pattern of deposition, tests contributing the most to the deposition, deposition density versus distance from the NTS, and the differences in deposition between radionuclides are discussed. In general the deposition of long-lived radionuclides such as Sr-90 and Cs-137 was about a factor of 20 less than that from "global fallout" from high yield weapons tests carried out in the Pacific and Soviet Union. However, the deposition of short-lived isotopes such as I-131 was greater than from "global" fallout".

Introduction

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

"Prepare crude estimates of the doses *from external irradiation* received by the American people as a result of the above-ground tests carried out *at the Nevada Test Site (NTS).* These dose estimates would be:

- based on a review of the readily available open literature and information; it is not expected that sophisticated computer models should be developed or used for this purpose. For the purposes of thia assessment, the extensive database of Iodine-131 that was prepared by NCI in the framework of the nationwide NTS fallout study could be used;
- averaged over large regions of the continental U.S., with indications on how the high-risk populations would be identified. However, if feasible, primary calculations should be carried out on a county by county basis, and averaged only for presentation purposes;
- calculated separately for the most important radionuclides produced in nuclear weapons tests. Those would include, but would not be limited to Te-I-132, Ba-La-140, Zr-Nb-95, Cs-137, and Np-239;
- provided in terms of average whole-body dose for gamma irradiation and of dose to the skin for beta irradiation.
- calculated by year and summed over all NTS tests, with a comparison to the published UNSCEAR latitudinal averages for all tests.

2. Provide a list of references regarding: (1) the history of nuclear weapons testing at the NTS; (2) the production of important radionuclides during those tests; (3) the networks of fallout measurements; (4) the assessment of the activities deposited on the ground; (5) the vertical migration of fallout radionuclides into deeper layers of soil; and (6) the assessment of the doses from external irradiation.

3. Identify reports that could be declassified. Examples of such reports are those that would provide the fission and total yields, and those that would greatly facilitate the estimation of doses due to the plutonium isotopees."

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

As per the scope of work, this report relies heavily on previous studies of NTS fallout (eg. NCI (1997); Hicks (1982, 1990); Church et al.(1990); Beck et al. (1990, 1996)). Exposure rates and deposition densities were calculated for about 60 of the approximately 100 atmospheric tests conducted at the NTS. These 60 tests accounted for over 95% of the total I-131 produced (NCI, 1997) and corresponded to the majority of tests for which total I-131 deposition was estimated by the NCI (1997) in their study of I-131 exposure to the American people from NTS fallout. A few tests considered in the NTS study for which only local fallout estimates were estimated were not treated in this study. The tests considered in this report are listed in Table 1. Table 1 also gives some specific information about each test that was used in the calculations described later in this report.

The basic starting point for the estimates in this report were the daily I-131 deposition density estimates and associated uncertainty estimates from NCI (1997). All calculations for this report were carried out separately for each county (and sub-county as defined in NCI (1997), Appendix 2, and then summed to provide estimates on a test by test, annual and total NTS basis. The total exposure and deposition density for other nuclides was calculated from the NTS I-131 deposition densities by using the relationships calculated by Hicks (1981) for each NTS shot. Besides the total free-in-air exposure rate from gamma emitters, provided by the Hicks data, estimates were also made of the annual whole body effective dose, the beta-ray dose to the skin from radionuclides in the surface soil, and the 50y committed effective dose. The radionuclides that contributed most to both gamma and beta-ray exposure were identified.

Deposition densities were estimated on a county by county basis for each test for the radionuclides listed in Table 2. These radionuclides were determined by Ng et al. (1990) to account for over 90% of the potential dose from ingestion in the ORERP (Church et al., 1990) study. A database (in Excel) containing the estimated deposition density of each radionuclide listed for each test on a county by county basis was provided to NCI earlier in partial fulfillment of this contract. The database containing these deposition density estimates and associated uncertainty estimates will be used by the NCI to estimate internal radiation doses due to ingestion of contaminated food. The patterns of total deposition for some of the longer-lived nuclides are discussed in this report and the total deposition of various radionuclides is compared to that from the "global” fallout resulting from the high yield tests carried out in the Pacific and in the USSR.

In addition to the references provided in the text of this report, an additional reading list is provided in fulfillment of item 2 of the scope of work. A list of data that is presently classified but if unclassified would be useful in improving the estimates made in this report and allowing similar estimates to be made for weapons test conducted outside the U.S. is also included in fulfillment of item3.

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

Table 1: Tests considered in this study

Test	**Test Date**	**yield (kT)**	**Type**	**Cs-137/ Sr-90**	**% Cs-137 from Pu***	**Pu-240/ Pu-239**	**Pu-241/ Pu-239**	**Cs-137/ Pu***
BAKER-1	1/28/51	8	air	1.79	72%	0.027	0.0006	5
Baker-2	2/2/51	8	air	1.79	72%	0.026	0.0005	5
BAKER	10/28/51	4	air	2.50	100%	0.033	0.0011	4
CHARLIE	10/30/51	14	air	1.16	18%	0.028	0.0010	20
DOG	11/1/51	21	air	1.27	31%	0.028	0.0010	12
EASY	11/5/51	31	air	1.24	28%	0.036	0.0011	13
SUGAR	11/19/51	1	surface	1.06	3%	0.001	0.0000	316
UNCLE	11/29/51	1	crater	1.06	3%	0.001	0.0000	299
ABLE	4/1/52	1	air	1.06	3%	0.001		142
BAKER	4/15/52	1	air	1.06	3%	0.001		144
CHARLIE	4/22/52	31	air	1.27	31%	0.051	0.0028	11
DOG	5/1/52	19	air	1.28	32%	0.035	0.0012	11
EASY	5/7/52	12	tower	1.27	31%	0.024	0.0005	24
FOX	5/25/52	11	tower	1.27	31%	0.024	0.0006	24
GEORGE	6/1/52	15	tower	1.27	31%	0.026	0.0015	24
HOW	6/5/52	14	tower	1.26	30%	0.027	0.0005	24
ANNIE	3/17/53	16	tower	1.28	32%	0.025	0.0010	23
NANCY	3/24/53	24	tower	1.27	31%	0.028	0.0012	23
RUTH	3/31/53	0	tower	1.06	3%	0.000		306
DIXIE	4/6/53	11	air	1.27	31%	0.022	0.0006	12
RAY	4/11/53	0	tower	1.06	3%	0.000		292
BADGER	4/18/53	23	tower	1.34	38%	0.034	0.0011	19
SIMON	4/25/53	43	tower	1.12	12%	0.027	0.0006	60
ENCORE	5/8/53	27	air	1.16	17%	0.052	0.0028	20
HARRY	5/19/53	32	tower	1.21	24%	0.038	0.0018	29
GRABLE	5/25/53	15	air	1.04	0%	0.001		833
CLIMAX	6/4/53	61	air	1.11	11%	0.034	0.0009	33
WASP	2/18/55	1	air	1.77	71%	0.055	0.0036	5
MOTH	2/22/55	2	tower	1.77	70%	0.078	0.0065	9

Test	Test Date	yield (kT)	Type	Cs/Sr	% Cs-137 fromPu*	Pu-240/239	Pu-241/239	Cs/Pu*
TESLA	3/1/55	7	tower	2.42	98%	0.019	0.0003	8
TURK	3/7/55	43	tower	1.20	23%	0.033	0.0008	32
HORNET	3/12/55	4	tower	1.38	43%	0.058	0.0036	16
BEE/ESS	3/22/55	9	tower/crater	1.42	46%	0.085	0.0071	13
APPLE/WASP'	3/29/55	17	tower/air	1.16	18%	0.025	0.0006	40
POST	4/9/55	2	tower	2.47	99%	0.019	0.0005	8
MET	4/15/55	22	tower	1.03	-1%	0.007	0.0001	10000
APPLE2	5/5/55	29	tower	1.06	4%	0.031	0.0008	186
ZUCCHINI	5/15/55	28	tower	1.11	10%	0.032	0.0008	69
BOLTZMANN	5/28/57	12	tower	1.51	53%	0.079	0.0060	12
WILSON	6/18/57	10	balloon	1.29	33%	0.082	0.0065	9
PRISCILLA	6/24/57	37	balloon	1.07	5%	0.011		74
HOOD	7/5/57	74	balloon	1.12	12%	0.067		27
DIABLO	7/15/57	17	tower	1.22	26%	0.062		26
KEPLER	7/24/57	10	tower	2.37	96%	0.072	0.0054	7
OWENS	7/25/57	10	balloon	2.44	98%	0.070	0.0047	3
SHASTA	8/18/57	17	tower	1.19	22%	0.057		30
DOPPLER	8/23/57	11	balloon	1.26	30%	0.070	0.0046	11
SMOKY	8/31/57	44	tower	1.08	6%	0.006		136
GALILEO	9/2/57	11	tower	2.19	90%	0.075	0.0050	7
WHEELER/ (+COULOMB)	9/6/57	1	balloon/ surface	1.04	0%	0.038		785
LAPLACE	9/8/57	1	balloon	1.07	6%	0.000		72
FIZEAU	9/14/57	11	tower	1.43	47%	0.063	0.0040	14
NEWTON	9/15/57	12	balloon	2.46	99%	0.072	0.0058	3
WHITNEY	9/23/57	19	tower	1.41	45%	0.073		14
CHARLESTON	9/28/57	12	balloon	1.29	33%	0.074		10
MORGAN	10/7/57	8	balloon	1.23	26%	0.077	0.0063	12
SEDAN	7/6/62	104	crater	2.44	98%	0.063		8
SMALLBOY	7/14/62	20	surf tower	2.51	100%	0.065	0.0056	8

*Estimated-see text

Table 2: Radionuclides for which deposition densities were calculated

Nuclide	**Halflife (parent), d**
Sr-89	52
Sr-90,Y-90*	10400
Sr-91	0.4
Y-91m (=0.65 * Sr-91)	*
Y-91	59
Y-93	0.4
Zr-97, Nb-97*	0.7
Zr-95, Nb-95*	64
Nb-97m (=0.96 * Zr-97)	*
Mo-99	2.8
Tc-99m (=0.96 * Mo-99)	*
Tc-99	7.8E7
Ru-103, Rh103m*	39
Ru-105, Rh-105m*	0.2
Rh-105	1.5
Ru-106, Rh-106*	368
I-131 (from NCI, 1997)	8
Te-132	3.3
I-132 (=1.03 * Te-132)	*
I-133	0.9
I-135	0.3
Cs-136	13
Cs-137	11000
Ba-140	13
La-140	1.7
Ce-141`	32.5
Ce-143	1.4
Pr-143	14
Ce-144, Pr-144*	284
Nd-147	11
Pm-147	956
Np-239	2.36
Pu-239	24131 y
Pu-240	6569 y
Pu-241	14.4 y
Am-241	430 y

* in equilibrium with parent

Methodology

Deposition Densities

The deposition densities of the nuclides listed in table 2 were calculated from the corresponding NCI estimates of I-131 deposition density. The daily geometric mean (GM) I-131 deposition densities and corresponding geometric standard deviations (GSD) were decay corrected back to H+12 hours. The ratio of the H+12 h I-131 value, which includes the I-131 that grew in from precursors (NCI, 1997), to the ratio of each of the radionuclides in Table 2, as a function of fallout arrival time, was calculated using Hicks (1981). The H+12 h I-131 value for each day of fallout was then multiplied by the appropriate ratio for a time of arrival corresponding to that day to obtain the respective deposition density.

Because the fallout estimates based on gummed-film data were decay corrected to the midpoint of the day of sampling and the test detonations were generally near the beginning of the sampling period (Beck, 1984), fallout arriving on the same day as sampling was assumed to have a time of arrival of 0.5 d, on the second day 1.5 d, etc..Generally, only about 10 days of data had to be considered for a given shot, although a few shots produced significant fallout for periods of up to two weeks. Daily deposition densities were calculated only for short-lived nuclides (half lives less than 30 d). For longer-lived nuclides, the ratio to H+12 h I-131 did not vary significantly over the first several weeks of fallout and thus their total test deposition could be calculated directly from the sum of the daily I-131 depositions.

The daily deposition densities were then summed to obtain a total test deposition density. Since the I-131 deposition densities were given as geometric means with a GSD, it was necessary to first transform the GM to a mean and the GSD to a variance before summing, using standard transformations as discussed in NCI (1997). After the means and variances were summed, the results were transformed back to geometric means and GSD's, assuming the sum of lognormally-distributed distributions is itself approximately lognormally-distributed (see NCI, 1997). The Excel spreadsheet database which accompanies this report contains both the mean values and the GM values. For the long-lived radionuclides, the deposition densities were calculated by multiplying the summed I-131 deposition density by the appropriate ratio for that test from Hicks' data. No additional uncertainty was assumed due to use of the Hick's calculated isotope ratios. Because of the large GSD's associated with the I-131 deposition data, any small additional error in Hicks' data would have a negligible effect on the error in the deposition densities.

Besides, the individual test values, the deposition densities for each test series (year of testing) and for all NTS tests were obtained by summing the individual test results in a similar manner. The short-lived nuclide deposition densities for radionuclides that did not contribute significantly to external dose were not summed to obtain annual or total values. It was assumed that for these short-lived nuclides, the exact week of deposition would be required to make reasonable estimates of ingestion dose. If annual sums are desired for these radionuclides, it is a fairly simple task to obtain them since the GM to mean transformed values are provided in the accompanying database.

A detailed example of the calculation of the deposition density of Cs-137 and Ba-140 for a representative county for a representative test is given in Appendix 1

Plutonium isotopes were also contained in the fallout from Nevada weapons tests. Pu isotopes do not contribute to external exposure and contribute in only a minor way to ingestion exposure. The main hazard from Pu is generally via the inhalation pathway. However, The inhalation pathway has been shown to not have been a significant contributor to population exposure from NTS testing (Church et al., 1990). Because of the generally high degree of interest by the public in Pu contamination, deposition densities of Pu-239, 240 and 241, and of Am-241 which is a decay product of Pu-241 are also estimated in this report. However, only crude estimates can be made for individual tests since Hicks does not provide any estimates of relative Pu deposition. The ratios of Pu to Cs-137, Sr-90, etc. are still classified (see Appendix 3). The reason for the classification still being in place is that knowledge of such ratios would allow one to estimate the fission efficiency of individual tests.. However, one can still roughly estimate Pu deposition densities for individual tests by assuming an average ratio of Pu/Cs-137 deposition density from Pu fission based on observed environmental measurements, if one can estimate the relative amounts of fission due to Pu-239 versus U-235 for each test..

In Table 1, we list the ratio of Cs-137/Sr-90 activity (Hicks, 1981) and the Pu-240/239 and Pu-241/239 atom ratios for each test (Hicks and Barr, 1984). Table 3 presents the fission yields for Pu and U-235 for a fission neutron spectrum and for a thermal neutron spectrum.

Table 3: Fission yields for Cs-137 and Sr-90 (England and Ryder, 1994)

Nuclide	**U-235$_f$**	**U-235$_{th}$**	**Pu-239$_f$**	**Pu-239$_{th}$**
Cs-137	6.22	6.19	6.58	5.50
Sr-90	5.46	5.78	2.05	2.10
Cs/Sr (atom)	1.14	1.07	3.21	2.62
Cs/Sr(activity)	1.06	1.00	3.00	2.44
Observed ratio	1.04		2.5	

Note that the Cs/Sr ratios in Table 1 range from a value of 1.04 to 2.5. Based on the fission yields in Table 3 one can infer that the Cs/Sr ratio of 1.04 represents shots where the fission was entirely from U-235, while the ratio of 2.5 represents fission entirely from Pu-239. It is assumed that for these low yield tests essentially none of the fission was from high-energy neutrons and that for at least most of the tests, no other fissionable material was used. As can be seen, both U-235 and Pu-239 fueled most of the tests[1]. Based on Hick's calculations, the tests inferred to be all U-235 also correspond to those that produced no Am-241 (Hick's, 1981) and exhibited very low Pu-240/239 atom ratios and little Pu-241 (Table 1), consistent with a pure U-235 weapon. (A small amount of Pu will be produced from Np-239 decay even in a pure uranium device since Np-239 is produced by the activation of U-238). Assuming only a mixture of Pu and U-235 as fuel, one can then derive equation 1) for the fraction f of Cs-137 activity that resulted from Pu-239 fission for each shot:

$$f = 1.71 * (x - 1.04) / x \quad \text{where x is the Cs/Sr activity ratio from table 1.} \qquad (1)$$

Using the Cs/Sr activity ratios from Hicks, given in Table 1, one can then estimate the fraction of the Cs-137 produced that was from Pu-239 fission for each shot from equation 1. This fraction is given in the fifth column of Table 1.

Since these were tests, it is expected that the fission efficiency, and thus the ratio of Cs-137 to Pu-239 from Pu fission probably varied considerably from shot to shot. However, if we choose a reasonable estimate for the mean for all tests and assign a conservative error estimate, we can make rough estimates of Pu deposition which, while possibly significantly in error for a given shot, should provide reasonable total deposition values when summed over all shots. A Cs/Pu ratio of 4 was thus adopted for tests where all the fission was from Pu. . Using this ratio then results in the crude estimates of total Cs/Pu for each test shown in the last column of Table 1. The choice of this particular ratio is somewhat arbitrary but seems to provide estimates of Cs/Pu reasonably consistent with measurements of Cs-137/Pu-239+240 in NTS fallout (Krey and Beck, 1981).

An uncertainty corresponding to a GSD of 1.5 was assigned to reflect the large uncertainty in this mean efficiency estimate and the likely large variability from test to test. Using this formulation, Pu-239+240 and Pu-241 deposition densities in fallout were estimated for each test, test series and for all NTS fallout. (Note that for tower and surface shots, since Pu is a refractory material, according to Hicks (1982, 1990) only ½ the Pu from tower and surface shots would be deposited outside the immediate vicinity of the NTS. Thus the Pu deposition estimates for these shots were multiplied by 1/2). Because of the large uncertainty, the Pu deposition estimated for a particular county for any particular test has a large uncertainty (GSD ≅ 2- 4), resulting both from the large uncertainty in the NCI I-131 deposition density estimates as well as the large uncertainty in fission efficiency. However, the sums over all tests have smaller uncertainty (GSD ≅ 1.5-2.0) and are believed to present a reasonable exposition of the total Pu deposition

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[1] (The very low Np-239 values given by Hicks for some shots that apparently used very little Pu, suggests that U-233 may have been used in a few tests.)

across the U.S. from NTS testing.[2] **Accurate estimates of Pu deposition from particular tests will only be possible if additional information on the Cs/Pu ratios for particular tests is eventually unclassified and thus the Pu results presented in this report should be treated as only preliminary crude estimates.**

Some additional Pu-239 is generated from the decay of Np-239. Np-239 is formed by the activation of U-238, present in all U fueled weapons and possibly also in Pu-fueled devices as a tamper. Hicks (1981) provides estimates of Np-239 for each shot and these were used to estimate the Pu-239 that would remain after the Np-239 had decayed. This Pu-239 contribution is included in the estimates of Pu-239 in this report. For devices partially or totally fueled by Pu, this contribution is small. However, for U fueled devices it is the only source of Pu in the fallout. Np-239 is also a significant contributor to external radiation exposure rates during the first few days after detonation.

Pu-241 was also estimated from the Pu-239+240 estimate and the reported 241/239 atom ratios. At this time most of the Pu-241 deposited has decayed into Am-241 with a resultant Am-241 activity equal to the ratio of Pu-241/Am-241 half-lives (see Table 2).

External Radiation Exposure

Hicks (1981) calculated the relative exposure rate versus time for each NTS test using deposition to exposure rate conversion factors published by Beck (1980). The conversion factors used by Hicks assume the radioactivity was distributed in the soil with a relaxation length of about 0.1 cm for all times (the relaxation length is defined as the depth at which an exponentially decreasing activity falls to 1/e of the value at the surface). This value was chosen since even fresh fallout is attenuated somewhat as a result of surface roughness (Jacob et al.,1986; Eckerman and Ryman,1993). However, it is well established (UNSCEAR, 1993, NCRP, 1999, Miller et al., 1990; Gale et al.,1964) that radionuclides penetrate deeper into the soil with time. Data from the Chernobyl accident indicates that that even after a few weeks a relaxation length of 1 cm is not uncommon (Likhtariov et al.,,1996; UNSCEAR, 1993), particularly in areas with typical rainfall levels. After a few months, measurements have generally shown that the distribution reaches about a 3 cm relaxation length before the penetration begins to slow and asymptote (Beck, 1966; UNSCEAR, 1988; Miller and Helfer, 1985). However, for heavily watered areas, relaxation lengths of up to 6-7 cm have been observed (Miller et al., 1990; Beck and Krey. 1980).

Because, as will be shown later, most of the radiation exposure occurred during the first few weeks, the use of a 0.1-cm relaxation length by Hicks (1981) for all time intervals had only a small impact on the total integral exposure. However, in this report, an attempt was made to use a somewhat more realistic model. The 0.1 cm relaxation length used by Hicks was maintained for the first 20 d after detonation, but from 20 d to 200 d, a

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[2] Note that the county Pu deposition-density estimates for a particular are correlated since the uncertainty in Cs/Pu (or I-131/Pu) is the same for all counties for a given test. Thus the uncertainty in the Pu deposited in the U.S. from a given test will have minimum uncertainty of GSD=1.5. This correlation was accounted for in calculating the total Pu deposition for the U.S. discussed later in this report.

relaxation length of 1 cm was used, while for times greater than 200 days, a relaxation length of 3 cm was used. The corresponding deposition-density to exposure conversion factors for each of these relaxation lengths are from Beck (1980). Although a gradually increasing relaxation length would be more physically realistic, the fact that most of the exposure occurs in the first 20 d, did not warrant the considerable effort that would be entailed in calculating dose rates using a continuously-variable relaxation length.

Since the penetration into the soil would be slower in more arid regions, maintaining the 0.1 cm relaxation length for the first 20 d provides a slightly conservative estimate of the exposure for sites with greater precipitation and early fallout arrival times. Table 4 illustrates the dependence of the exposure rate in air on the various relaxation lengths. Note that the exposure rate is reduced by about 1/3 as the activity penetrates to a relaxation length of 1 cm and about ½ as the activity penetrates to a relaxation length of 3 cm from 0.1 cm. This accentuates the importance of the first few weeks after a test with respect to total external radiation exposure to an even greater degree than previous calculations based only on radionuclide decay.

Table 4: Exposure rate (: R/h per mCi/km^2) versus relaxation length for selected fission products (Beck, 1980)

Nuclide	**Relaxation length (cm)**		
	0.1	**1**	**3**
Zr-95	1.20E-02	7.94E-03	5.63E-03
Ru-103	7.85E-03	5.25E-03	3.58E-03
Rh-106	3.37E-03	2.25E-03	1.56E-03
Te-132	3.38E-03	2.29E-03	1.54E-03
Cs-137	9.29E-03	6.15E-03	4.32E-03
Ce-141	1.09E-03	7.25E-04	4.92E-04
Ce-144	2.53E-04	1.70E-04	1.16E-04
Np-239	2.56E-03	1.75E-03	1.17E-03

Since Hicks already calculated exposure rate versus time for the first 0-20 days using a relaxation length of 0.1 cm, his results for 0.5-20 d were adopted directly and fit to a function of the form at^{-x}. This function was then integrated to obtain the total exposure from TOA to 20 d , where TOA is the time of arrival in days. In all cases the correlation coefficient for the fit over the period 0.5-20 d was greater than 0.99. The variation in the exponent from shot to shot also turned out to be quite low (x = 1.109 " 0.022). To obtain the integral from 20 d to the end of the year, the subsequent year, and to 50y, the Hicks' data for nuclides that contribute to the exposure at those times were entered into a spreadsheet. The variation with time from 20 d on was calculated directly from the appropriate Bateman equations that account for ingrowth of precursors and radioactive decay. By using the appropriate analytical formulae normalized to Hicks' data at 20 d, it was possible to integrate analytically over the various intervals of interest. Note that due to the change in depth profile at 200 d, integration had to be done by first integrating from 20 d to 200 d (or to the end of the first year if less than 200 d) and then from 200 d to the end of the year.

Thus for each test, the total exposure was obtained for the year of the test, the next year, and finally for a total period from fallout time-of-arrival to 50 y. Hicks' calculations were normalized to unit exposure rate at H+12 h, which corresponds to a particular value of effective I-131 deposition density at H+12 h. Thus the ratio of the effective I-131 deposition for each day calculated by the NCI (1997), was multiplied by the appropriate normalized exposure integral to obtain the actual exposure for that interval and time-of-arrival. The individual daily estimates were then summed to obtain annual and 50y committed exposure estimates for each test, test series, and for all NTS tests. Again, no additional uncertainty was assigned for the exposure estimates since the error in the deposition density estimate dwarfs the estimated error in exposure rate estimates. The uncertainty in normalized integral exposure for a particular day is estimated to be at most 10-20%, due primarily to variations in the depth profile from site to site. The error in the conversion factors themselves are thought to be less than 5% (Beck, 1980).

A detailed example of the calculation of total exposure for a representative county for a representative test is given in Appendix 1.

Because the NCI deposition data are given for a particular day, the exposure estimates for sites where the fallout arrived very early (less than 12 h) are underestimated in this report. The exposure rate falls very rapidly during the first few hours (see Table 5) and thus the integral is very sensitive to arrival time for short arrival times. For this report it was assumed that the fallout that occurred on the day of the test occurred at H+12 h (H + 0.25 h for the 1952 tests due to a different gummed-film sample interval). Thus, for those sites where significant fallout occurred prior to H+12 h, the data presented here may be significantly in error (up to 50% too low). This is illustrated by Table 5, which gives the exposure rate and integral exposure versus time for a typical test. However, the exposure rates and external doses for close-in sites have been calculated in great detail for each community (Anspaugh and Church, 1990; Henderson and Smale, 1990; Thompson et al., 1990) and these dose estimates should be used in lieu of those in this report.

Table 5 also gives the fraction of the exposure occurring in various time intervals. One can see that that the exposure rate falls off rapidly with time and that over 80% of the exposure occurs in the first 20 d for an arrival time of 12 h. Thus only a small fraction of the total exposure (about 1% as shown later) is incurred in the year(s) after the test occurred unless the tests were very late in the year, particularly for locations where the fallout arrived within a day or two. The drop off in exposure rate was of course accentuated by the penetration of the activity into the soil with time. Previous calculations that did not take this penetration into consideration overestimated the total exposure. Note that the common assumption of a $t^{-1,2}$ decay rate and no penetration would imply only about 50% of the dose being incurred in the first 20 d!. The difference results

not as much from the greater penetration with time but more to the fact that the exposure rate drops off much more rapidly than
$t^{-1.2}$ after 20 d (Hicks, 1981).

Table 5: Relative Exposure rate and total exposure versus time of arrival (TOA)*

TOA, d	Exposure rate, mR/h	Total Exposure (50 y), mR
0.25	2.1	53
0.5	1.0	45
1.5	0.30	33
2.5	0.17	27
3.5	0.12	24
5.5	0.071	20
10.5	0.035	14
20	0.015	6

*values are for shot HARRY but are similar for all tests.

The exposures calculated in this report are generally based on estimates or measurements of radionuclide deposition densities and conversion factors from deposition density to exposure rate. Very few actual measurements of exposure were made outside the immediate vicinity of the NTS. However, for states immediately downwind from the NTS, all available data was used to estimate deposition densities including actual exposure rate measurements if any (Beck and Anspaugh, 1991; Beck, 1996). The conversion factors relating deposition density to exposure rate in air have been validated in many studies and as mentioned previously are believed to be accurate to better than 5% for a given depth distribution (NCRP, 1999).

Whole Body Effective Dose

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

Thus the dose to adults exposed outdoors is about 2/3 the outdoor exposure. However, most people spend most of their time indoors and thus their exposure is reduced greatly due to attenuation of the radiation by building materials. The amount of shielding (i.e. the shielding factor) will depend on the type of structure. In general, based on a review of the available literature, it is estimated that heavily constructed buildings made of brick or concrete will provide a shielding factor of about 0.2 ± 20% (1 s,d,) while lightly constructed buildings will provide a shielding factor of about 0.4. ± 20% (NCRP, 1999). These estimates are fairly conservative and allow for a small amount of radioactivity that may be tracked into the home from contamination of shoes, etc. Assuming that on average most persons spend about 80% of their time indoors (UNSCEAR, 1993; NCRP, 1999) with an average shielding factor of 0.3, their whole body effective dose would be 0.66 * (0.2 + 0.8 * 0.3) = 0.29 x Outdoor exposure. However, the UNSCEAR estimated that persons who work outdoor spend on average only 40% of their time indoors and the most exposed outdoor worker spends only about 30% of his/her time indoors. The NRC (1977) made a similar estimate of 40% of time spent indoors for the maximum exposed individual. Assuming only 30% indoors in a lightly shielded structure for the maximum exposed outdoor worker, the dose to the most exposed individuals would be
0.66 * (0.7 + 0.3 * 0.4) = 0.54 x Outdoor exposure or almost twice that of the average exposure. Conversely, the UNSCEAR (1993) estimated indoor workers spend only about 10% of their time outdoors while other estimates indicate some individuals spend even less time outdoors. Assuming 5% as a reasonable estimate for the least exposed individual living in a well shielded house and/or working in a well-shielded building, the minimum exposed individual would receive a dose of about 0.66 * (0.05 + 0.95 * 0.2) = 0.16 x outdoor exposure, or about ½ that of the average dose.

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

Note that no additional uncertainty has been incorporated in the dose estimates in this report above that for the uncertainty in the underlying deposition density estimates that were used to estimate exposure. However, using a S.D of ± 20% for the shielding factors, ± 0.05 for the conversion from rad to rem and 0.8 ± 0.05 for the fraction of time spent indoors by an average individual implies that the uncertainty (one S.D.) in the average conversion from exposure to dose of 0.3 is about 0.04, or about 10%. Even for the sum over all tests, the uncertainty (GSD) in the outdoor exposure in a given county averages about 1.3 (GSD). Thus, this additional uncertainty in converting to dose can be ignored provided one adjusts their individual dose estimate for time spent outdoors on average, particularly during the first few weeks after each test.

Beta Skin Dose

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

Besides the beta radiation itself, the beta rays produce a small amount of gamma radiation via bremsstrahlung (Eckerman and Ryman,1993). This gamma radiation, although only a small fraction of the energy of the beta ray itself, can produce a small whole body exposure and add to skin dose. Furthermore, it is generally the only way a beta emitter can irradiate body organs other than the skin. In order to account for both beta radiation itself as well as the accompanying bremsstrahlung, we have used the dose factors calculated by Eckerman and Ryman (1993) to estimate doses to skin for the deposition densities of the various fission products reported in Hicks (1991). Unfortunately, however, Eckerman and Ryman (1993) do not separate out beta and gamma dose contributions in their tabulated results and also did not calculate values for exponentially decreasing concentrations in soil. Thus the beta dose for beta-gamma emitters for a 1 cm slab source was inferred by plotting their doses for pure beta emitters versus their total energy of emitted betas and using this curve to estimate the beta doses from beta-gamma emitters. The dose for a source with a 0.1-cm relaxation length, corresponding to the distribution used for gamma rays for the first 20 days, was then estimated. For this estimate, it was assumed that all the activity is contained in a 0.144 cm thick slab, corresponding to the mean depth of a 0.1 cm relaxation length exponential distribution and that any activity from depths greater than that would not contribute significantly due to attenuation. Thus the skin dose values from Eckerman and Ryman (1993) for a 1 cm slab with 1 Bq/cm^3 were multiplied by a factor of 5.3 to correspond to the concentration in a 0.144 cm slab for a deposition density of 1 nCi/m^2 with a 0.1 cm relaxation length.

The beta skin dose from fallout distributed with a 0.1 cm relaxation length was then calculated to be about 25-50% of that from a plane source on the soil surface, depending on the age of the fallout. The early fallout contains a greater fraction of higher energy beta rays and thus the attenuation in soil is lower. The results of these calculations are presented in the next section and compared to the gamma ray exposure results.

Results

Fallout Deposition

The total deposition density of Cs-137 from all NTS tests examined through 1962 is shown in Figure 1. The pattern of deposition is similar to that for I-131, shown in Figure 2 (from NCI, 1997) although, due to its long-half life, the drop off in activity in the eastern U.S. is less than that for I-131. Deposition densities range from less than 5 mCI/km^2 in the western and northwestern states to over 20 near the NTS. As for the I-131 deposition, the regional and local variations are due to variations in precipitation, which is the main fallout mechanism at distances remote from the test site. The well-documented elevated region in northern New York state was due to heavy thunderstorm activity during passage of the cloud from shot SIMON in April, 1953 (NCI, 1997; Beck et al., 1990). The deposition density patterns for most of the other radionuclides covered in this report were in general intermediate to the patterns for Cs and I, with any differences reflected by the differences in respective half-lives.

The deposition density data for each test for all covered nuclides is contained in the database accompanying this report. However, the patterns for Sr-90 and Pu-239+240 vary somewhat from those for Cs-137 and I-131due to the differences in Sr and Pu production as a function of the device fuel. Figure 3 shows the ratio of total Cs-137 to total Sr-90..Figure 4 is for the ratio of Cs-137 to Pu-239+240. Note that the Cs to Sr ratio varies from about 0.8 to 1.9 with relatively low Sr deposition in Idaho, western Montana, western Nevada and the S.E. states and relatively higher Sr deposition relative to Cs in areas of the Midwest. The differences, of course, reflect the fact that the fallout in different regions resulted from different test(s). The Cs/Pu ratios, shown in Figure 3 vary from 3 to over 50. The highest relative Pu deposition was in counties near the NTS. However, areas in the mountain states, eastern NM and the Midwest exhibited generally low relative Pu deposition. For most of the country, the Cs to Pu activity ratio was about 10-20. As discussed previously, the Pu estimates in this report for any particular county are very uncertain and should be viewed only as illustrative of the variations across the country due to the varying tracks of Pu-fueled tests versus U-235-fueled tests. The number of counties within each range is shown in parenthesis in the figure captions.

Figure 5 shows the fraction of the total Cs-137 deposition in the continental U.S. resulting from each test series. The 1957 Plumbbob series deposited 35% of the total Cs followed by the 1953 Upshot Knothole series (23%). Of course the fraction of the total deposition in a particular year for any particular county will differ from this distribution due to the varying fallout tracks during different years. (The maps shown later of external exposure versus year reflect the relative annual depositions of fission products in each area). The ten tests depositing the most Cs in the continental U.S. are shown in Figure 6, while figure 7 shows comparable data for the population-weighted deposition density.

Two tests from the 1953 UPSHOT-KNOTHOLE series deposited the most Cs-137 (SIMON and HARRY). HARRY also deposited the most I-131 (NCI, 1997).. The comparable plot for the tests resulting in the highest population-weighted deposition density differs somewhat from the total deposition. Foe example, HARRY's impact on a population-weighted basis was much less than for total deposition, reflecting the fact that the fallout tracks and deposition patterns for each test differed, sometimes significantly (NCI, 1997; Beck et al., 1990)..

The total amount of Cs-137 deposited in the continental U.S. from all tests was 62500 Ci. The total deposition for a number of other selected radionuclides is shown in Table 6

The total deposition density was calculated for several r radionuclides in order to compare with the deposition from "global" fallout as reported by UNSCEAR (1993). For this purpose, the calculated values for each county were weighted by population and then summed. Because of the sharp gradations in deposition from west to east, and the higher populations in the eastern U.S., these population-weighted values are slightly less than the mean unweighted deposition obtained by dividing the total deposition by the total area of the continental U.S. However, they are a fairer indicator of the impact the deposition had with respect to both external and internal population doses. The resulting population-weighted deposition densities for the U.S. are given in Table 6 and compared with corresponding estimates by UNSCEAR for the 40-50 degree latitude band of the northern hemisphere

Table 6: Total deposition and population-weighted mean deposition density of selected radionuclides for NTS fallout and "global" fallout.

Nuclide	**Total Deposition** (kCi)	**Population weighted Deposition density** (nCi m^2)	
	NTS	NTS	"global fallout"**
Cs-137	62.5	6.9	140
Sr-90	49.2	5.3	87
Zr-95	5900	680	1030
Ru-103	11500	1240	760
Ba-140	37600	3900	620
Ce-141	13500	1460	570
Ce-144	1070	123	1300
Ru-106	635	71	650
Sr-89	9000	980	540
I-131	40100	5200	513
Pu-239+240	3.6#	~0.42	1.6
Pu-241	14.6	~1.6	20

**for 40-50 degree latitude band, # About 5% of total is from the decay of Np-239.

Thus for the long-lived radionuclides, NTS fallout contributed only about 5% of the total deposition. The deposition of short-lived radionuclides such as Sr-89, Ba-140 and I-131 was several times that of "global" fallout. These results are consistent with the fact that although the total fission yield of NTS tests was only about 1 MT, compared to about 150 MT for tests outside the U.S., most of the debris from the large thermonuclear tests outside the U.S. was injected into the stratosphere. According to the UNSCEAR (1993) the average residence time for this stratospheric debris before re-entering the troposphere and depositing is about 1 y. This delay in fallout coupled with a more uniform deposition over the entire globe accounts for the reduced impact of global fallout and in particular the very much-reduced short-lived activity relative to the amounts produced.

Another factor contributing to the greater deposition per unit yield in the continental U.S. of NTS tests is the fact that tests detonated near the ground, either on the surface or from relatively low towers, deposit a large fraction of their debris locally and regionally compared to tests detonated higher in the atmosphere. Figure 8 compares the cumulative Cs-137 deposition versus distance from the NTS as a fraction of that produced for various types of tests. Figure 9 compares the deposition as a fraction of the total deposited in the U.S. From figure 8, one sees that less than 10% of the activity produced in an air burst deposits within 4400 km (or within the continental U.S.) compared to about 45% for tower and surface shots. Balloon-borne devices deposited 30% in the U.S., less than tower shots but much more than air bursts. (The height of detonation for balloon shots was generally on the order of 500 m compared to ~100-200 m for tower shots (Beck, 1984)). For all NTS tests, 34% of the Cs-137 produced deposited in the continental U.S. In terms of the total deposited in the U.S., all types of tests deposited the same approximate fraction of their total U.S. deposition at distances greater than 2000 km. However, tower shots, as expected, deposited a greater fraction very close to the NTS, while air bursts seemed to deposit a greater fraction from 1500-2500 km.

Overall, air bursts deposited only about 8% of the total activity produced within the continental U.S., consistent with the UNSCEAR estimate of an average tropospheric residence time of 30 d. assuming a cross-country transit time of about 4 d on average.

The estimates of total deposition and fractional deposition discussed above of course rely upon the accuracy of the underlying I-131 deposition densities calculated by interpolating a relatively small number of gummed film measurements and weighting interpolated values by measured precipitation (NCI, 1997). However, most of the random uncertainty in total deposition is averaged out when summing over a large number of tests, days per test, and counties. The calculated propagated uncertainty in total deposition is less than 5% (GSD < 1.05). This assumes of course that there is no large systematic error and that the daily deposition estimates are not correlated. The values for a particular day are correlated with values for nearby counties since that is the basis of the kriging method used (see NCI, 1997), however, results from one day to another and one test to another should not be correlated.

Exposure and Dose

The geographical distribution of total whole-body effective dose from all NTS tests for a typically exposed individual (80% indoors, 0.3 shielding factor) is shown in Figure 10. The specific mean and GM free-in-air exposures for each county for each test, year, and total NTS are included in the database that accompanies this report. The interested reader can estimate his/her exposure and dose by multiplying by the appropriate indoor/outdoor and shielding factor correction factor as discussed in the previous section. As expected, the dose pattern is similar to the I-131 deposition pattern presented in NCI (1997) since the exposure rate is closely related to the deposition of short-lived radionuclides. The most exposed were individuals who lived in states immediately downwind from the NTS. However, pockets of higher and lower exposures occurred throughout the U.S. as a result of the uneven deposition of fallout and the variation in tracks of the many tests that contributed. The geographical distribution of doses varied significantly from year to year as shown in Figures 11-16. As can be seen the 1952 TUMBLER-SNAPPER series impacted areas to the north of the NTS more than did the tests in other years, while the fallout from the 1955 TEAPOT series was concentrated in the center of the U.S. The 1957 Plumbbob series accounted for much of the exposure to residents of ND, MN and surrounding areas.

The relative impact of various test series was investigated by calculating the population exposure, i.e. the product of the exposure for a given county multiplied by its population, and then summing over all counties. The population exposure versus year of exposure is given in Table 7.

Table 7: Population exposure and per capita exposure versus year of exposure

Year	**Annual**	**50 y Committed**	**per capita**
	-------10^6 person-R----------		mR
1951	2180	2250	13
1952	5040	5310	31
1953	6320	6630	39
1954*	56		0.34
1955	3930	4170	24
1956*	37		0.23
1957	6730	7530	41
1958*	275		1.7
1962	1570	1640	9.7
Total NTS	26400	27900	162 (49 mrem), 171 committed

*From previous years fallout.

The uncertainty in the above calculated population exposures was less than 1.1 (GSD) for all years except 1951 and 1962. The GSD for 1951 was 1.2 due to the large uncertainty in the I-131 deposition density estimates for some of the early Ranger series tests. The GSD for the 1962 fallout which was due mainly to the SEDAN cratering shot is very large, 1.8, again due to very uncertain estimates of I-131 deposition. The population exposure for each year includes that from fallout in that year plus from fallout in the previous year, if any. The per capita exposure of 162 mR corresponds to an average whole body effective dose of about 0.5 mSv (50 mrem), for the years of testing, about what an average person would receive from natural background radiation in 1-2 years depending on the area of the country. Residents of some counties near the NTS received doses in excess of 3 mSv (300 mrem) while residents of the extreme western and northwestern states and some Midwestern counties received average doses less than 0.25 mSv (25 mrem). The committed (50 y) dose from all NTS tests is about 5 % higher than the dose received during the testing years. In contrast, the UNSCEAR, 1993, has estimated the population-weighted per capita dose from external radiation from "global" fallout in the latitude band 40-50 degrees to be about 1 mSv. Twenty-five tests accounted for over 80% of the population exposure but no single test accounted for greater than 7%. The ten top contributors that account for about 50% of the population exposure are shown in Figure 17. Again, the impact of the SEDAN shot is very uncertain (GSD = 1.8) while the GSD of the population exposures for the other 9 tests are all in the range 1.1-1.3.

A large number of fission products are produced in a nuclear explosion. However, only a relatively few account for most of the external exposure. Different radionuclides contribute significantly to the exposure rate at different times and thus the most important radionuclides with respect to total exposure depends on the time of arrival of the fallout. Table 8 shows the largest contributors to total integrated exposure (% of total integrated exposure from nuclide and decay products) for several different times of fallout arrival. The data are for shot HARRY but vary only slightly from shot to shot with volatile nuclide contribution being greater for tower and surface shots as opposed to air bursts. However, as shown earlier, the surface and tower shots account for most of the radiation exposure to the population of the continental U.S. As can be seen, at early arrival times the short-lived iodine isotopes contribute relatively more to the exposure while after a few days, I-132, Ba-140, Zr-Nb-95 and Ru-103 dominate. I-132 is a major contributor even for later arrival times. Note that by contrast, most of the external dose from "global" fallout was due to the longer-lived nuclides, with Cs-137 accounting for about 50% of the exposure and Ru-103, Ru-106, Ce-Pr-144 and Zr-Nb-95 most of the remainder (UNSCEAR, 1993). In contrast, these nuclides contribute only small amounts to the integral dose from NTS fallout.

Figures 18-22 show the fraction of the total dose from all NTS tests that resulted from Te-I-132, Ba-La-140, Zr-Nb-95, Np-239, and Ru-103, respectively. Note that as expected from the dependence on arrival time shown in Table 8, the shorter-lived nuclides such as Np-239 (2.4 d) have a larger impact close to the NTS while the relative contribution of nuclides with relatively long half lifes such as Zr-95 (64 d) is much greater at large distances from the NTS. Because of this strong dependence on time of fallout arrival, the radionulide composition accounting for the total exposure varies significantly with distance from the NTS.

Table 8: Percentage of total integral exposure contributed by various fission products as a function of fallout arrival time

TOA= **Nuclide**	**0.5 d** **(%)**	**2.5d** **(%)**	**5d** **(%)**
Te-I-132	23	27	20
Ba-La-140	21	35	43
I-133	13	3	<1
Np-239	6	6	4
Zr-Nb-95	6	10	14
Zr-Nb-97, 97m	6	1	<1
I-135	5	<1	<1
Ru-103	3	6	7
I-131	3	4	4

The doses discussed above are from gamma irradiation. Table 9 presents the estimates of the ratio of beta skin dose to whole body gamma dose outdoors for shot HARRY as a function of time of arrival of fallout. This ratio is about 2 for fallout shortly after the test but falls to about 1.0 after a few days. The ratio of dose rates is about 5 at early times and falls to about 1 at about 5d. Note that it has been assumed that the beta dose can be neglected after 20 days. The activity is then assumed to be distributed with a relaxation length of 1 cm, deep enough to reduce the beta-ray flux to a negligible level. The beta dose estimates determined here are in reasonable agreement with previous. For example the ICRU (1977) estimated the beta skin dose rate from a plane source of fission products to be about 8-16 time the total effective dose. The ratio of dose rates for a 0.1 cm relaxation length for early arrival times is about 3-5 from Table 9. Dose rate ratios calculated for a plane source for the same beta spectrum (HARRY) ranged from about 7-11 over the first 2-3 days, with the higher value, that likely corresponds better to the beta ray spectrum assumed by the ICRU, corresponding to earlier arrival times. Only a relatively few nuclides emitting higher energy beta rays contribute significantly to the dose: Rb-88, Sr-91, Y-92, Y-93, Sb-128, Te-129, I-132. I-133, I-135, Ce-143, and Pr-145. The relative contributions of each to the total dose depended on fallout time-of – arrival

The actual impact of beta exposure is of course even less than the ratios in Table 9. The average individual would be exposed to beta radiation only for the 20% of time spent outdoors, resulting in an actual beta skin dose to gamma whole body dose ratio of about 0.2-0.4. Furthermore, since the radio-sensitivity of the skin is generally accepted to be much lower than for other organs, even the beta dose to the most exposed individuals who spend up to 70% of their time outdoors can be considered insignificant compared to their whole-body gamma exposure.

Two sources of beta radiation exposure might be significant in some cases. One, the direct deposition of radioactivity onto the skin during cloud passage. The second, contamination to the skin from children playing in contaminated soil, both from soil adhering to the skin as well as due to a closer proximity to the source. The former case is only of significance to individuals living close to the test site and was considered by Henderson and Smale (1990), in the ORERP study. Neglecting the dose from soil adhering to the skin, the dose to a child playing on the ground would probably be about a factor of two higher than that to a standing adult due to the closer proximity to the source plane. However, this would still probably not constitute a significant exposure. A more significant exposure route would likely be direct ingestion of soil (NCRP, 1999).

Table 9: Beta ray skin dose divided by whole body gamma dose as a function of fallout time of arrival-shot HARRY

Time of arrival, d	dose rate ratio	integrated dose ratio*
0.5	4.8	1.9
1.5	3.0	1.3
2.5	1.5	1.1
5.5	1.1	0.8
10.0	0.7	0.4

*100% outdoors

Summary and Conclusions

Fallout from atmospheric tests at the NTS resulted in an average external radiation exposure of about 0.5 mSv to the population of the U.S., about ½ that incurred from “global” fallout from the large scale testing outside the U.S. However, residents in the states immediately downwind from the NTS received much higher exposures while the exposures in the western and northwestern U.S. and some areas of the Midwest and SE were much less than the average. Most of this exposure occurred with the first 3 weeks of each test and was due to relatively short-lived radionuclides. In contrast, the exposure from “global” fallout occurred over a much greater span of time (1952-62) and primarily from a few long-lived radionuclides. Thus the dose rate was more uniform with time. Almost the entire whole-body effective dose to the population was from gamma rays emitted by fission products deposited on the ground. The actual dose received by any individual depended on the fraction of time he/she spent outdoors 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. Beta radiation from fission products in the surface soil did result in additional dose to the skin when outdoors. However, this contribution was not large enough to be considered an important component of total fallout radiation exposure except perhaps for children who played in the soil for significant intervals of time.

The deposition of fission products contributed to internal radiation exposure via ingestion as well as external exposure. The deposition densities of all nuclides that could contribute significantly to ingestion doses were calculated for this study although the internal doses via ingestion will be treated in a separate report. It is noteworthy that the deposition of long-lived nuclides was much less than from global fallout, while the deposition of short-lived radionuclides was generally higher. About 1/3 of the fission products produced by the roughly 1 MT of NTS explosions was deposited within the continental U.S. Surface shots and shots conducted on towers produced much more fallout in the U.S. per unit yield than air bursts.

The annex to this report, in the form of Excel spreadsheet files, gives the calculated deposition densities of all the radionuclides considered for each test for each county of the U.S. The free-in-air exposure resulting from each test and test series is also tabulated for each county. By accessing the data for their particular county of residence for any given year(s) and applying the appropriate correction factor to convert from exposure to dose by adjusting for the actual fraction of time spent outdoors, the interested reader can estimate his/her whole body dose from NTS fallout.

Three appendices follow. Appendix 1 provides a detailed example of the calculation of deposition density and exposure for a representative county to illustrate the calculational procedure. The other two appendices are included to satisfy the scope of work given in the introduction of this report. The first is a bibliography of additional references on weapons testing in Nevada and Assessments thereof. The second discusses the need for declassification of documents that might improve our ability to assess the impact of fallout from weapons testing, both within the U.S. and outside the U.S., on the American population.

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Appendix 1: Example of Calculation Procedure

In this appendix the calculation of the deposition density of Ba-140 and of Cs-137 for a particular arbitrarily-chosen county, St. Louis (FIPS=29189), from shot HARRY, 5/19/53, is shown in detail. The calculation of the total external exposure for St. Louis County resulting from shot HARRY is also illustrated.

DEPOSITION DENSITY

All calculations start with the measured effective I-131 reported by the NCI (1997). These measured I-131 values (mCi/km^2) for St. Louis county for various days after the detonation (TOA) are shown in the second column of Table A1. As discussed in the text a TOA of 1.5 d refers to fallout on the second day after the detonation or in this case on 5/20/53, etc. The corresponding GSD reported in NCI (1997) is given in column 3. The effective I-131, denoted as I-131*, is just the measured value decayed back to H+12 h (column 5). The effective I-131 includes the contributions of I-131 that will subsequently grow in from Te-131 and Te-131m since these contributions are included in the reported measured I-131 (NCI, 1997).

In order to calculate the corresponding Ba-140 and Cs-137 for each day with I-131 deposition it is necessary to know the ratios of Ba-140/I-131* for each of these days. These values, from Hicks (1981) are given in columns 5 and 6, respectively. Note that the values in the Hicks Tables (Ci/km^2) for all nuclides are normalized to a unit exposure rate of 1 mR/h at H+12 h. In each case the value of Ba-140 or Cs-137 for the particular TOA was obtained from the Hicks (1981) Table for test HARRY and divided by the corresponding I-131* H+12 h value from Hicks for test HARRY,.819 mCi/km^2. The latter value was obtained from the tabulated values for test HARRY for I-131, Te-131, Te-131m at H+12 h (I-131* =[I-131 *193 h + Te-131m * 30 h + Te-131 * 0.417 h] / 193h) and represents the total I-131 at H+12h plus the I-131 that will subsequently grow in from Te-131 and Te-131m.

Table A1: Measured I-131 deposition density (mCi/km^2), ratios of Ba-140 and Cs-137 to I-131*, and calculated Ba-140 and Cs-137 deposition densities (mCi/km^2).

TOA, d	I-131	GSD	I-131*	Ba-140/I*	Ba-140	Cs-137/I*	Cs-137
0.25	0			0.85		0.00121	
0.5	0			0.83		0.00121	
1.5	20	2	21.8	0.78	17.0	0.00121	0.026
2.5	16	2	19.0	0.74	14.1	0.00121	0.023
3.5	50	2.5	64.8	0.70	45.3	0.00121	0.078
4.5	8	2	11.3	0.66	7.5	0.00121	0.014
5.5	16	1.5	24.6	0.63	15.5	0.00121	0.030
6.5	16	1.5	26.8	0.59	15.8	0.00121	0.032
7.5	0			0.57		0.00121	
8.5	0			0.54		0.00121	
9.5	0			0.51		0.00121	
10.5	0			0.48		0.00121	

Multiplying the Ba-140/I-131* and Cs-137/I-131* by the measured I-131* provides the estimated GM deposition densities of Ba-140 and Cs-137 for each day of fallout. Since the uncertainty in the Hicks (1981) ratios of deposition densities is assumed to be minor compared to the larger uncertainty in the measured deposition densities, the GSD for Ba-140 and Cs-137 are assumed to be the same as that for the corresponding measured I-131.

In order to calculate the total Ba-140 and Cs-137 deposition densities for this county from shot HARRY one must sum the daily values. However, one cannot sum GM values so one must first convert each daily GM to the corresponding mean. As discussed in NCI (1997), the conversion is given by mean, $m = GM * \exp (0.5 * s^{2)}$ where $s^2 = \ln (GSD)$. The corresponding variance, var $= m^2 = [\exp (s^2) -1]$. Table A2 gives the calculated means and variances for the days with fallout.

Table A2: mean and total deposition densities (mCi/km^2).

	Ba-140			Cs-137		
TOA	GM	mean	var	GM	mean	var
1.5	17.0	21.6	288.4	0.0264	0.0335	0.000694
2.5	14.1	17.9	197.4	0.0230	0.0292	0.000528
3.5	45.3	69.0	6258	0.0784	0.119	0.0187
4.5	7.45	9.48	55.4	0.0137	0.0174	0.000186
5.5	15.5	16.8	50.7	0.0298	0.0323	0.000187
6.5	15.8	17.2	52.8	0.0325	0.0353	0.000222
SUM:		152	6903		0.267	0.0205
GM =		134			0.235	
GSD =		1.7			1.7	

The mean of the total deposition density of Ba-140 is thus 152 mCi/km^2 with a variance of 6003. As discussed in NCI (1997), the sum of lognormally-distributed distributions can themselves be assumed to be approximately lognormally distributed with a GM given by GM = m / SQRT [1 + var / m^2] and a GSD given by GSD = exp [SQRT (ln {1 + var / m^2)}. Using these equations, the GM Ba-140 deposition density for this county for shot HARRY is thus 134 mCi/km^2 with a GSD of 1.7. The corresponding Cs-137 deposition density is 0.235 with a GSD of also 1.7.

In a similar manner the deposition densities resulting from all other tests conducted in 1953 were calculated and the total Ba-140 and Cs-137 deposition densities from all 1953 (UPSHOT-KNOTHOLE) tests obtained by summing the **means and variances** of the individual test results. To obtain the total deposition density from all NTS tests, the means and variances calculated for each test series were summed. These sums are provided in the database that accompanies this report along with the calculated conversions to GM and GSD for each test, test series, and NTS totals.

EXPOSURE

The calculation of free-in-air exposure again starts with the measured I-131* values and the I-131* value per mR/h at H+12 h (= 819 mCi/km^2) for HARRY given in Hicks (1981). The exposure rate at any time t is given by the deposition density at time t in mCi/km^2 multiplied by a dose rate conversion factor :R / h per mCi /km^2 taken from Beck (1980). As discussed in the text, these conversion factors are a function of the assumed depth distribution. For t < 20 d, a depth distribution with a relaxation length of 0.1 cm was assumed. This was the value used in Hicks (1981) for all times. For t > 20 d < 200 d, a relaxation length of 1 cm was assumed in this report, and for > 200 d, a relaxation length of 3 cm. The conversion factors for Ba-140, La-140 and Cs-137 for each relaxation length are given below:

Table A3: Conversion factors from deposition density to exposure rate, :R / h per mCi /km^2

Nuclide	RL =0.1 cm	RL- 1 cm	RL = 3 cm
Ba-140	2.41E-03	1.62E-03	1.10E-03
La-140	3.33E-02	2.28E-02	1.60E-02
Cs-137	9.28E-03	6.15E-03	4.32E-03

In order to calculate the total exposure rate as a function of time from TOA to the end of the year, and to 50 y after detonation for a particular test, it is necessary to sum the exposure rates per unit I-131* from each of a large number of radionuclides contributing to the total exposure rate at any particular time, multiply this total by the measured I-131* deposition density, and then integrate the total from all nuclides over the period of interest. For the first 20 d after detonation a very large number of nuclides contribute to the exposure rate (> 100). .Since Hicks already calculated the total exposure rate per unit I-131* for this period for a range of t, it was not necessary to attempt to recalculate and tabulate the individual radionuclide exposure rates for this period. They can be obtained directly from the Hicks (1981) tables if desired. The exposure rates versus time per unit I-

131* for the first 20 d as reported in Hicks (1981) for shot Harry are given below (The reported exposure rates have been normalized to unit deposition density of I-131* by dividing by 819.

Table A4: Exposure rate versus time of arrival for test HARRY per mCi /km^2 I-131*

TOA (h)	mR/h
18	7.84E-04
21	6.57E-04
24	5.54E-04
48	2.50E-04
120	9.83E-05
240	4.54E-05
480	1.81E-05

In order to calculate the total exposure from any particular time of arrival (TOA) to 20 d after detonation, the exposure rates in Table A4 were fit to a function of the form a t^{-b} for the period 12 h to 20 d (480 h). The results of this fit for test HARRY was a = 5.62E-04; b=-1.0958 with a correlation coefficient r^2 of 0.9995. The integral from any time TOA to 20 d is then $\int$a t^{-b} dt = [0.4602/ (0.0958)] [TOA$^{-0.0958}$ –20$^{-0.0958}$]. The resultant total integral exposure from TOA to 20 d for various TOA are given in the second column of Table A5 below. Note that this formulation actually assumes a 0.1 cm relaxation length for times TOA to 20 d rather than for a period totaling 20 d after deposition. This is reasonable, however. As the time of arrival of fallout increases due to increasing distance of the fallout cloud from the NTS, a greater fraction of the deposition is due to washout from precipitation (NCI, 1997). This wet deposition resulted in greater penetration into the soil than that from the dry deposition that occurred near the NTS at early arrival times.

The exposure rate from 20 d post detonation to 200 d could not be taken from the Hicks (1981) tables directly since we use an exposure rate conversion factor that assumes a 1 cm relaxation length. However, the number of radionuclides contributing significantly to the total exposure during this period is much smaller (about 24). It was thus possible to use the actual time variation of the deposition density for each of these radionuclides multiplied by the appropriate dose rate factor from Beck (1980) to calculate the integral exposure for each for the desired interval. For example: the exposure rate for Cs-137 for the period 20 d to 200 d is given by:

I (t) μR/d = Cs(20 d) mCi /km^2 * 6.15E-03 μR / h per mCi /km^2 * 24 h/d * exp(-λ * t),

where Cs(20 d) is the deposition density of Cs-137 (per unit I-131*) at 20 d after detonation, from Hicks (1981) and $\lambda = \ln(2) / T_{1/2}$.

The integral from 20 d to 200 d is thus:

I (mR) = Cs (20 d) * 6.15E-03 * 24 * 1/λ * [exp (- 20 * λ) –exp (-200 * λ)]/ 1000.

The half life of Cs-137 is 11000 d (Table 2). The exposure rates of the other radionuclides contributing to the exposure rate during this period were calculated in a similar manner. Note that for a few radionuclides that grow in from precursors (e.g. Nb-95 from Zr-95) the activity versus time is a function of the parent activity and the analytical relationship is sometimes more complicated than that for a single radionuclide. The daughter to parent activity for these nuclides is given by $D/P = 0\,(T_{1/2\ p})/(T_{1/2p} - T_{1/2\ d}) * [1 - \exp(-8_d - 8_p)\,t]$, where 0 is the number of daughter atoms produced per parent decay and the subscripts p and d stand for parent and daughter, respectively. This equation is easily integrated to provide the integral exposure of the daughter activity in a manner similar to that for the parent as described above. (If the daughter half life is short compared to that of the parent the activity of the daughter is approximately equal to that of the parent at all times, and the exposure rate is just the parent activity multiplied by the exposure rate conversion factor for the daughter).

Since HARRY was detonated on the 139th day of the year (May 23), there were 226 d remaining in the year 1953. The total exposure for the year from a deposit on day TOA was thus the sum of the exposures from TOA-20 d, 20-200d and 200-226 d. For the last 26 days, the calculation was similar to that for 20-200 d except that the integration was from 200 d to 226 d and the deposition densities from 200-226 d were multiplied by the exposure rate conversion factors for a 3 cm relaxation length, rather than for a 1 cm relaxation length. For the year 1954, and for the remainder of the 50 y period for which the exposure was calculated, only a few radionuclides contributed to the exposure. Again, the integrated doses were calculated individually for each as shown above for Cs-137, integrating over the appropriate time interval.

Table A5 gives the final integrated exposure for each of the time intervals of interest, TOA-20 d, 20-200 d, the entire year (1953), 1954, 1955 – 50 Y, and the total = TOA - 50 Y. By multiplying each of these normalized exposure values by the corresponding measured I-131* for each day with fallout (from Table A1), one obtains the mean and GM exposures for St. Louis County for test HARRY shown in Table A6, along with the corresponding variances and GSD's. Again, the means are calculated from the measured GM, as described previously for the deposition density calculations, and then summed to obtain the total exposure resulting from all days of fallout. The total exposure from all tests in the year 1953, and from all NTS tests, was calculated in a similar manner by summing the mean exposures from each test.

Table A5: Integral exposure from time of arrival to 20 d, 20 d to end of year, 1953, 1954, TOA-50 y, per unit I-131* deposition density (mR per mCi/km2)

TOA	TOA-20 d	20 d- 226 d	1953	1954	1955-50Y	TOA-50 Y
0.25	0.0551	0.008108	0.0632	0.000404	0.001255	0.0649
0.5	0.0448	0.008108	0.0529	0.000404	0.001255	0.0545
1.5	0.0297	0.008108	0.0379	0.000404	0.001255	0.0395
2.5	0.0233	0.008108	0.0314	0.000404	0.001255	0.0330
3.5	0.0192	0.008108	0.0273	0.000404	0.001255	0.0290
4.5	0.0162	0.008108	0.0243	0.000404	0.001255	0.0260
5.5	0.0139	0.008108	0.0220	0.000404	0.001255	0.0237
6.5	0.0120	0.008108	0.0201	0.000404	0.001255	0.0218
7.5	0.0104	0.008108	0.0185	0.000404	0.001255	0.0202
8.5	0.0090	0.008108	0.0171	0.000404	0.001255	0.0188
9.5	0.0078	0.008108	0.0159	0.000404	0.001255	0.0176
10.5	0.0067	0.008108	0.0148	0.000404	0.001255	0.0165

Table A6: Total exposure from HARRY for St. Louis County, mR

	--------------For 1953--------------			----------TOA - 50 Y -----------------		
TOA	GM	mean	var	GM	mean	var
1.5	0.83	1.05	0.68	0.86	1.10	0.74
2.5	0.60	0.76	0.36	0.63	0.80	0.39
3.5	1.77	2.69	9.52	1.88	2.85	10.71
4.5	0.27	0.35	0.08	0.29	0.37	0.09
5.5	0.54	0.59	0.06	0.58	0.63	0.07
6.5	0.54	0.59	0.06	0.58	0.63	0.07
SUM:		6.02	10.75		6.39	12.07
GM =		5.28			5.68	
GSD =		1.7			1.7	

Although the exposure contribution from each radionuclide was not estimated separately in the database accompanying this report, the exposure from all tests for a few specific radionuclides was calculated from the corresponding deposition densities and used to prepare the data shown in figures 18-22. These figures illustrate the fraction of the total exposure from these particular radionuclides. The mean deposition densities of each radionuclides for each test and test series is provided in the database and can be used to estimate exposures for a particular year from any particular radionuclide by multiplying by an appropriate dose rate conversion factor from Beck (1980).

Appendix 2: Additional Reading

(1) The history of nuclear weapons testing at the NTS:

Anders R.M., Holl, J.M., Buck, A.L. and Dean, P.C., The United States nuclear weapons program. A summary history. US Dept. of Energy rept. DOE/E5-0005 (draft), March, 1983.

Frieson, H.N. A perspective on atmospheric nuclear tests in Nevada. Nevada Operations Office rept. NVO-296; Aug. 1985.

Joint Committee on Atomic Energy . The nature of radioactive fallout and its effects on man, Congressional hearings transcript.; 1997.

Joint Committee on Atomic Energy. Fallout from nuclear weapons tests, Congressional Hearings transcript; May, 1959)

U.S. Dept. of Energy. Announced Unted States Nuclear Tests, July 1945 through December, 1987. Nevada Operations Office rept. NVO-209, Rev. 8; 1988.

(2) The production of important radionuclides during those tests:

Environmnetal Contamination from Weapons Tests. USAEC rept. HASL-42; 1958.

Hicks, H.G. Radiochemical data collected on events from which radioactivity escaped beyond the borders of the Nevada test range complex. Lawrence Livermore National Laboratory rept. UCRL-52934; Feb. 1981.

Radiological Health Data. U.S. dept of Health, Education and Welfare, Public Health Service. Monthly reports, 1958+

Public Health Service. Tabulation of findings, rdaiation surveilance network", available from CIC, Las Vegas.

Schoengold, C.R., DeMarre, M.E., McDowell, E.M., Radiological effluents released from announced U.S. continental tests: 1961 through 1988. U.S. Dept. of Energy Nevada Operations Office rept. DOE/NV-317; May, 1990.

USAEC, Health and Safety Laboratory Fallout Quarterly Reports, 1958-.

(3) The networks of fallout measurements:

Bouville, A. and Beck, H.L. The HASL gummed-film network and its use in the reconstruction of doses resulting from nuclear weapons tests. Environ. Intl; in press.

Eisenbud, M. An Environmental Odyssey. People, Pollution, and Politics in the Life of a Practical Scientist, University of Washington Press, Seattle and Washington, 1990.

Harley, John H., A Brief History of Long-Range Fallout, in Health and Safety Laboratory report HASL-306, Environmental Quarterly, July 1, 1976, pp I-3 to I-1

(4) The assessment of the activities deposited on the ground:

Bouville, A., M. Dreicer, H.L. Beck, W.H. Hoecker, and B.W. Wachholz. Models of radioiodine transport to populations within the continental U.S. Health Phys. **59**(5): 659-668; 1990.

Bouville, A. Reconstructing doses to downwinders from fallout. Proceedings of the Thirty-First Annual Meeting of the National Council on Radiation Protection and Measurements. Proceedings No. 17, pp. 171-189. NCRP, Bethesda, MD, 1996.

Whicker, F.W. Environmental pathway analysis in dose reconstruction. Proceedings of the Thirty-First Annual Meeting of the National Council on Radiation Protection and Measurements. Proceedings No. 17, pp. 93-106,. NCRP, Bethesda, MD, 1996.

(5) The vertical migration of fallout radionuclides into deeper layers of soil:

See references in text.

(6) The assessment of the doses from external irradiation:

Beck, H.L.; Krey, P.W. Radiation exposure in Utah from Nevada nuclear tests. Science **220**:18-24; 1983.

Lloyd, R.D.; Gren, D.C.; Simon, S.L.; Wrenn, M.E.; Hawthorne, H.A.; Lotz, T.M.; Stevens, W.; Till, J.E. Individual external exposures from Nevada Test Site fallout for Utah leukemia cases and controls. Health Phys. **59**(5):723-737; 1990.

Simon, S.L.; Till, J.E.; Lloyd, R.D.; Kerber, R.L.; Thomas, D.C.; Preston-Martin, S.; Lyon, J.L.; Stevens, W. The Utah leukemia case-control study: dosimetry methodology and results. Health Phys. **68**(4):460-471; 1995.

Haskell, E.H., I.K. Balliff, G.H. Kenner, P.L. Kaipa, and M.E. Wrenn. Thermoluminescent measurements of gamma-ray doses attributable to fallout from the Nevada Test Site using building bricks as natural dosimeters. Health Physics **66**, 380-391; 1994.

Appendix 3: Classified Data that could be of Use in Assessing Fallout Impact on U.S. Population

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

Also classified is the fraction of the total yield of individual shots that resulted from fission versus fusion. Again, this information will be needed to make reasonable estimates of deposition and resultant doses from tests held outside the U.S. In some cases, even the exact value of the total yield is classified. Since tritium is a byproduct of fusion, any information on the amount of tritium released from a particular test is probably also classified.

For the NTS tests, the efficiencies of fission are classified as well as any information that would allow one to infer those efficiencies, such as ratios of Cs-137/Pu activity. Thus the amounts of residual (unfissioned) Pu in the fallout had to be inferred as discussed in this report. The resultant crude estimates of Pu deposition thus have relatively large uncertainty compared to the deposition of fission products.

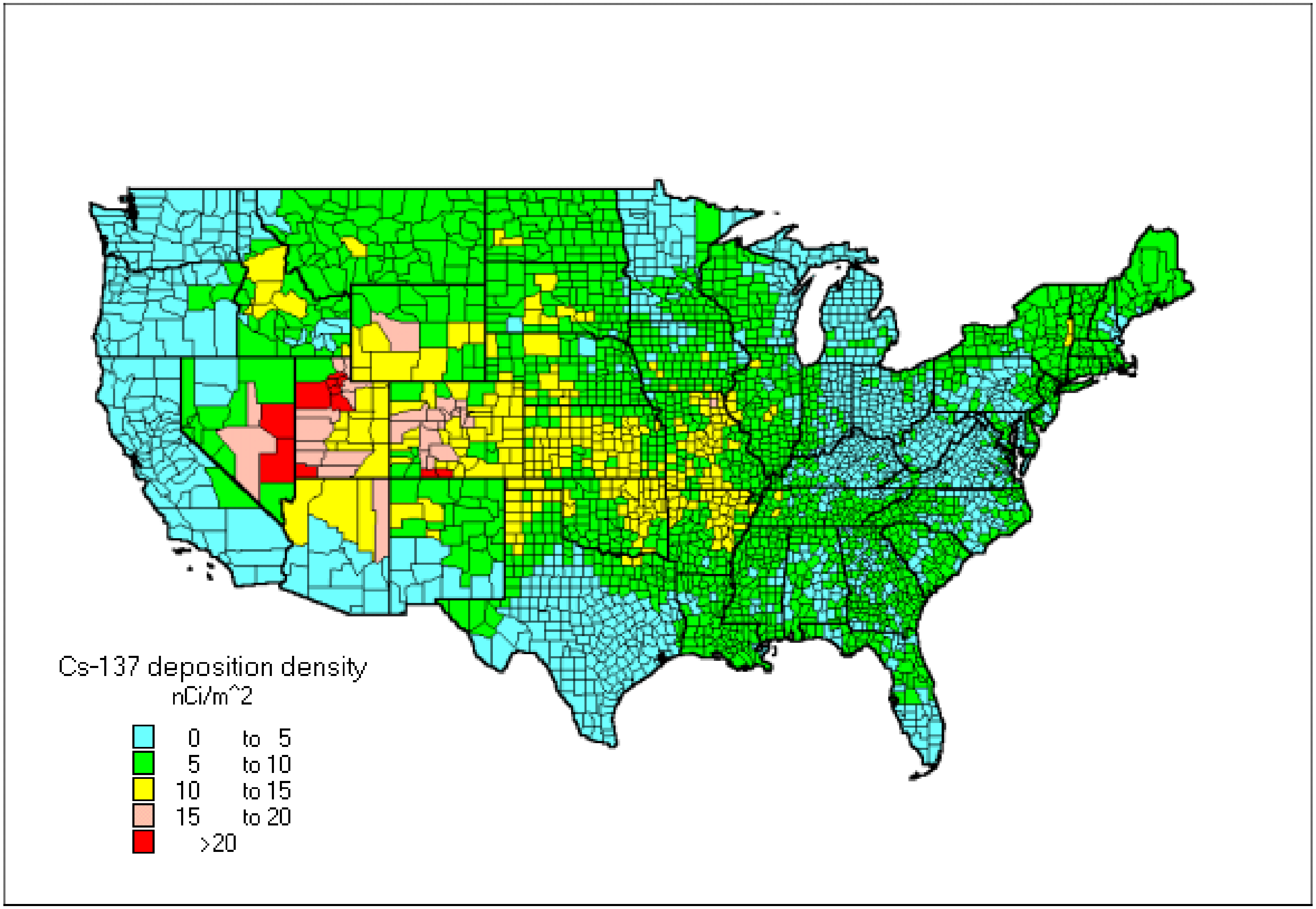

Figure 1. Cs-137 deposition density due to all NTS tests.

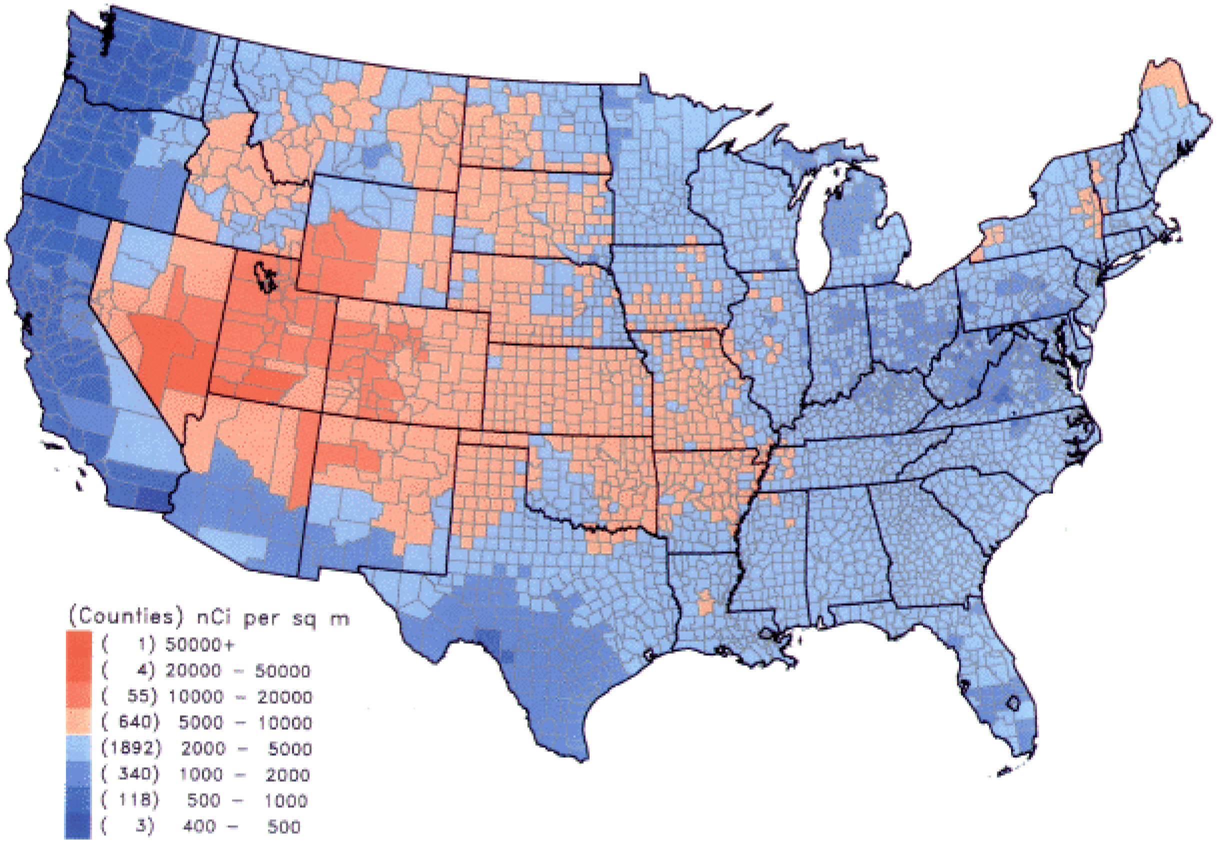

Figure 2. I-131 deposition density due to all NTS tests.

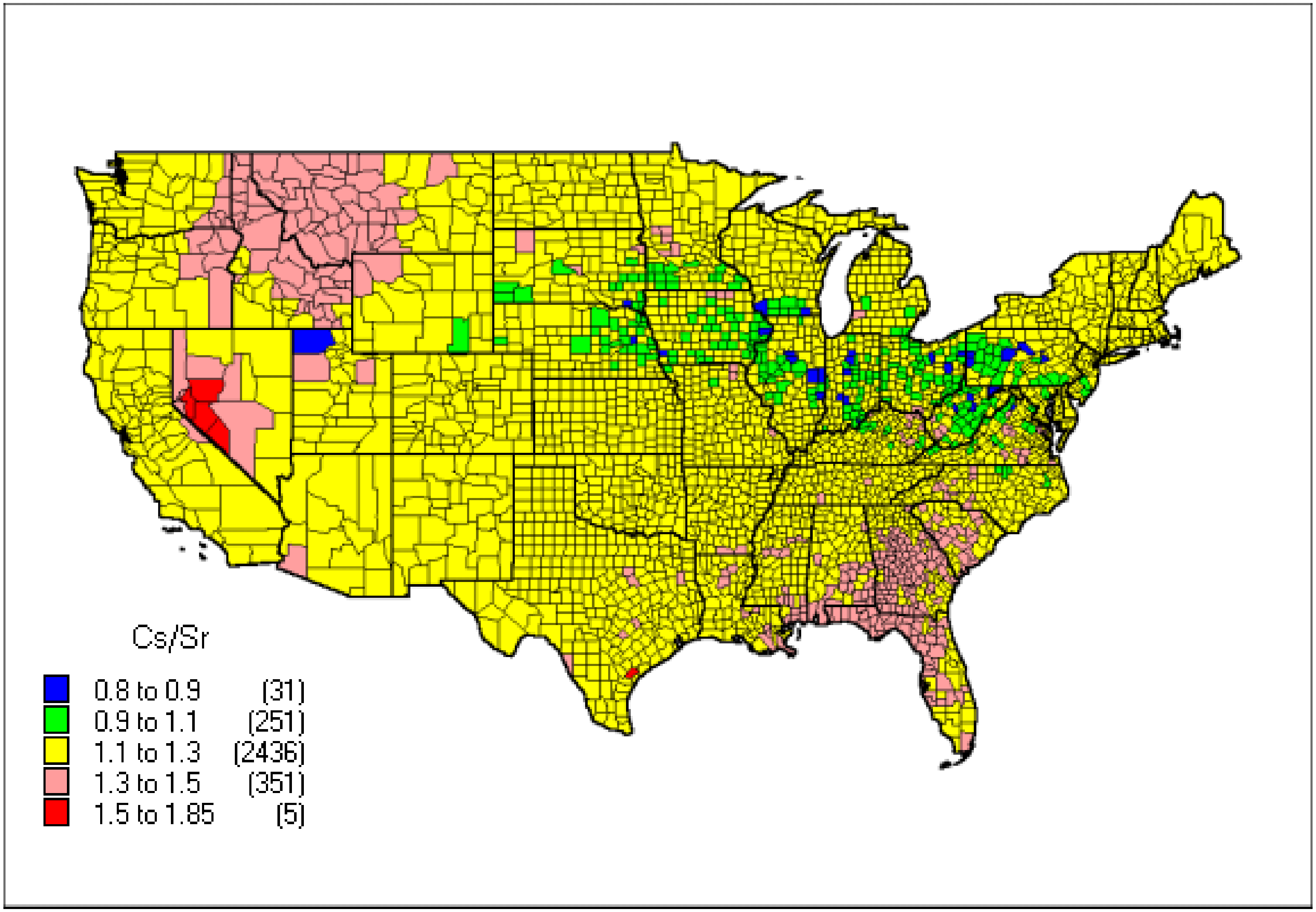

Figure 3. Ratio of Cs-137 to Sr-90 deposition density from all tests. Number of counties in each group shown in parenthesis.

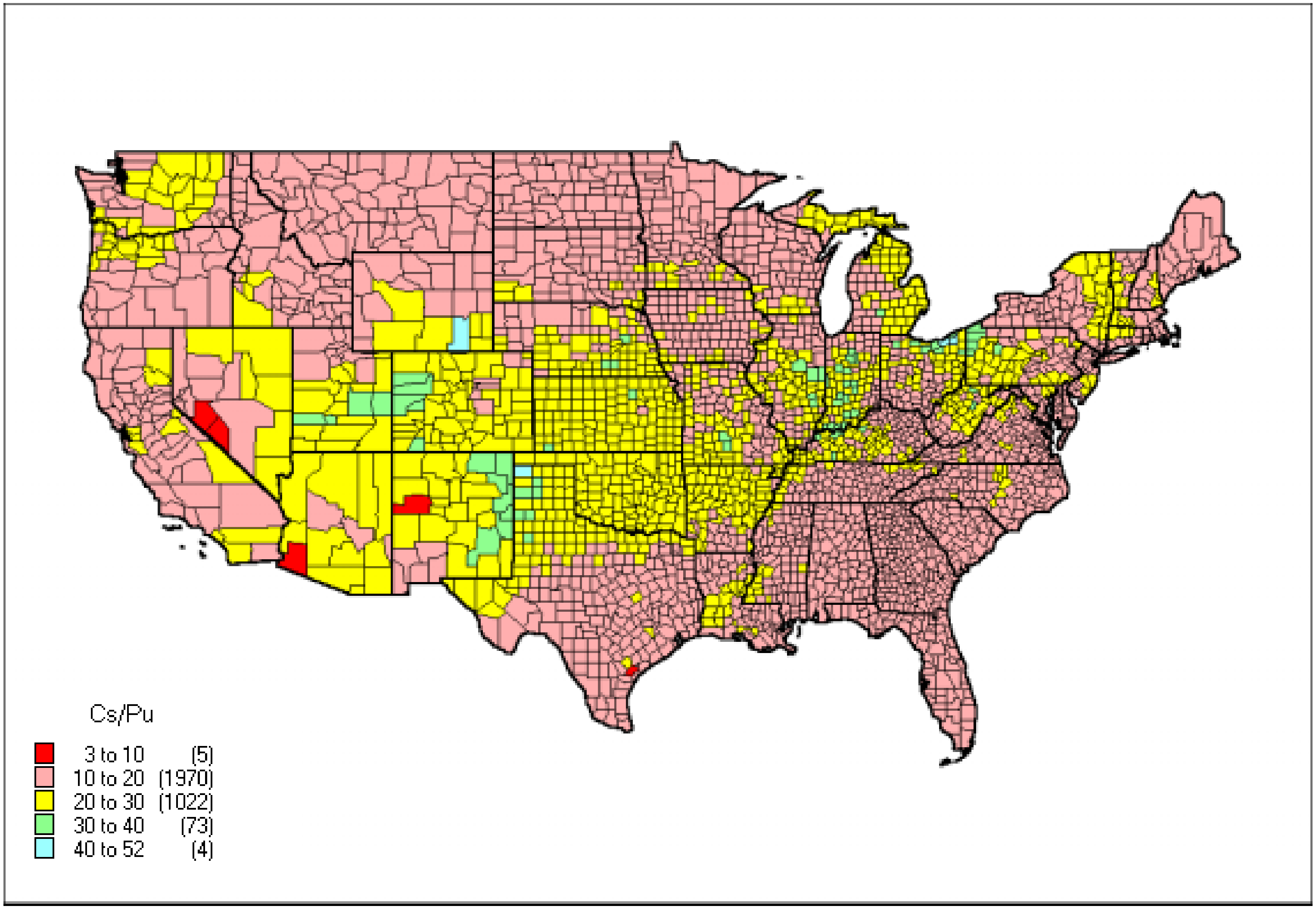

Figure 4. Estimated ratio of Cs-137 to Pu-239+249 deposition density. Number of counties in each group shown in parenthesis.

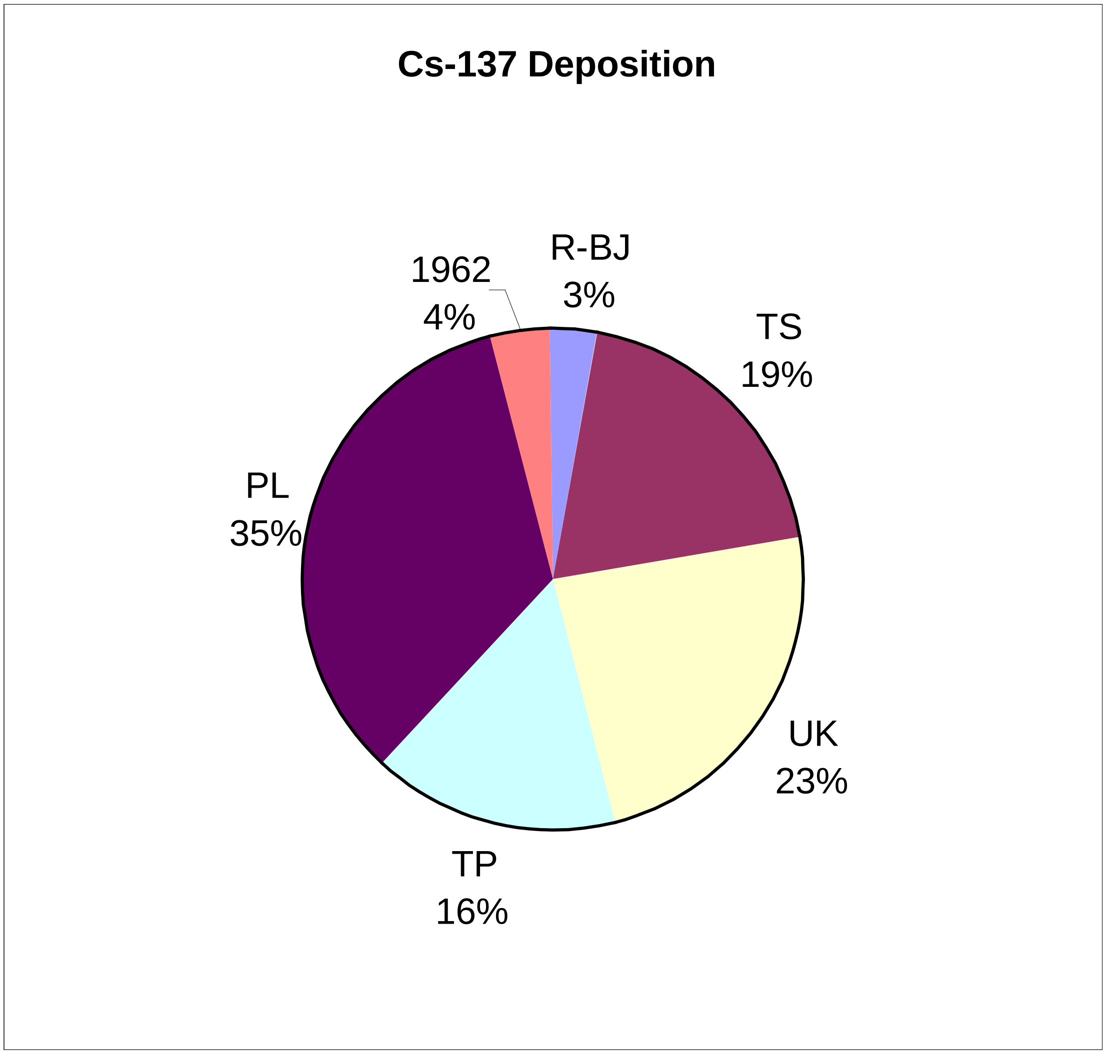

Figure 5: Fraction of total Cs-137 deposition from each test series.

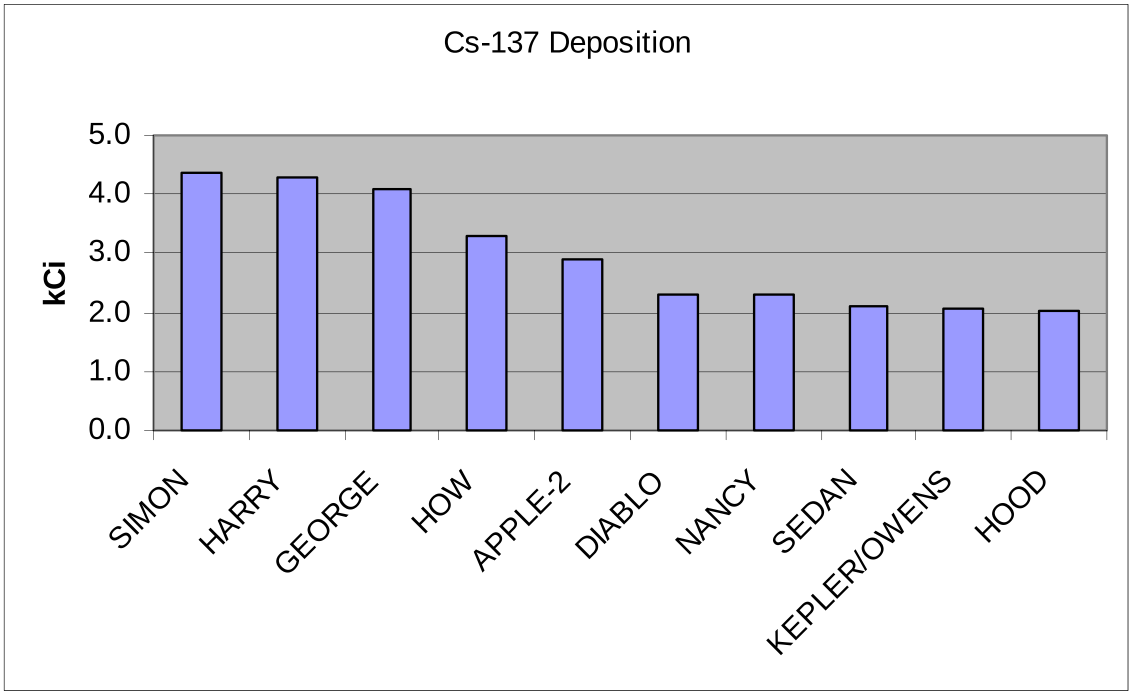

Figure 6: Ten tests depositing the greatest amounts of Cs-137 in the continental U.S

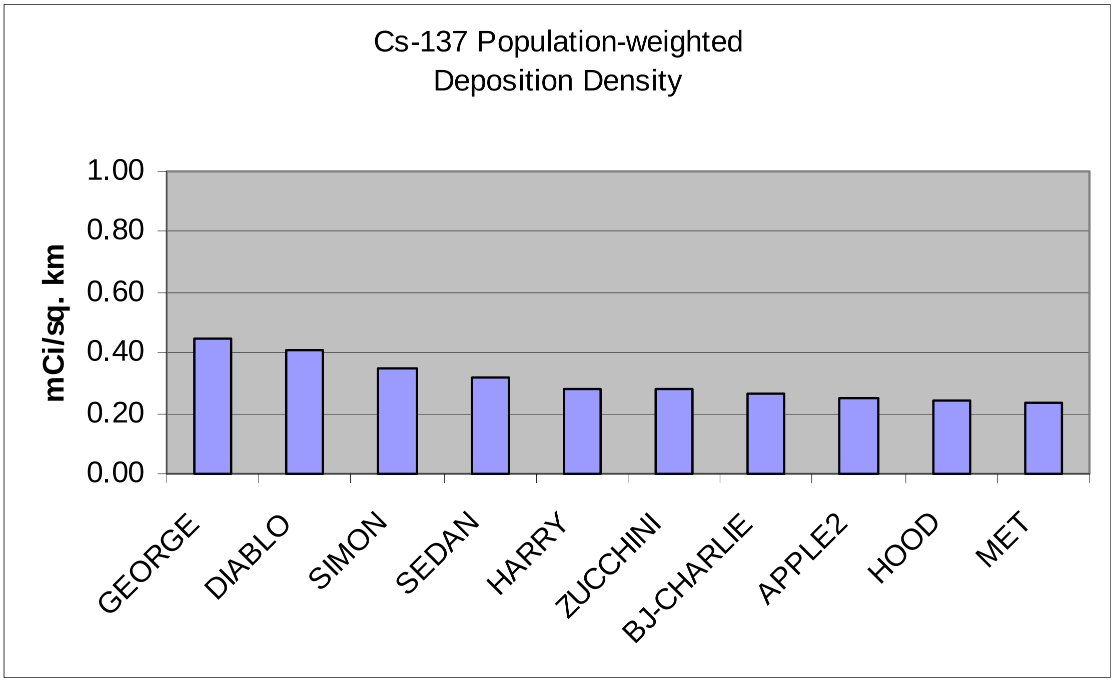

Figure 7: Ten tests producing the greatest population-weighted Cs-137 deposition density.

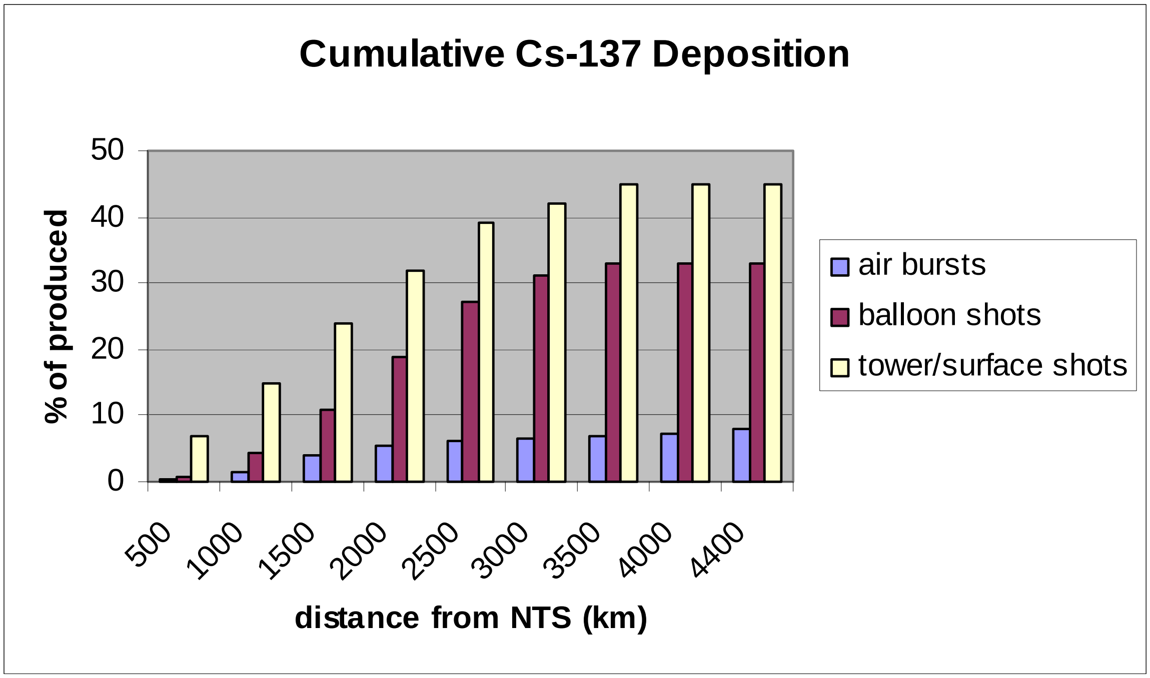

Figure 8. Cumulative Cs-137 deposition relative to total produced versus distance from the NTS

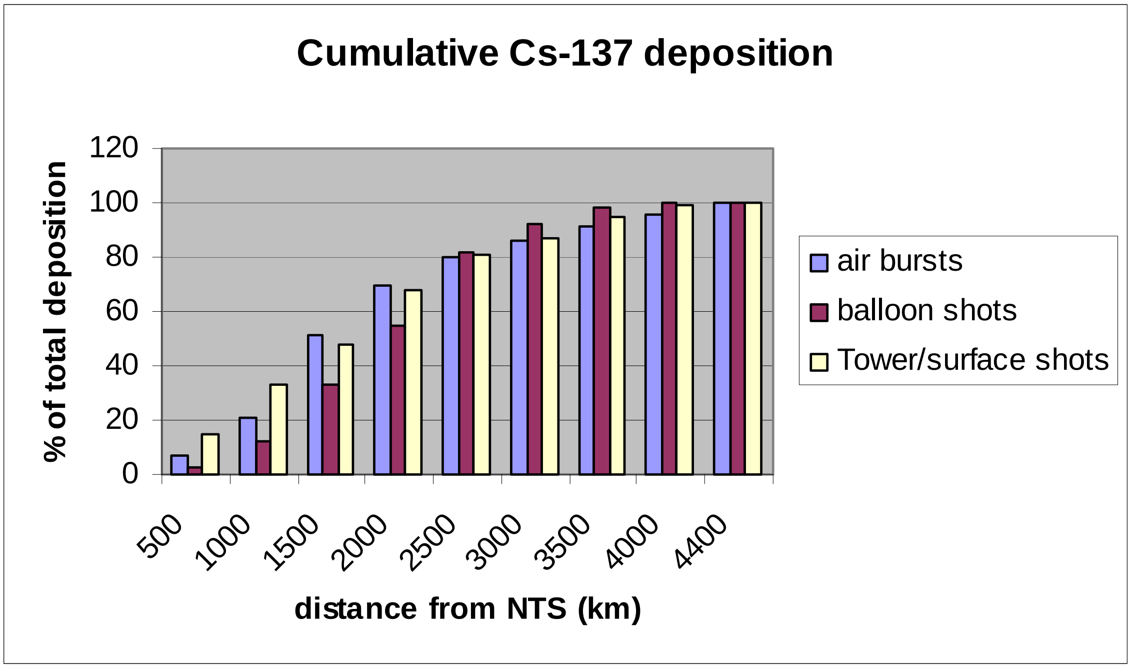

Figure 9: Cumulative Cs-137 deposition relative to total deposited in the U.S. versus distance from the NTS .

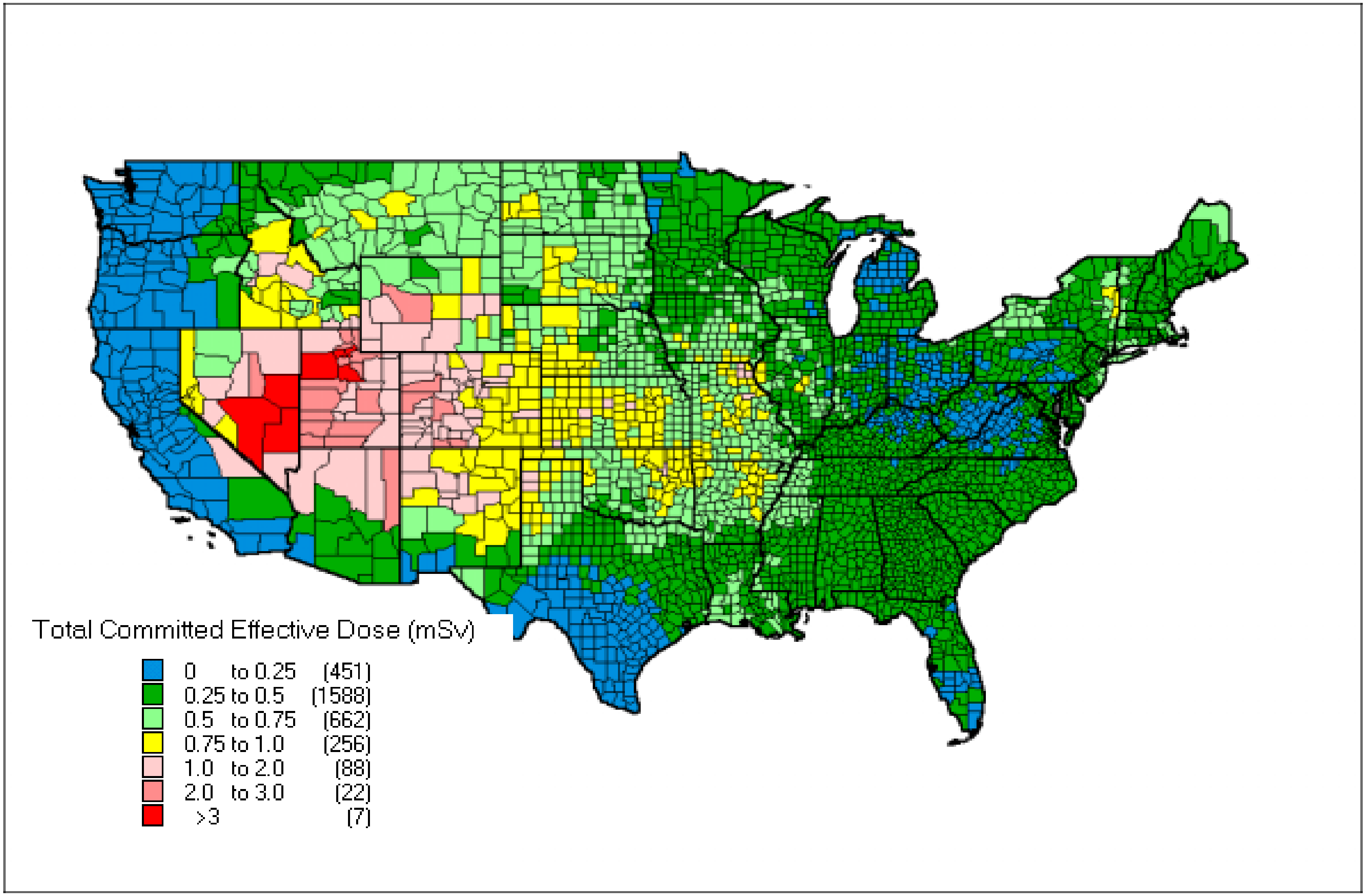

Figure 10: Total dose to average exposed individual from all tests. Number of counties in each group shown in parenthesis.

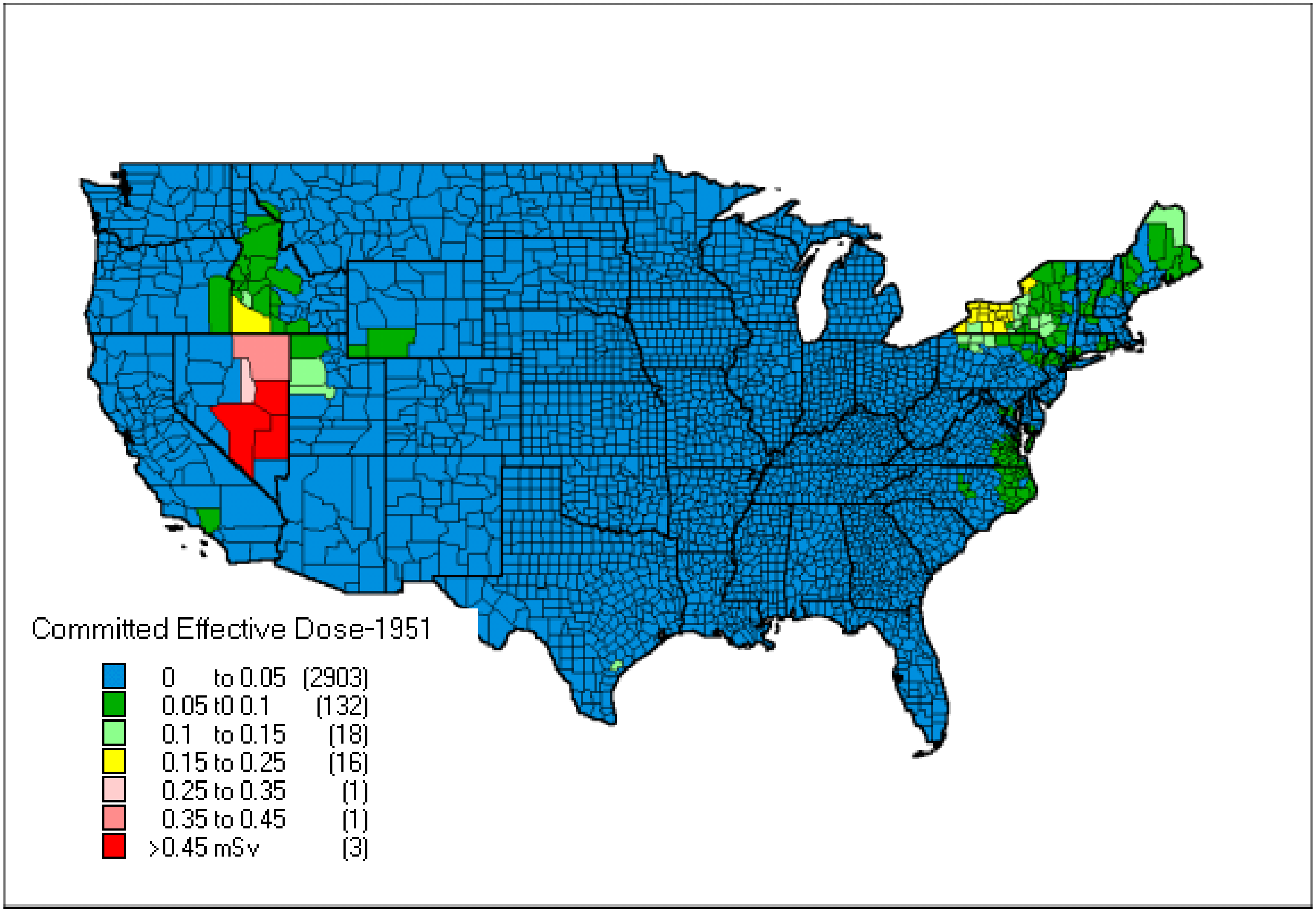

Figure 11. Dose to average exposed individual from tests in 1951. Number of counties in each group shown in parenthesis

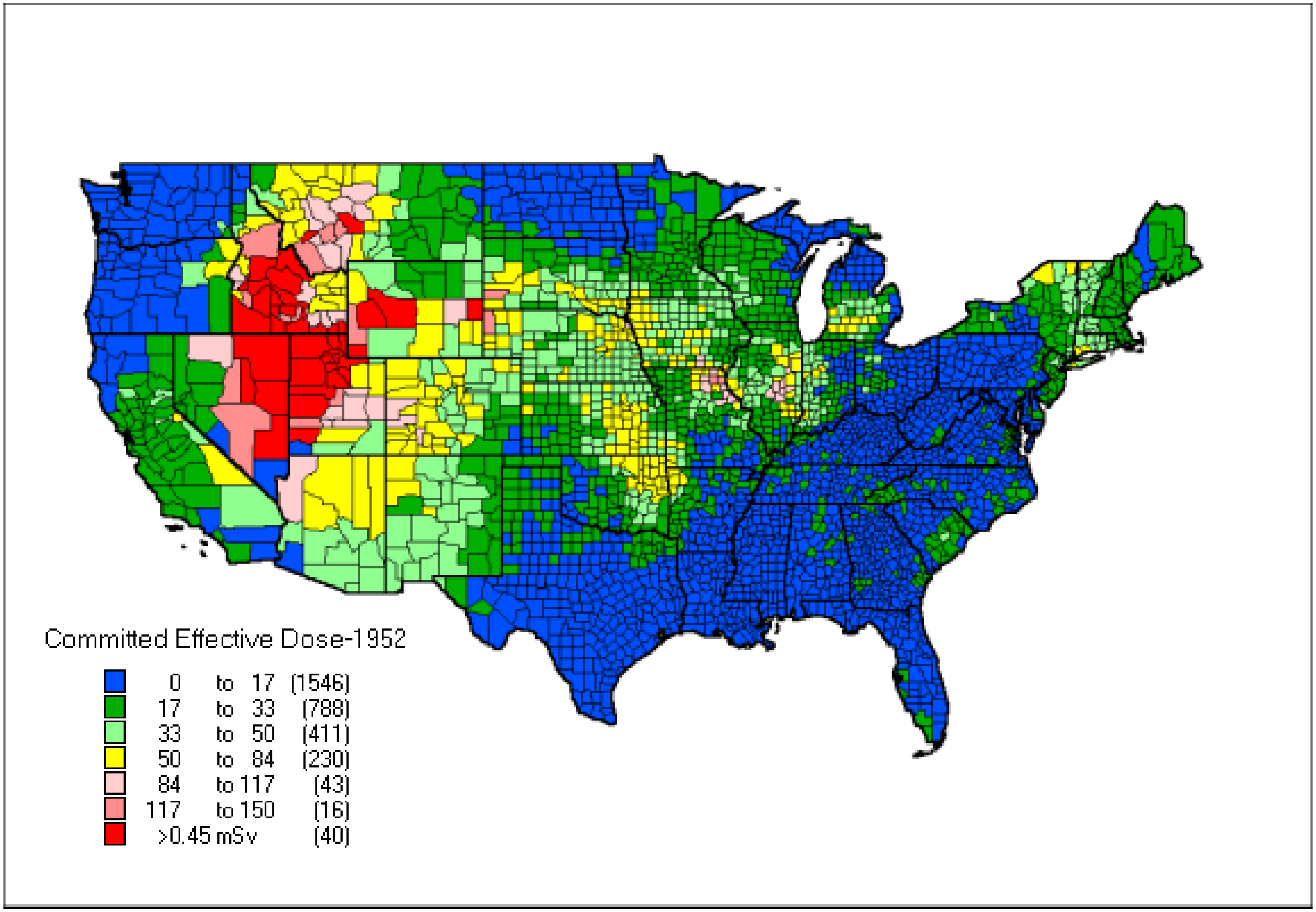

Figure 12. Dose to average exposed individual from tests in 1952. Number of counties in each group shown in parenthesis

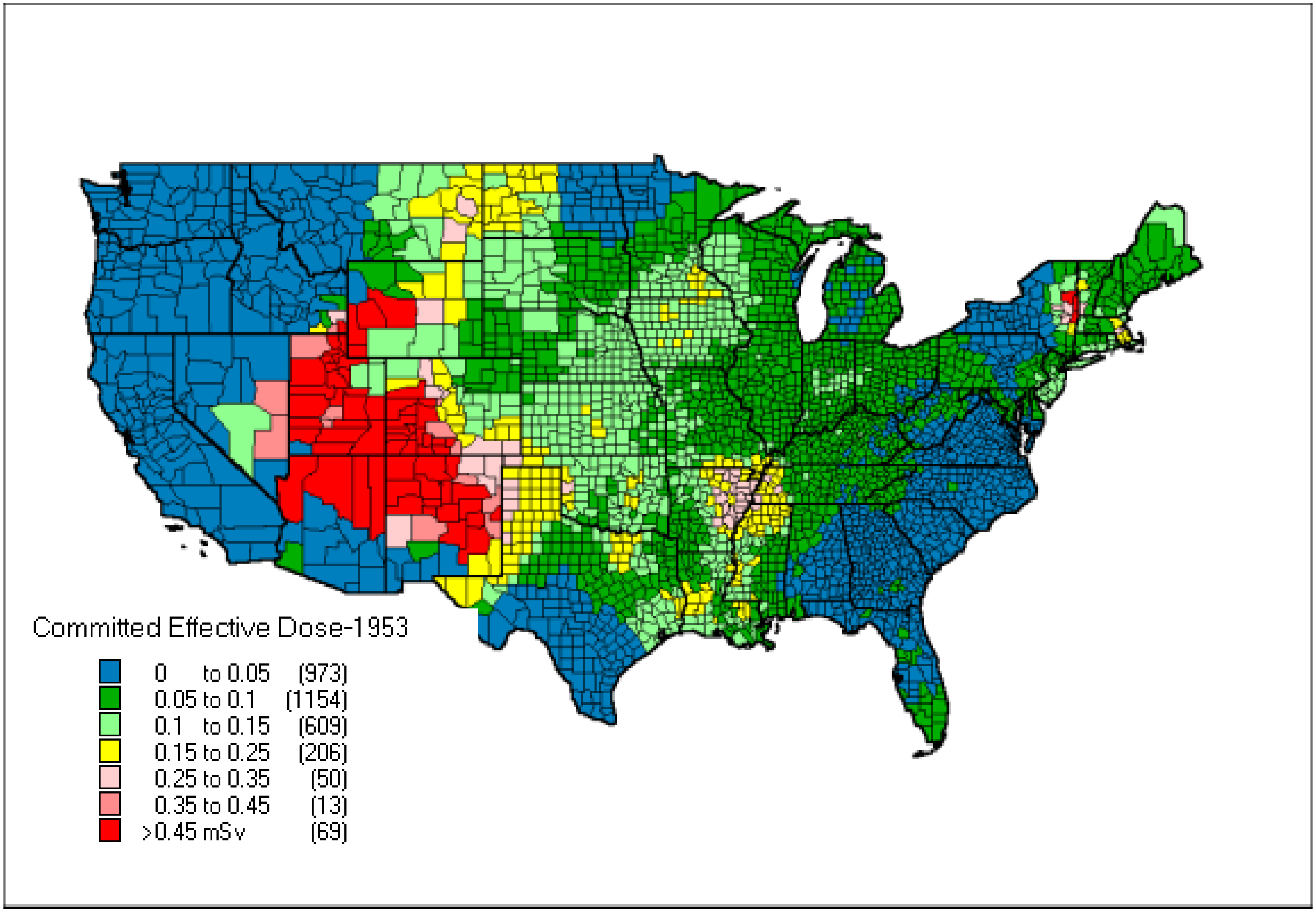

Figure 13. Dose to average exposed individual from tests in 1953. Number of counties in each group shown in parenthesis

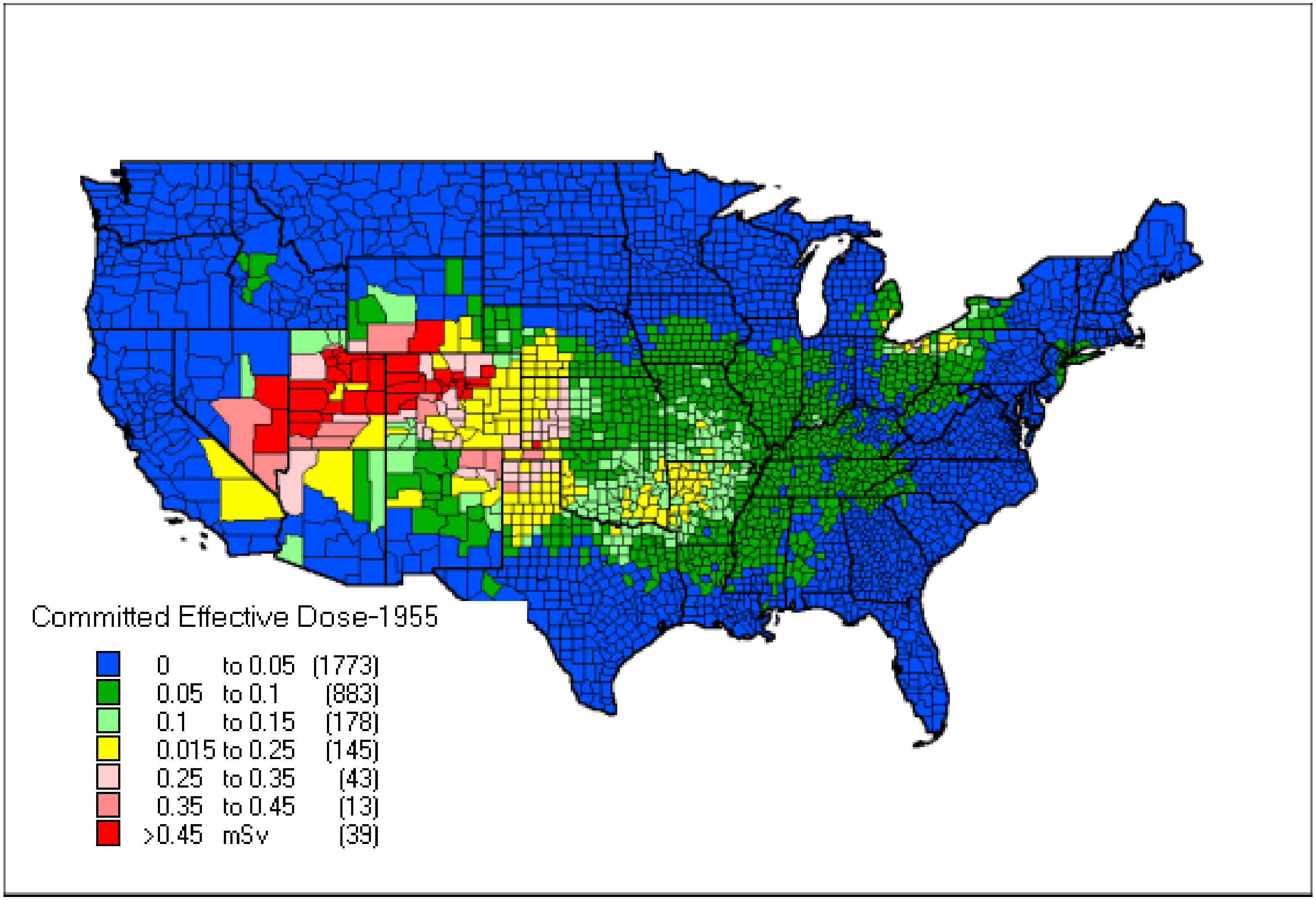

Figure 14. Dose to average exposed individual from tests in 1955. Number of counties in each group shown in parenthesis

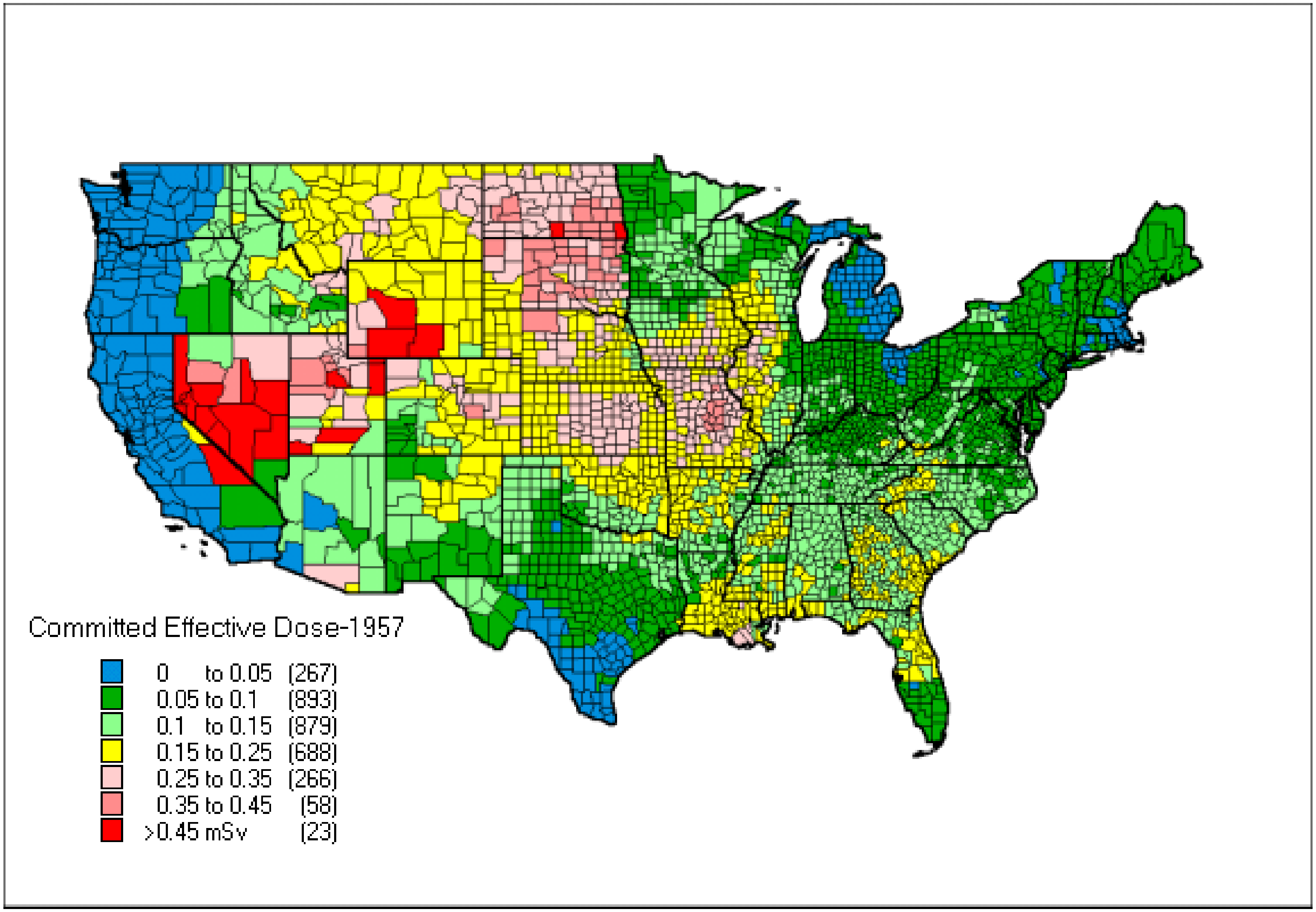

Figure 15. Dose to average exposed individual from tests in 1957. Number of counties in each group shown in parenthesis

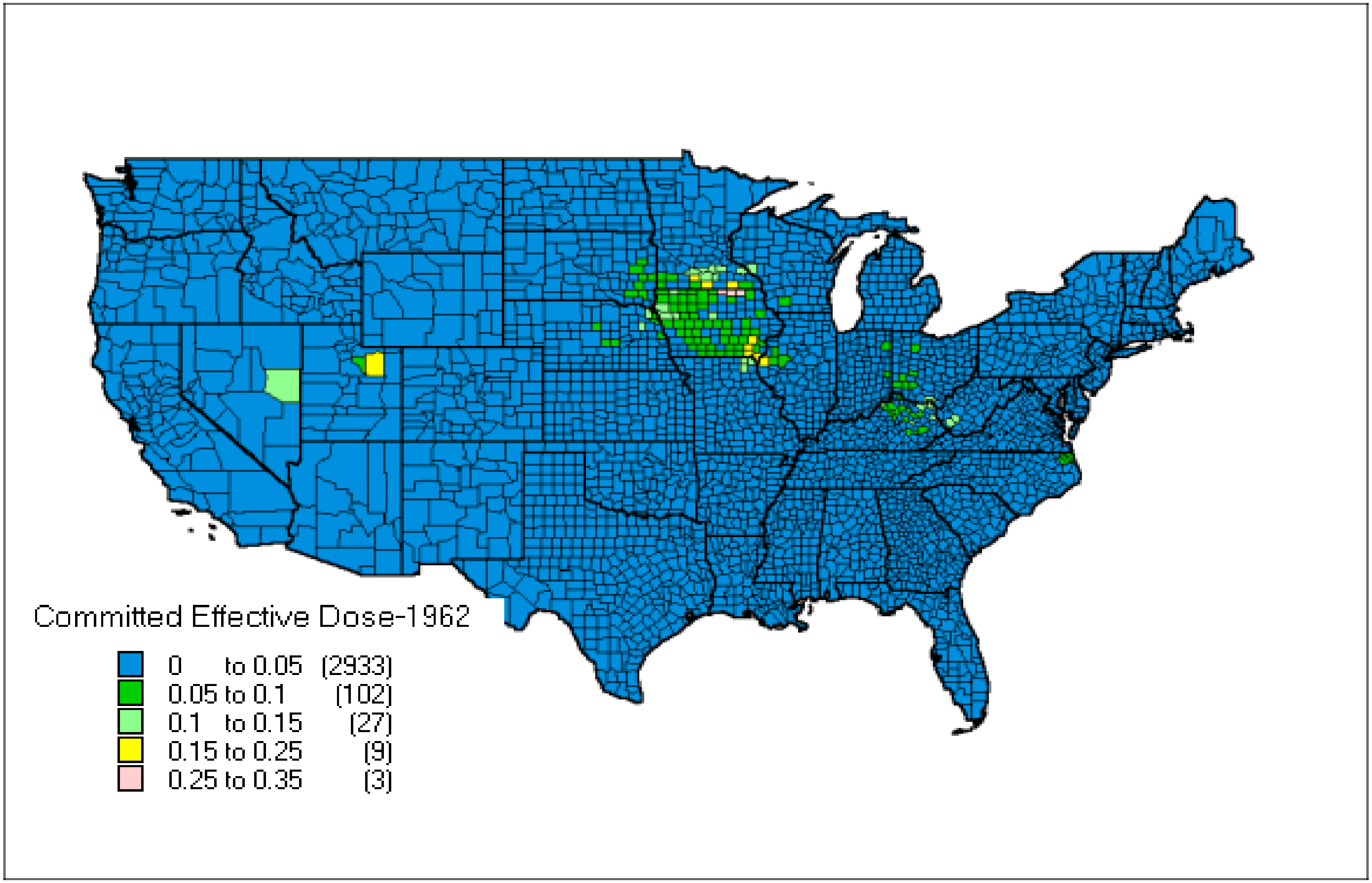

Figure 16. Dose to average exposed individual from SEDAN and Smallboy. Number of counties in each group shown in parenthesis

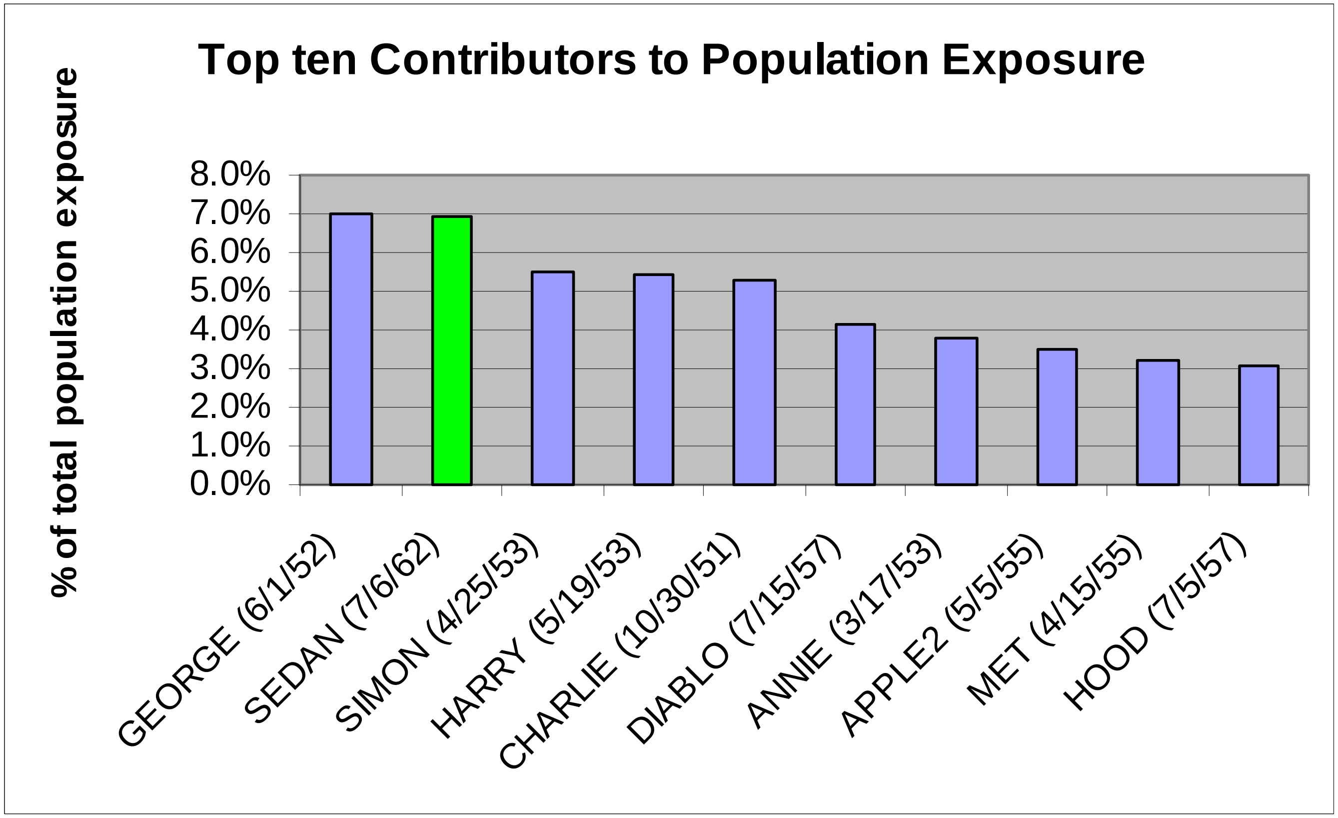

Figure 17: Ten tests with the greatest contributions to total population exposure. The value for SEDAN is much more uncertain than that for the other tests.

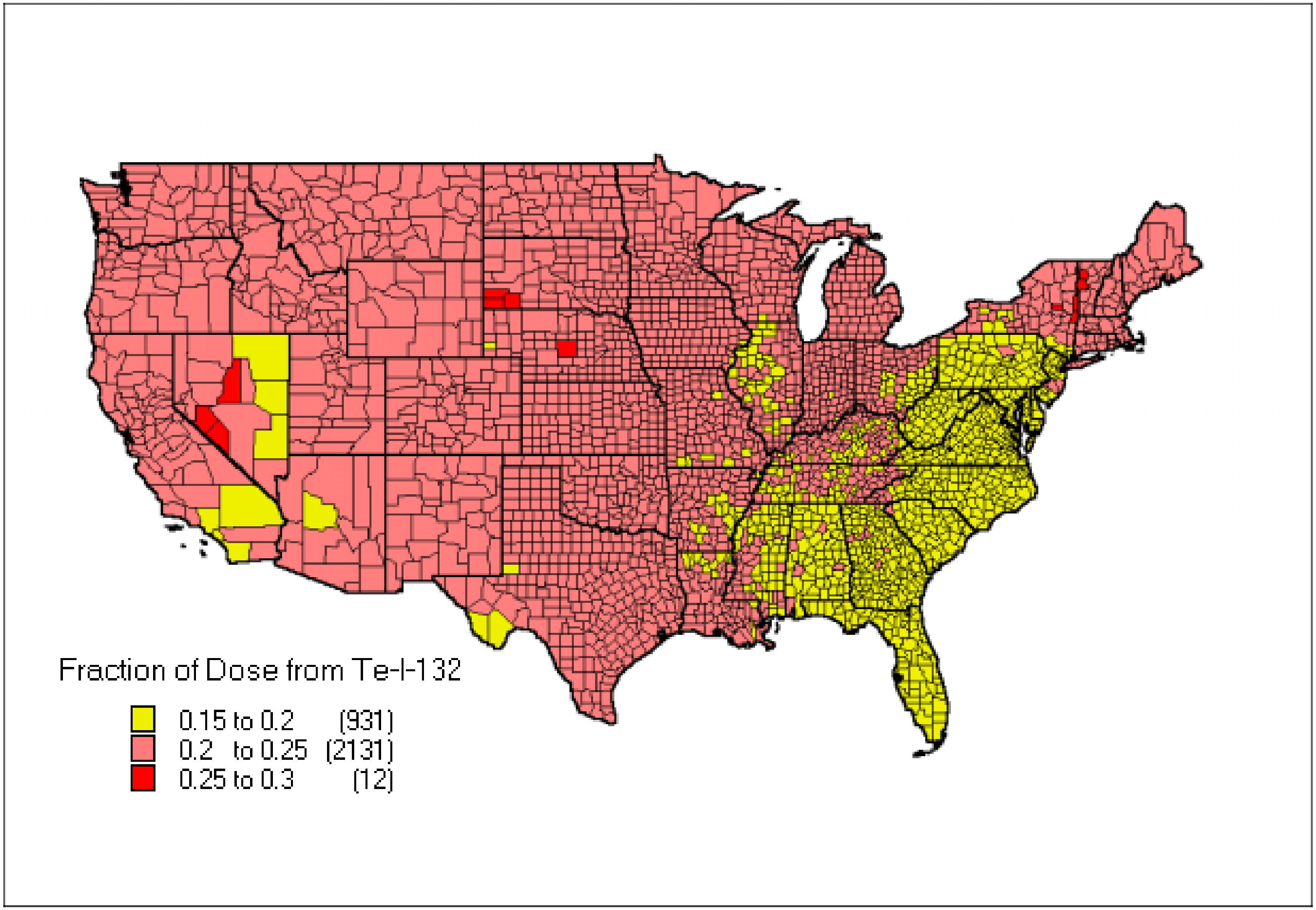

Figure 18: Fraction of total dose from Te-I-132. The number of counties in each group is shown in parenthesis.

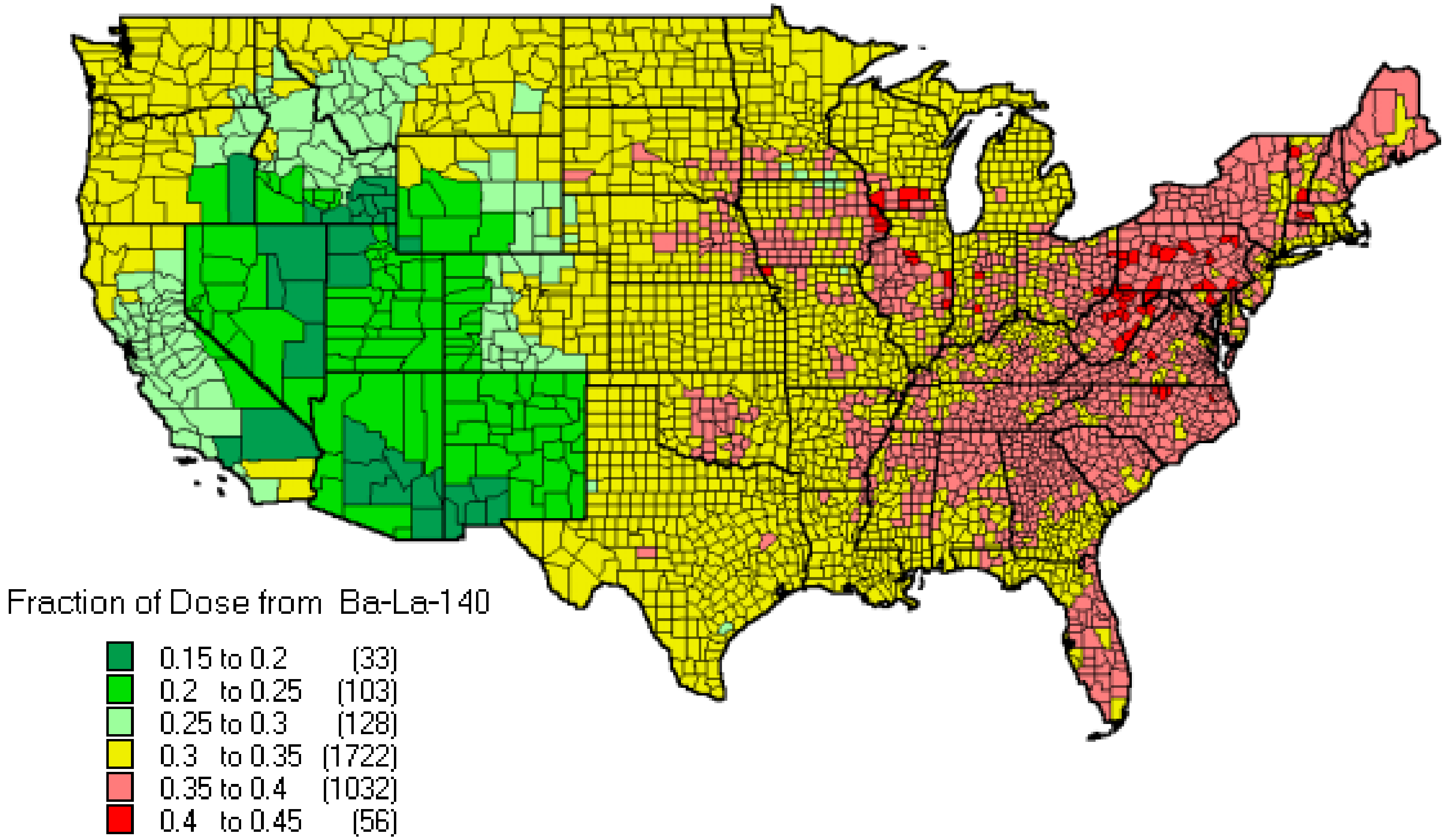

Figure 19: Fraction of total dose from Ba-La-140. The number of counties in each group is shown in parenthesis.

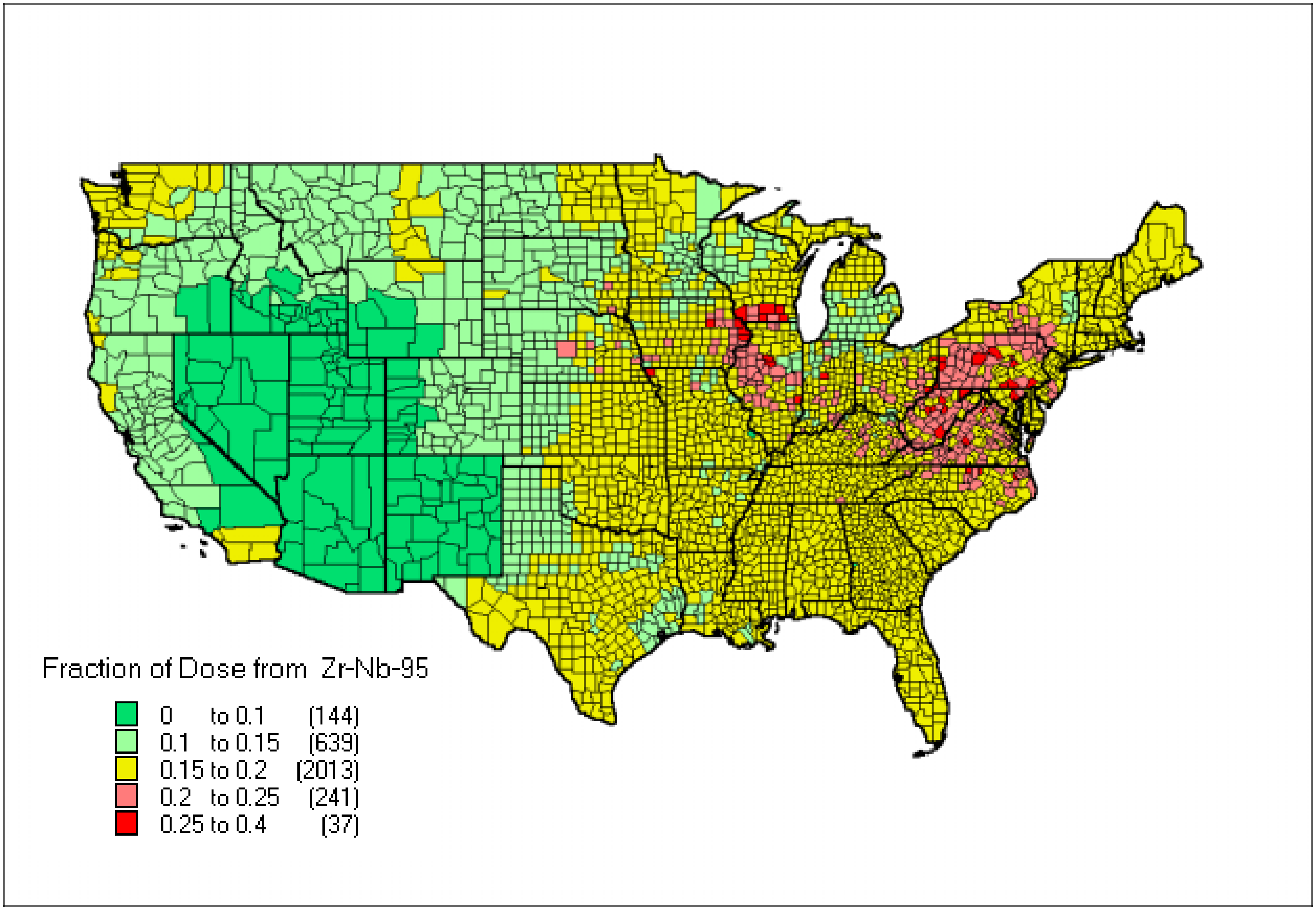

Figure 20; Fraction of total dose from Zr-Nb-95. The number of counties in each group is shown in parenthesis.

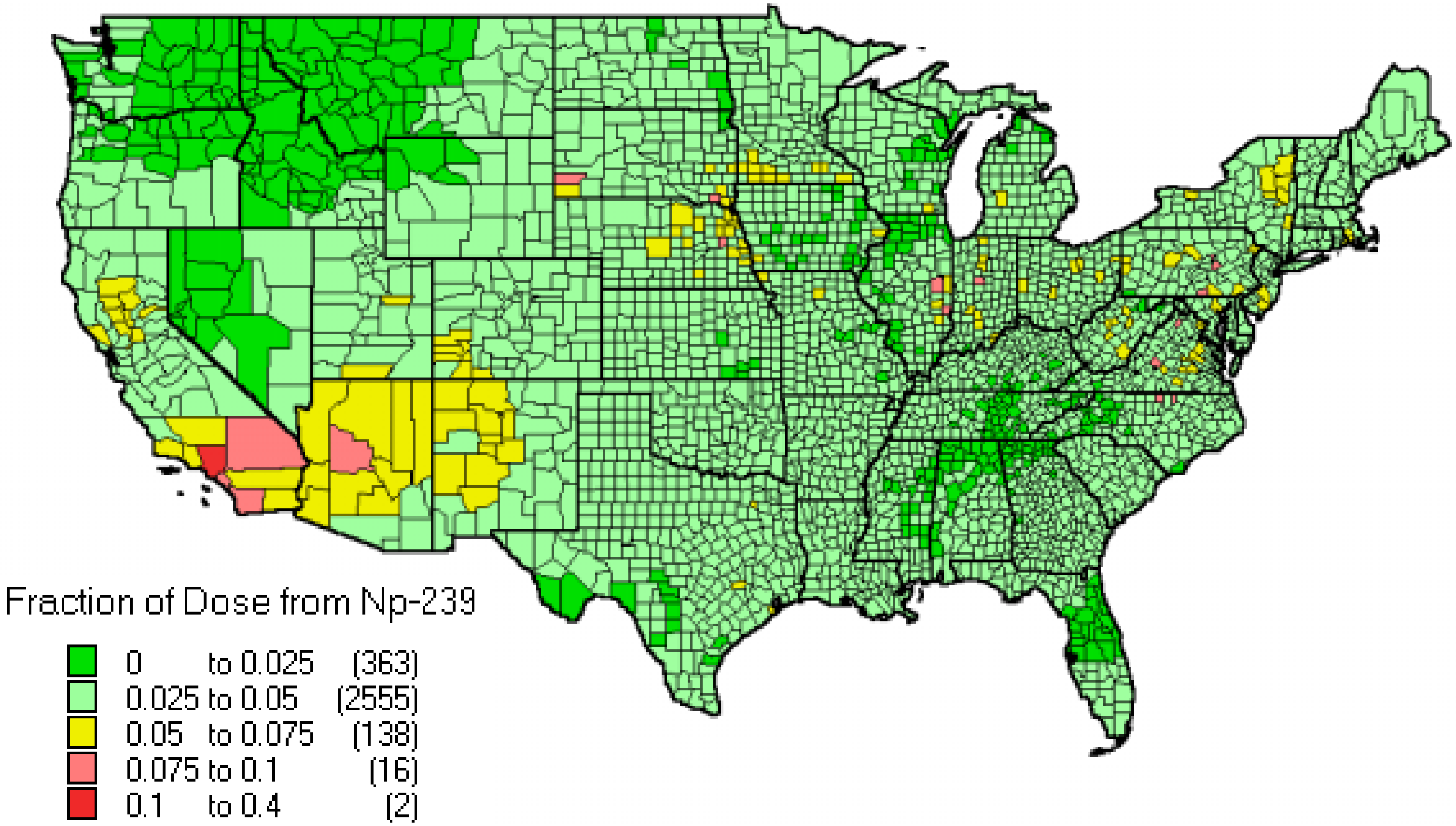

Figure 21: Fraction of total dose from Np-239. The number of counties in each group is shown in parenthesis.

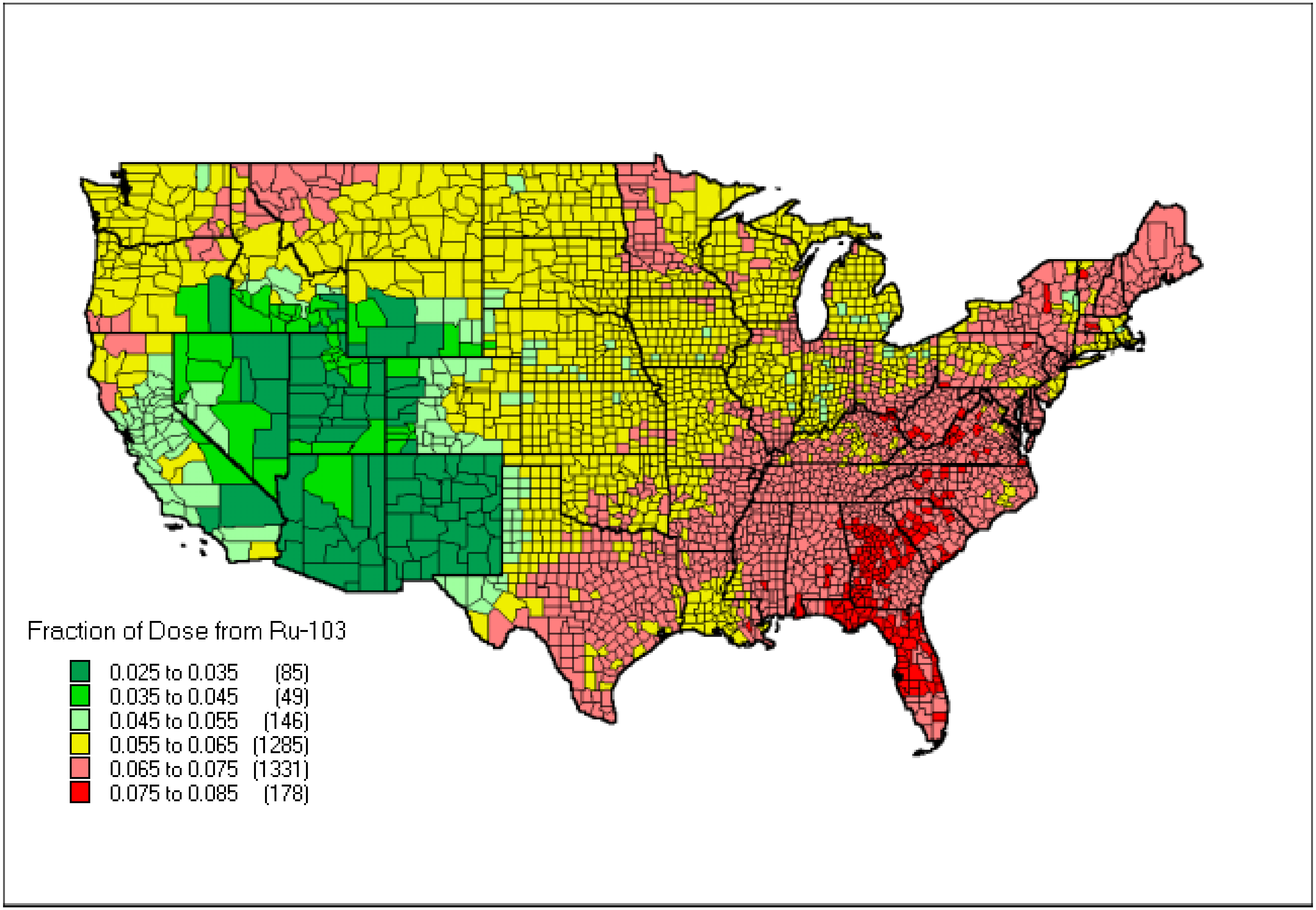

Figure 22: fraction of total dose from Ru-103. The number of counties in each group is shown in parenthesis.

Appendix E

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

February 4, 2000
(Revised May 30, 2000)

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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 I. Estimates of Dose

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

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

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 1950's 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 3100 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 Appendix of this report provides 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 (CD's).

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

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[*] 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

[western Colorado, southwestern Wyoming, southern Idaho, southeastern Oregon, 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). 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 3100 counties in the contiguous United States. Nearby the NTS where some of the larger counties experienced

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[‡] 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.

[§] 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.

considerable gradations in deposition, counties have been broken into subparts. In all, estimates are provided for 3094 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 (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 foodchains and 2) the age-dependant 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 to 19. Each point in the plots of Figs. 2–19 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.

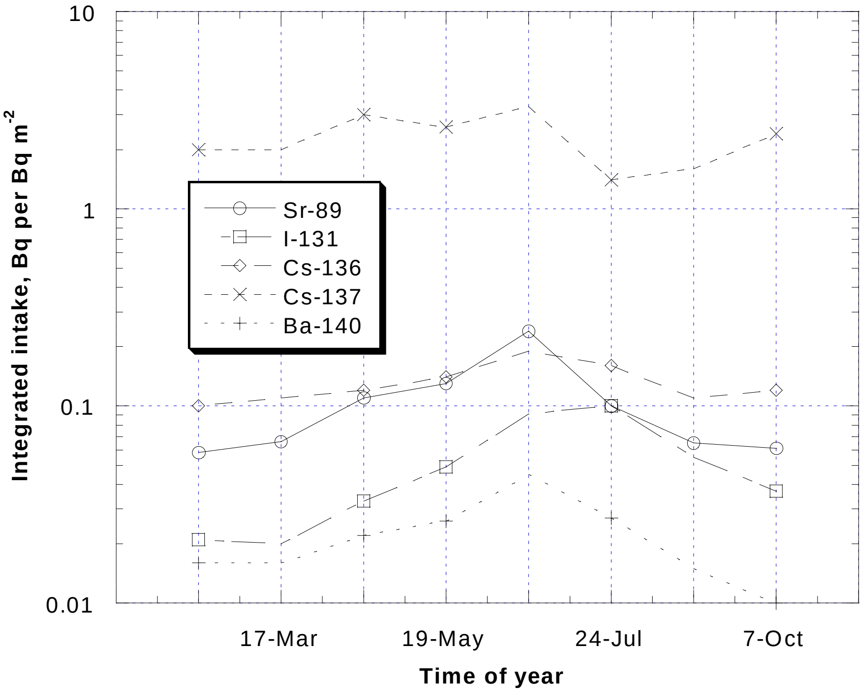

Fig. 1. Examples of the seasonally dependent values of integrated intake reported by Whicker and Kirchner (1987) for four of the more important radionuclides.

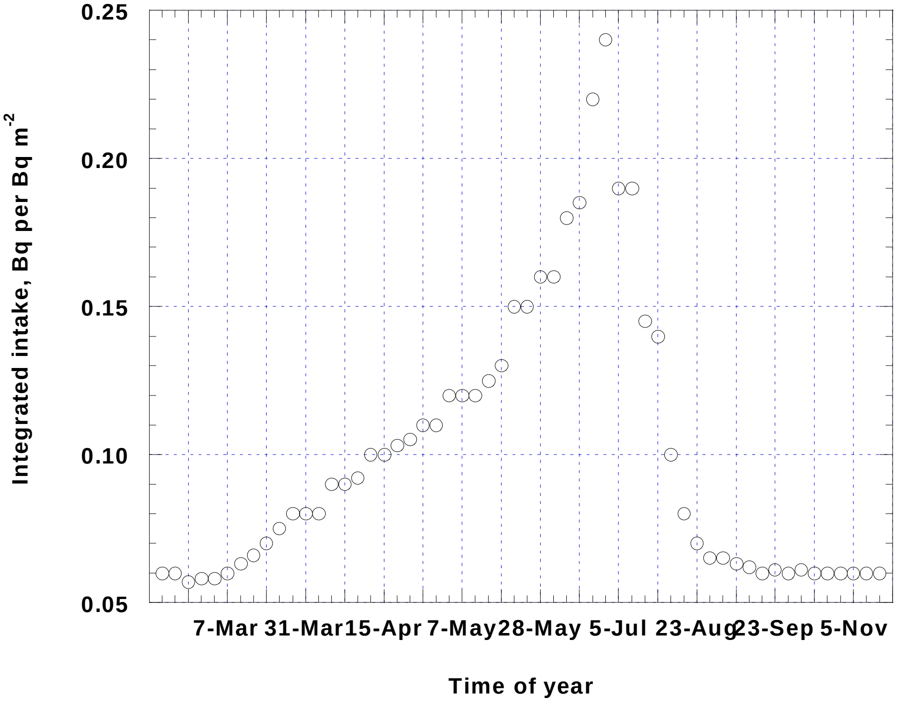

Fig. 2. Values for integrated intake used for ^{89}Sr.

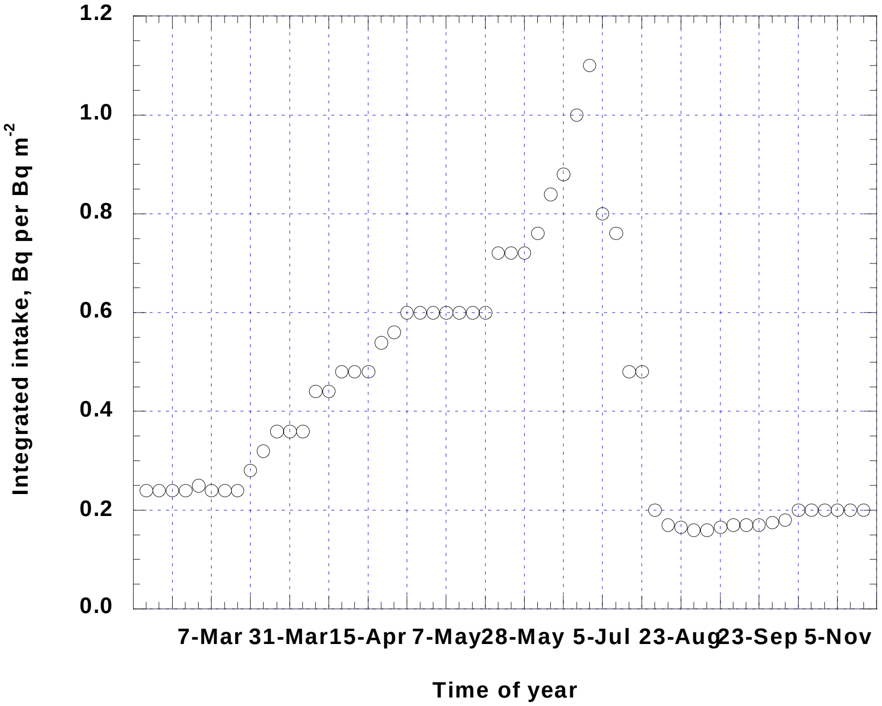

Fig. 3. Values for integrated intake used for ^{90}Sr.

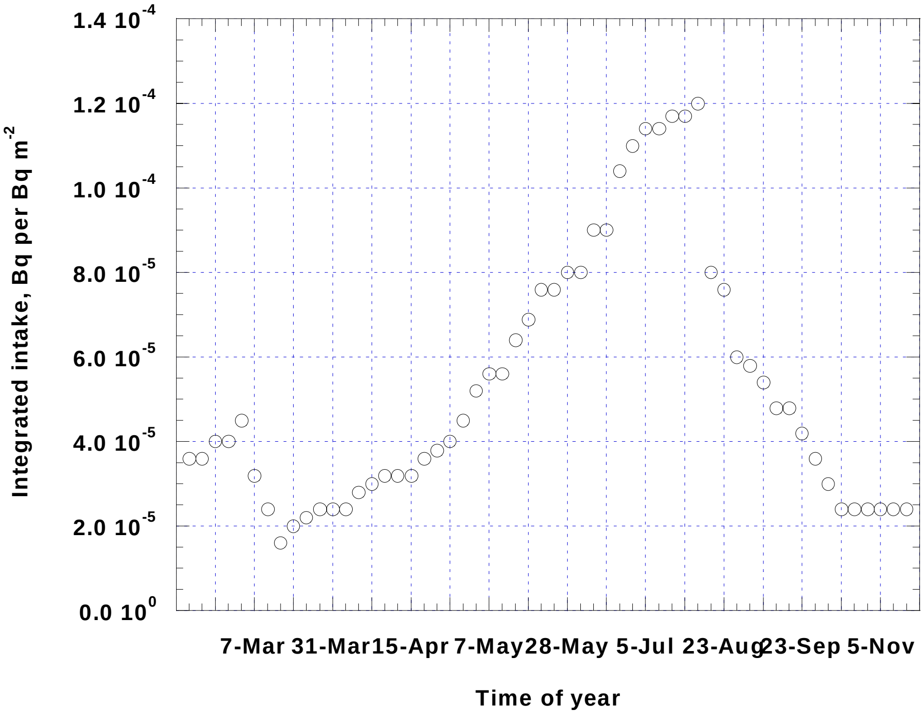

Fig. 4. Values for integrated intake used for ^{91}Sr.

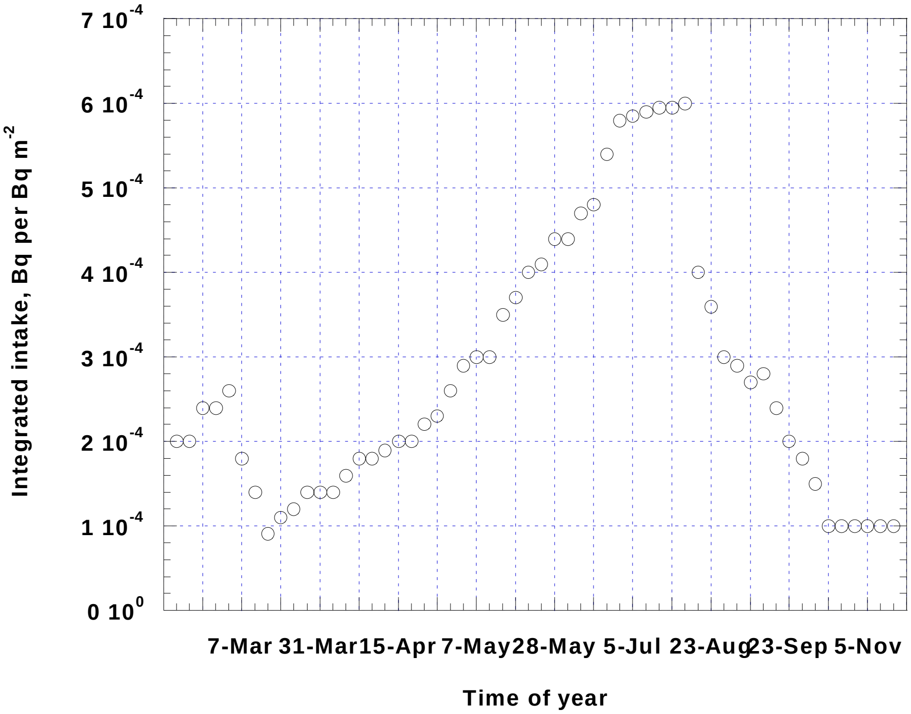

Fig. 5. Values for integrated intake used for ^{97}Zr.

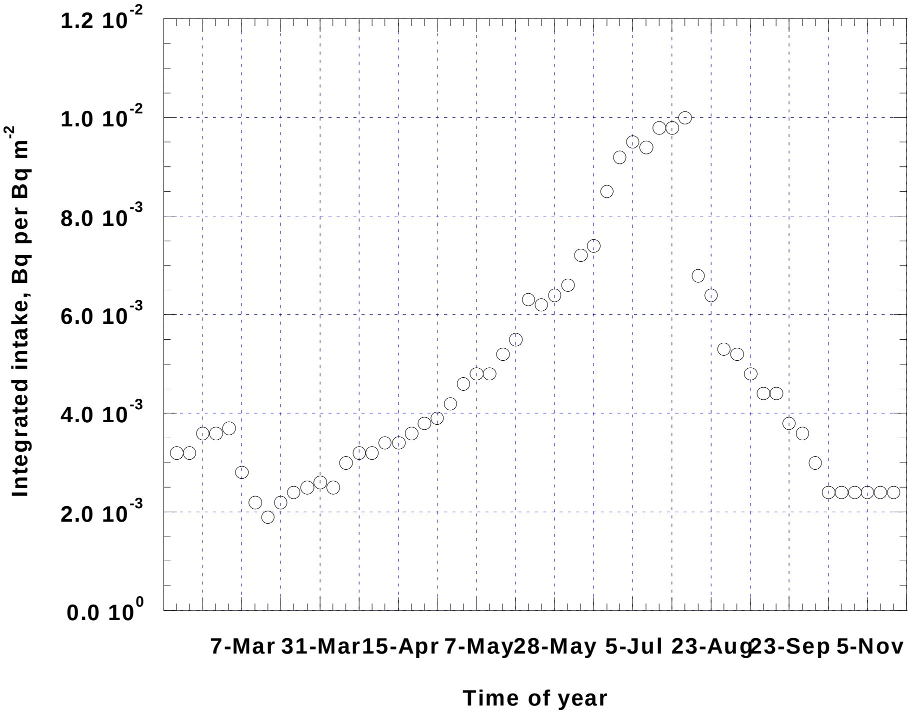

Fig. 6. Values for integrated intake used for ^{99}Mo.

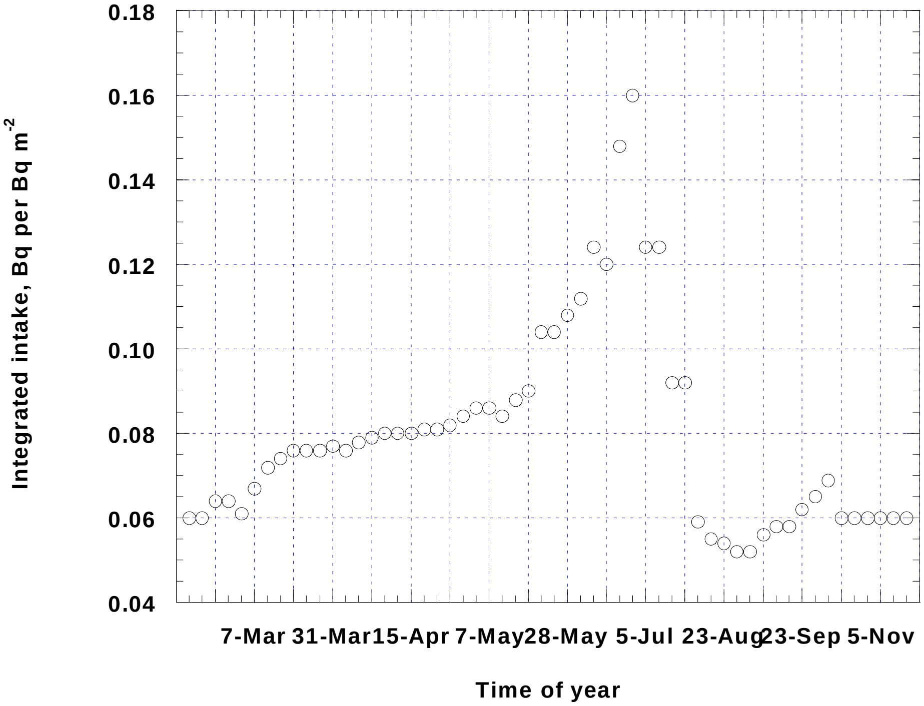

Fig. 7. Values for integrated intake used for ^{103}Ru.

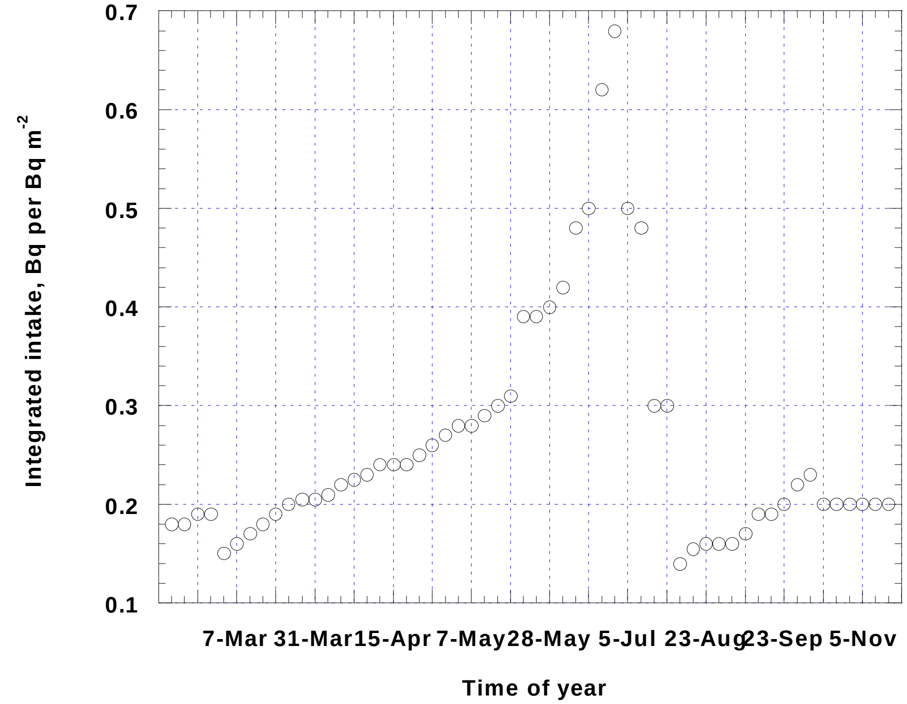

Fig. 8. Values for integrated intake used for ^{106}Ru.

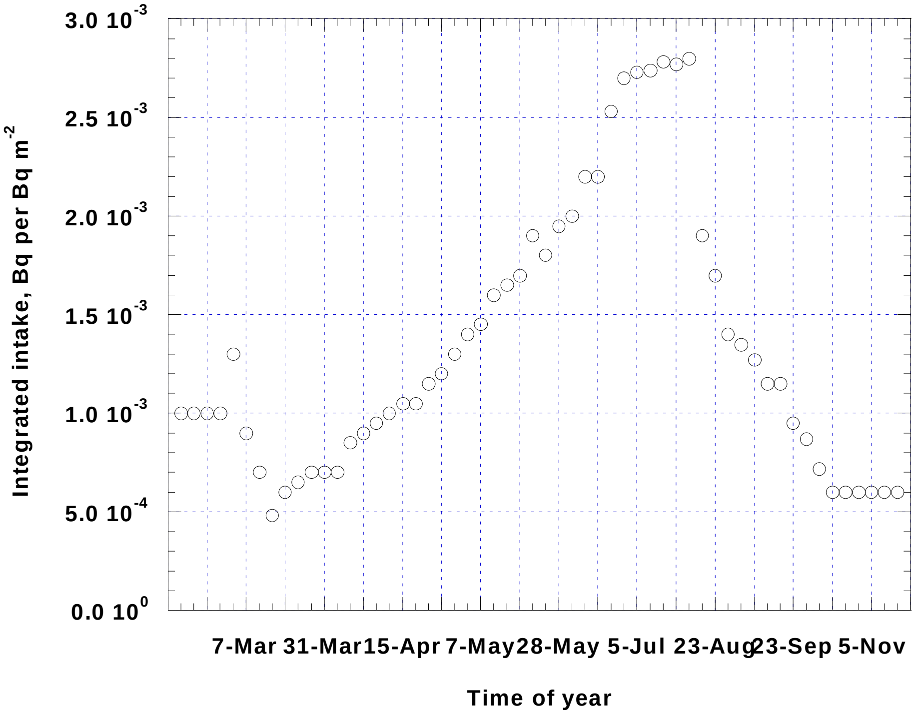

Fig. 9. Values for integrated intake used for ^{105}Rh.

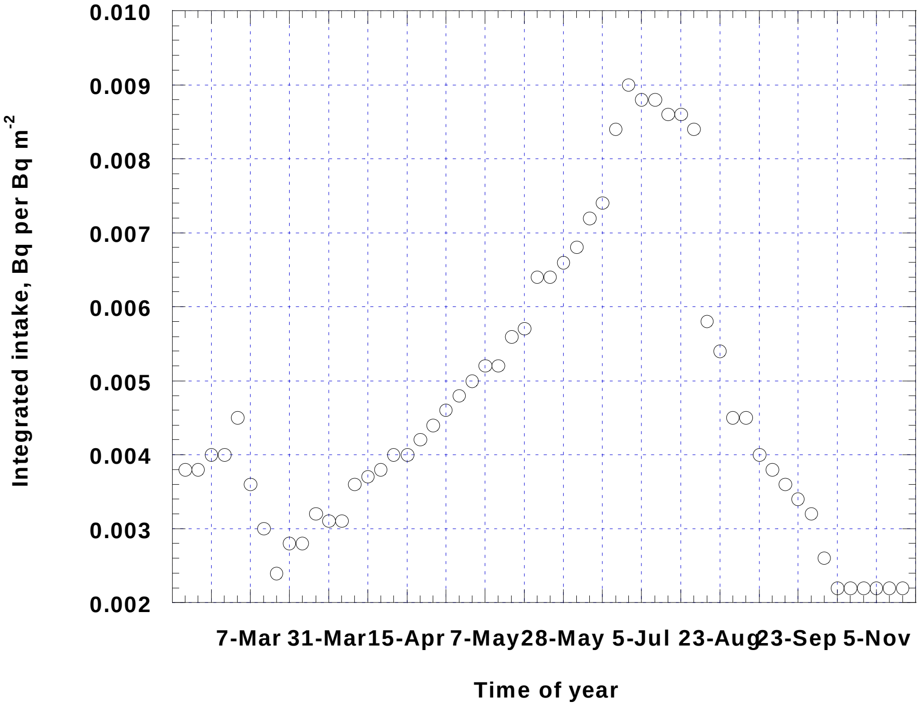

Fig. 10. Values for integrated intake used for ^{132}Te.

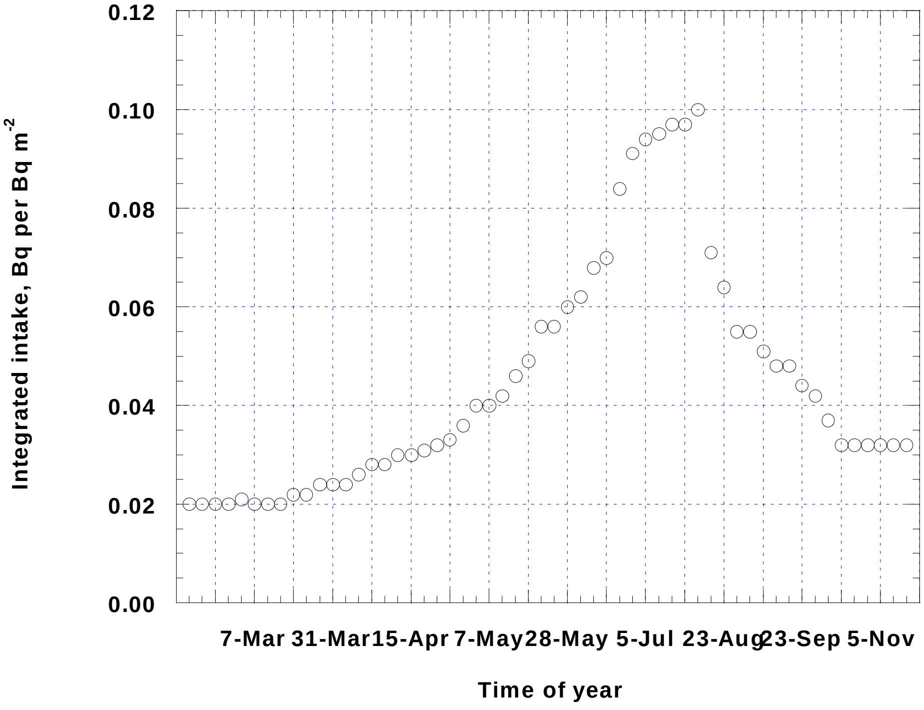

Fig. 11. Values for integrated intake used for ^{131}I.

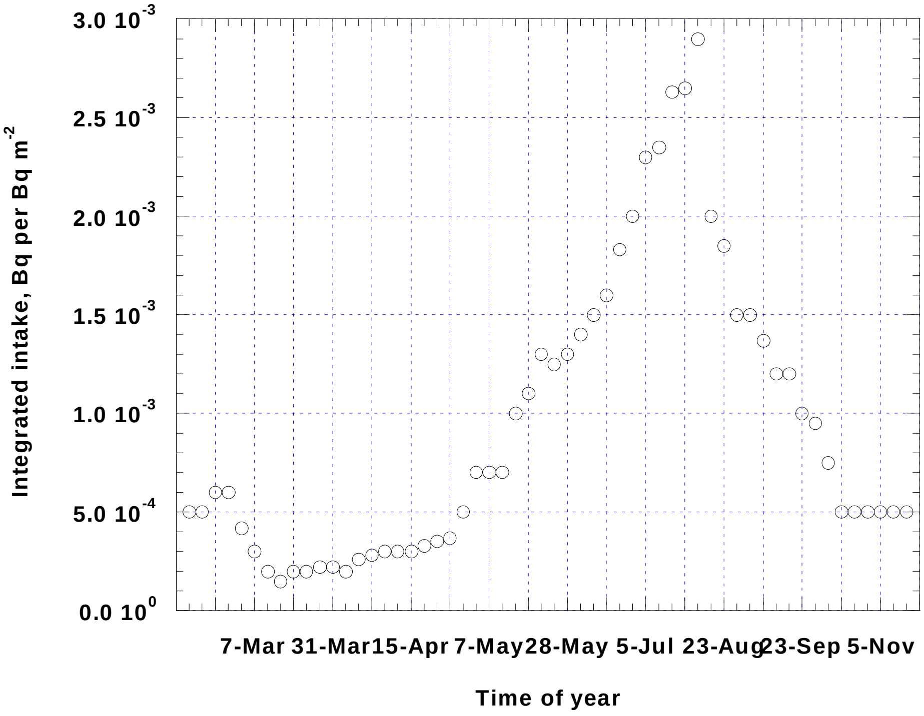

Fig. 12. Values for integrated intake used for ^{133}I.

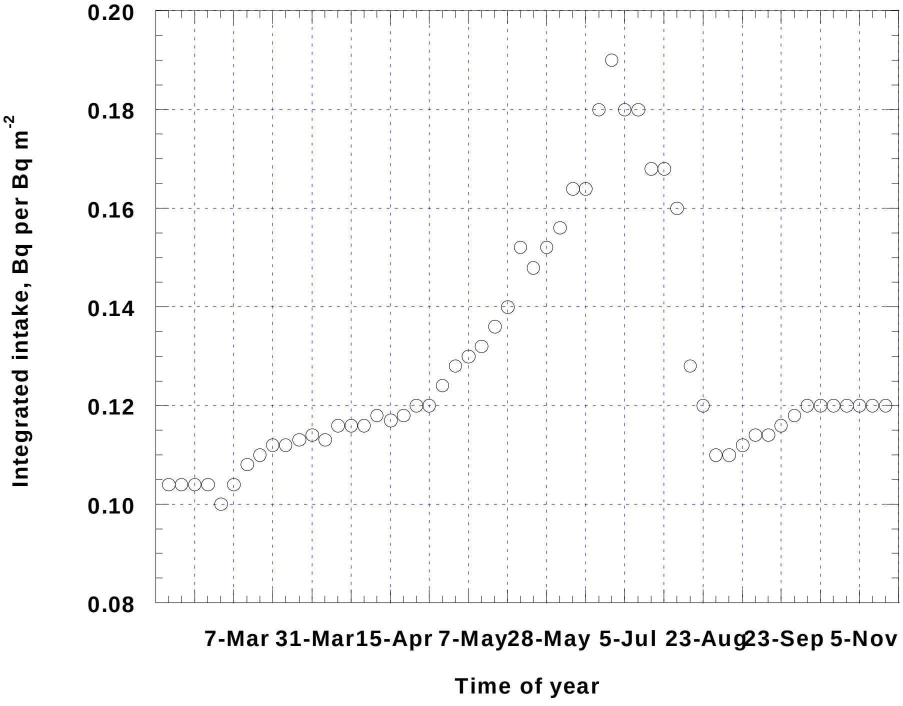

Fig. 13. Values for integrated intake used for ^{136}Cs.

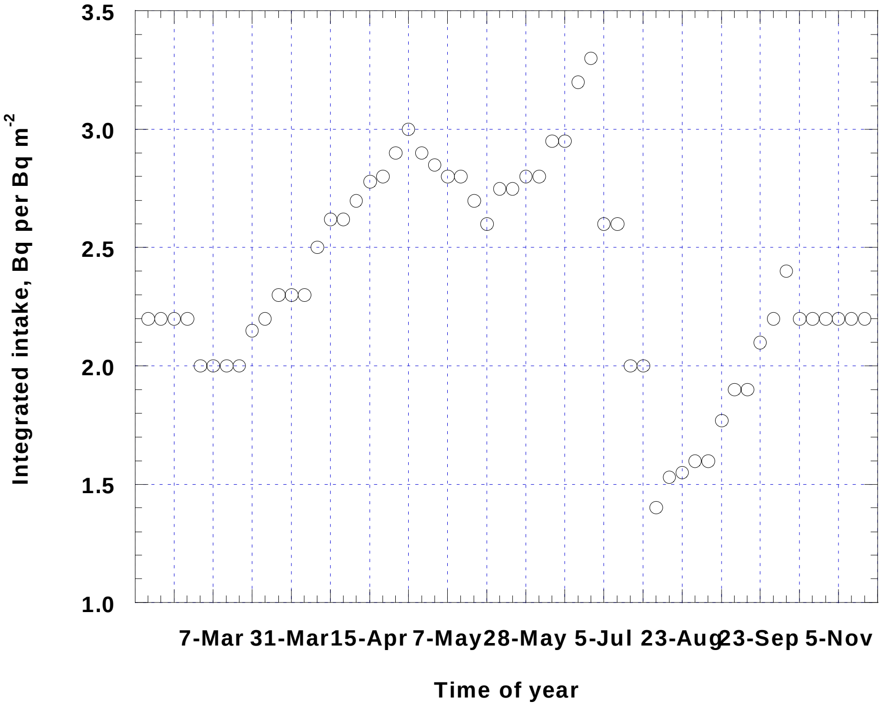

Fig. 14. Values for integrated intake used for ^{137}Cs.

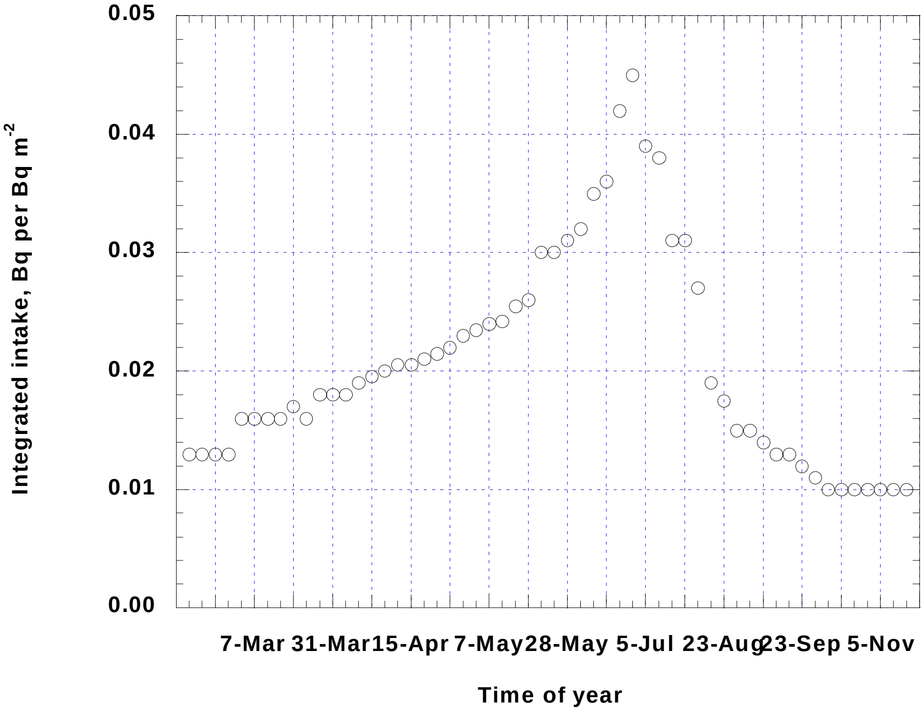

Fig. 15. Values for integrated intake used for ^{140}Ba.

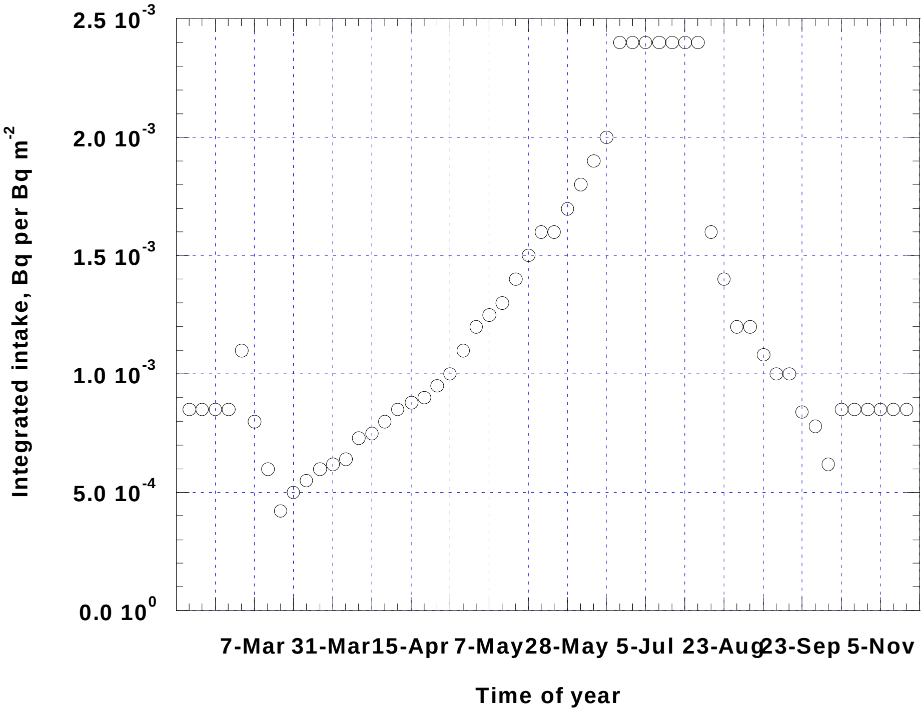

Fig. 16. Values for integrated intake used for ^{143}*Ce.*

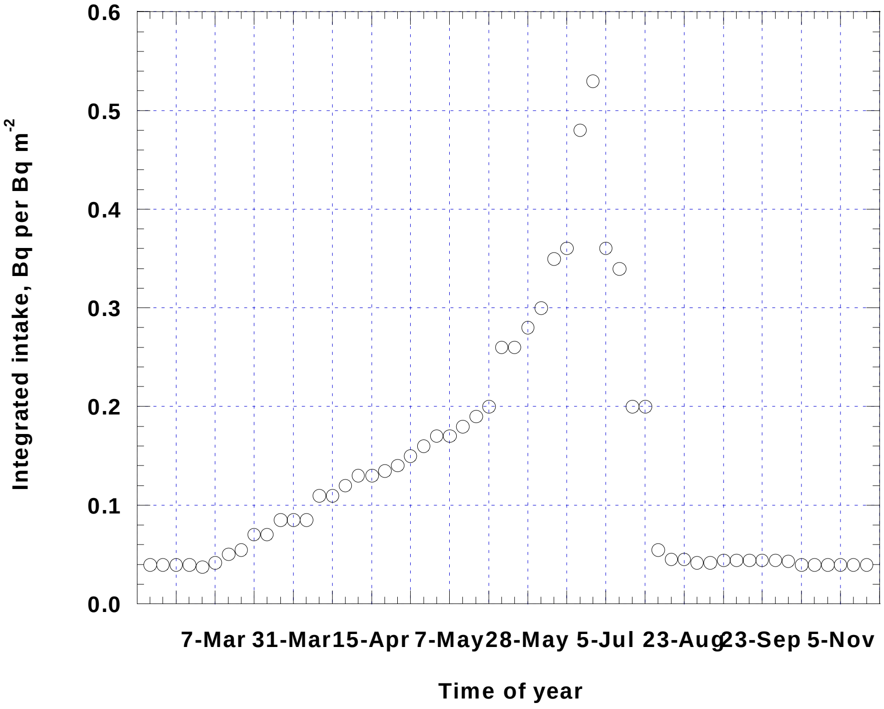

Fig. 17. Values for integrated intake used for ^{144}*Ce.*

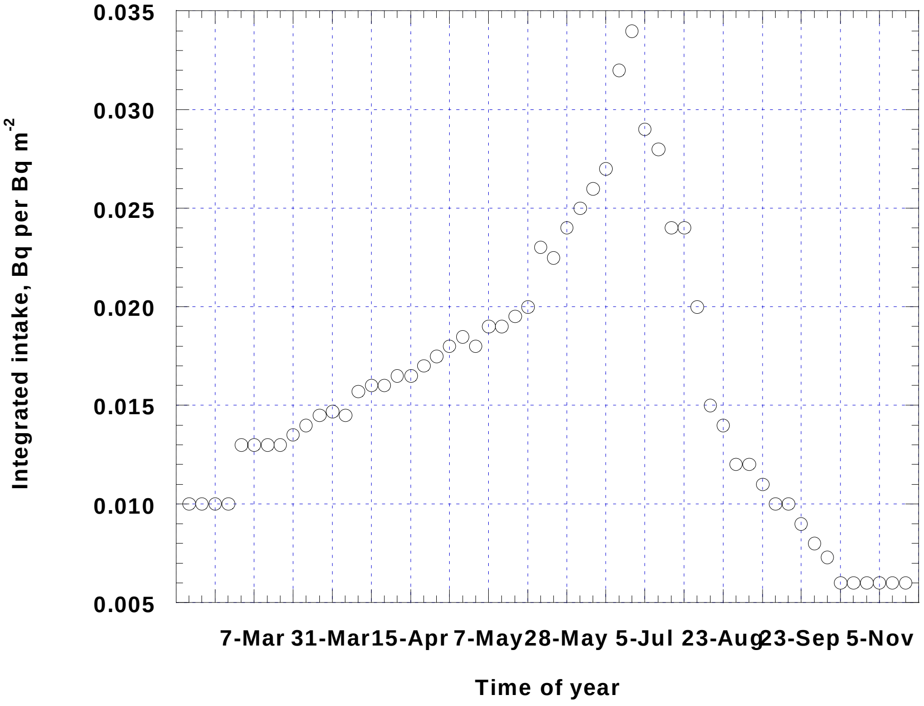

Fig. 18. Values for integrated intake used for ^{147}Nd.

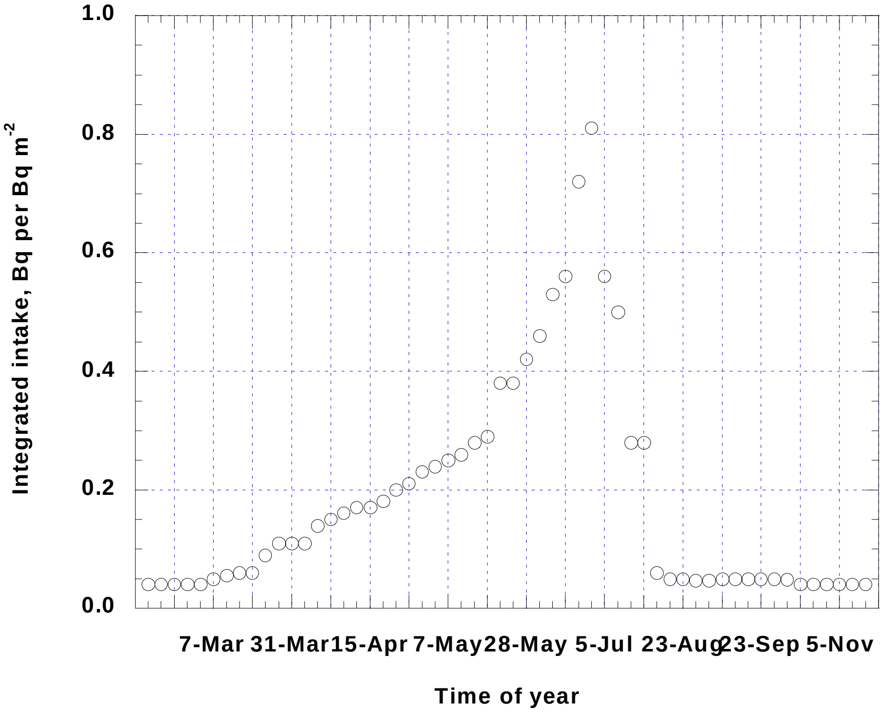

Fig. 19. Values for integrated intake used for $^{239+240}$Pu and ^{241}Pu.

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

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[**] 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 CD's that accompany this report. Information on the CD's 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 to 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 CD's. 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).

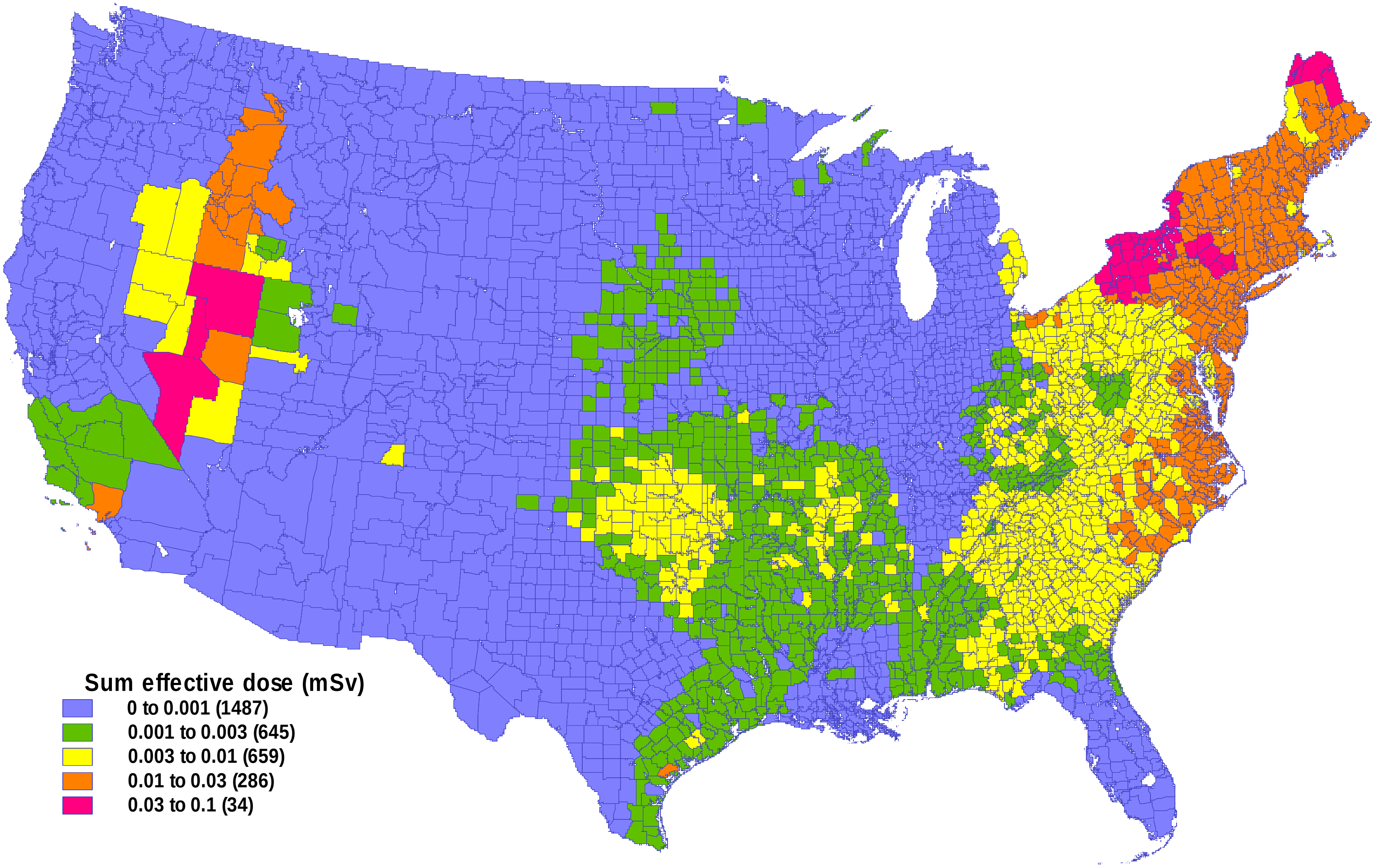

Fig. 20. Map of the effective dose by geographical area for the tests conducted in the year 1951.

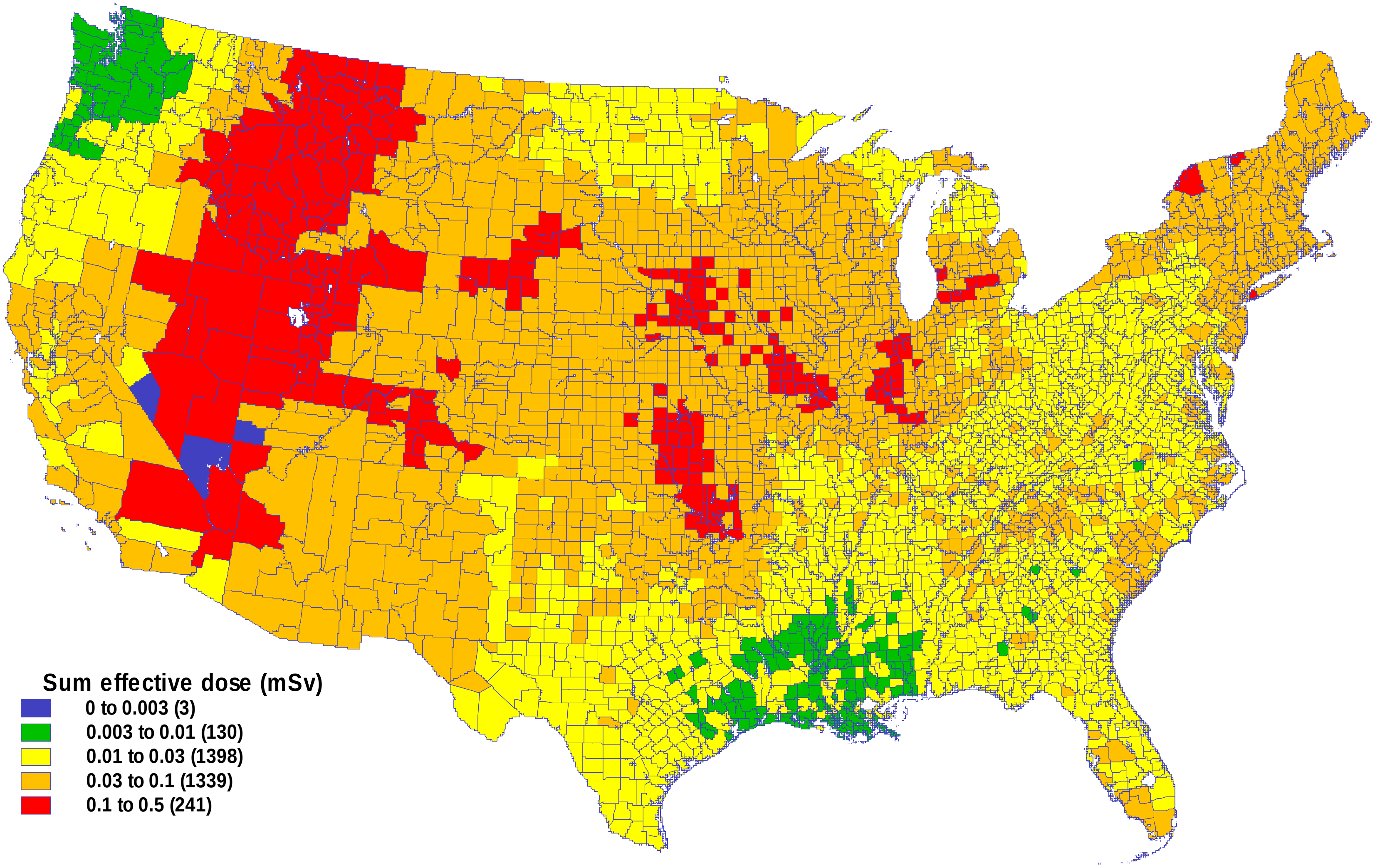

Fig. 21. Map of the effective dose by geographical area for the tests conducted in the year 1952.

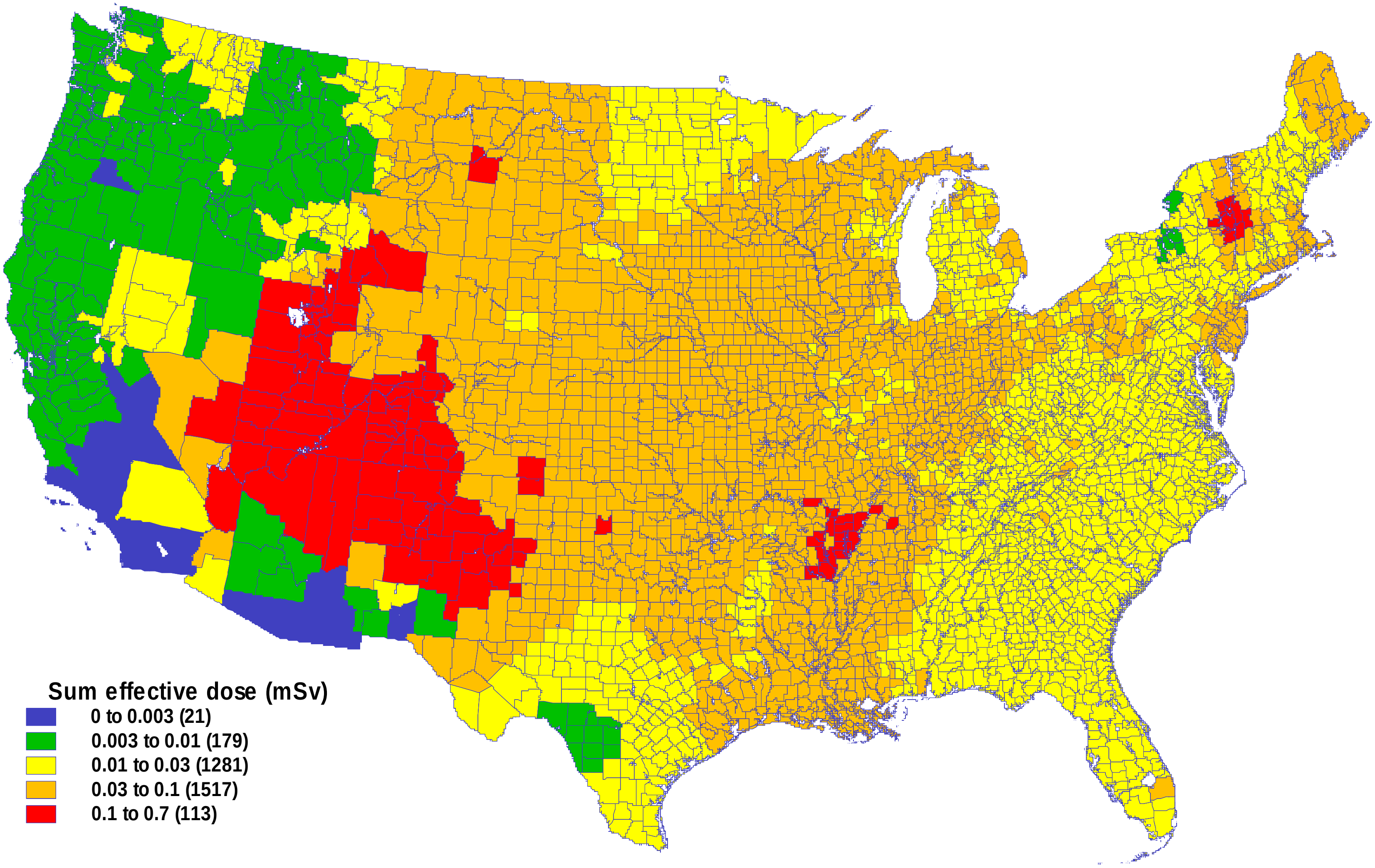

Fig. 22. Map of the effective dose by geographical area for the tests conducted in the year 1953.

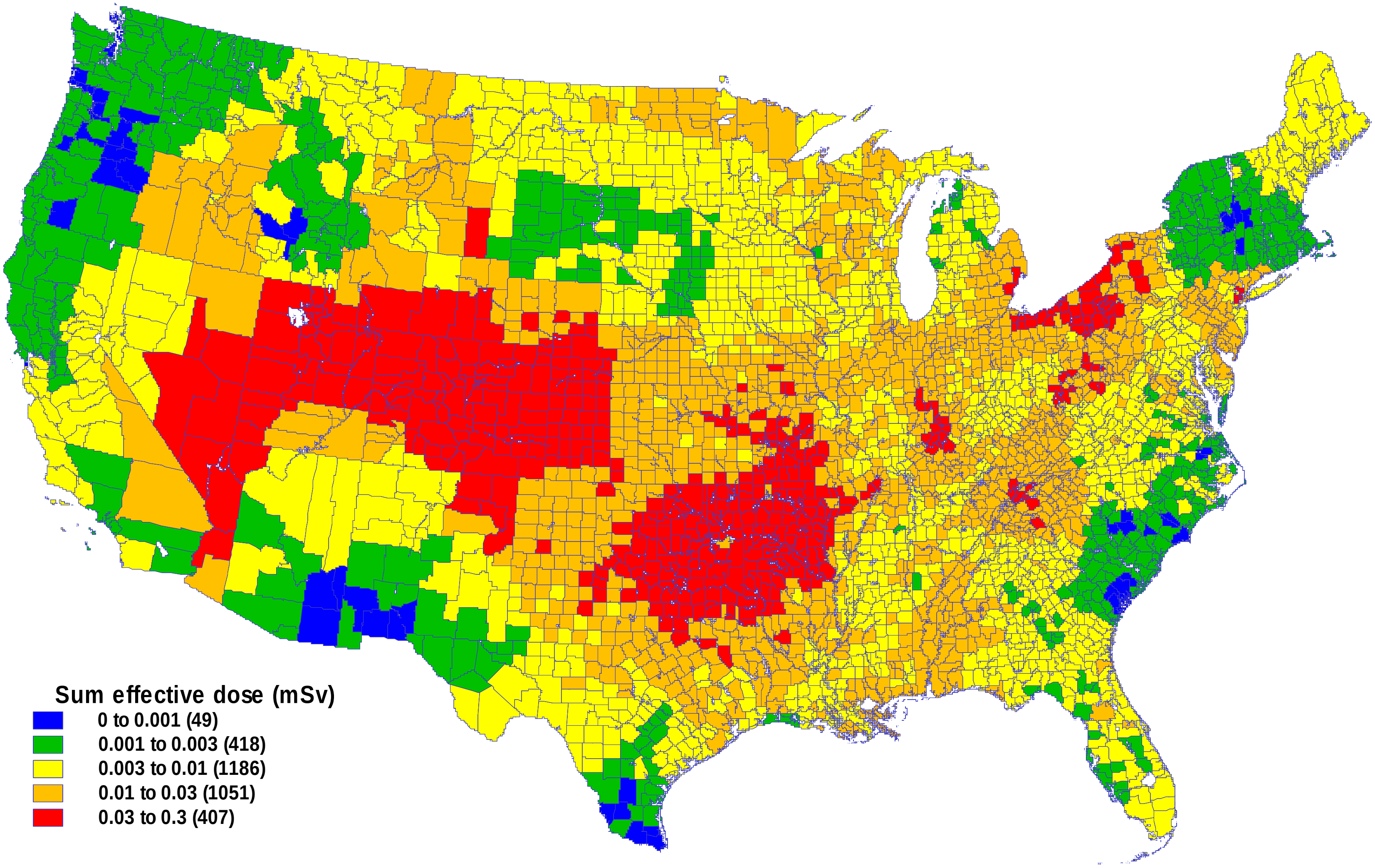

Fig. 23. Map of the effective dose by geographical area for the tests conducted in the year 1955.

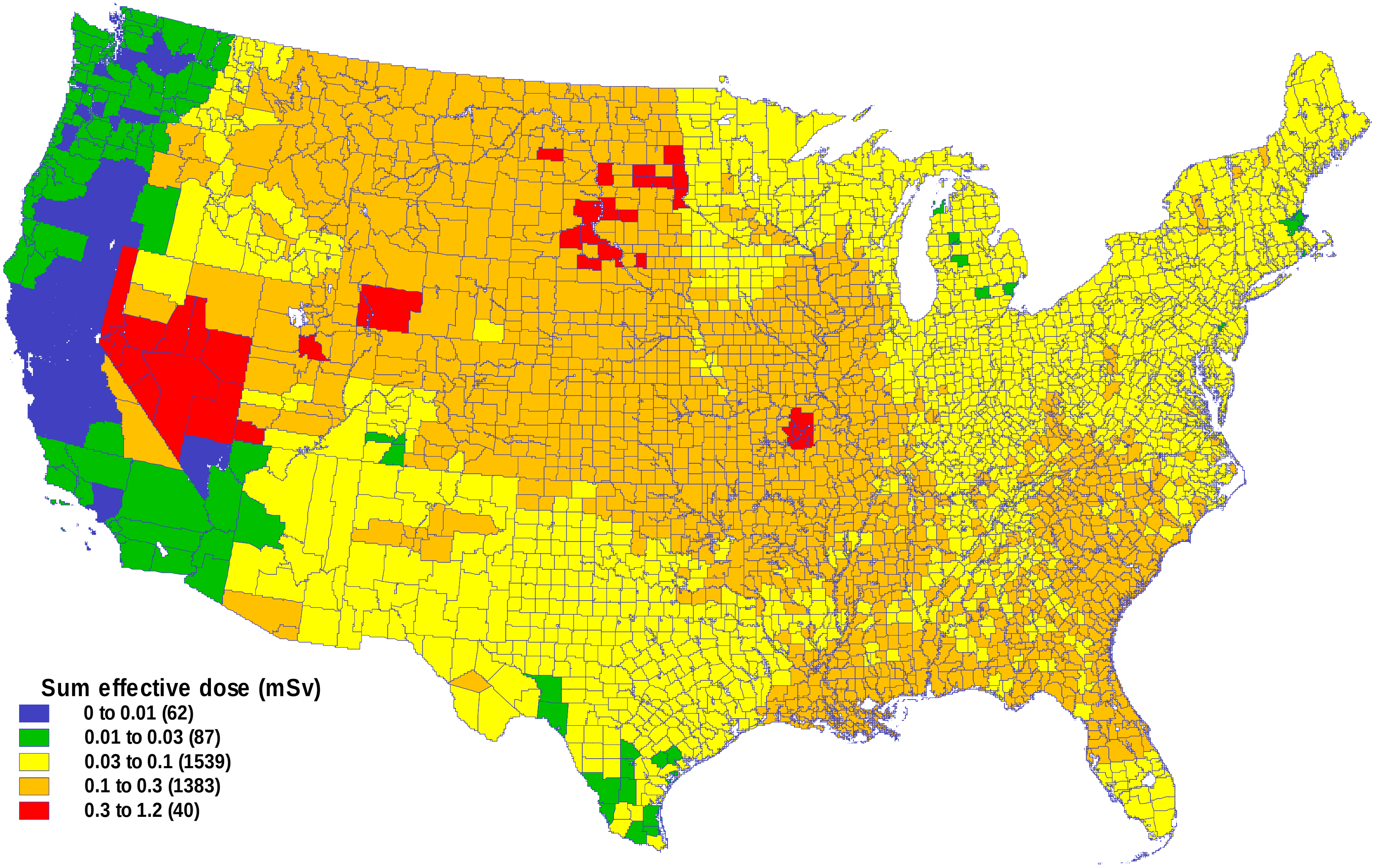

Fig. 24. Map of the effective dose by geographical area for the tests conducted in the year 1957.

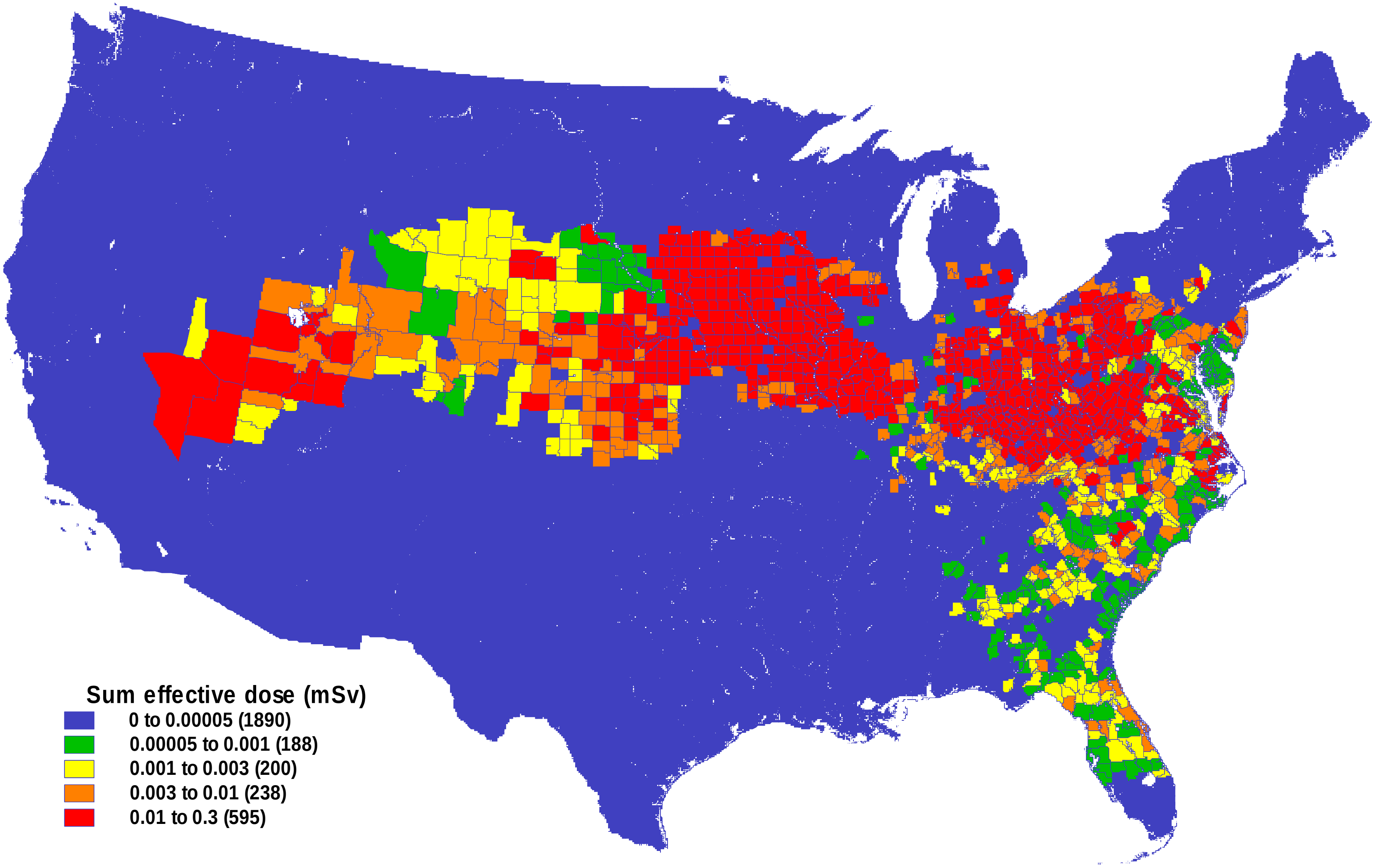

Fig. 25. Map of the effective dose by geographical area for the tests conducted in the year 1962.

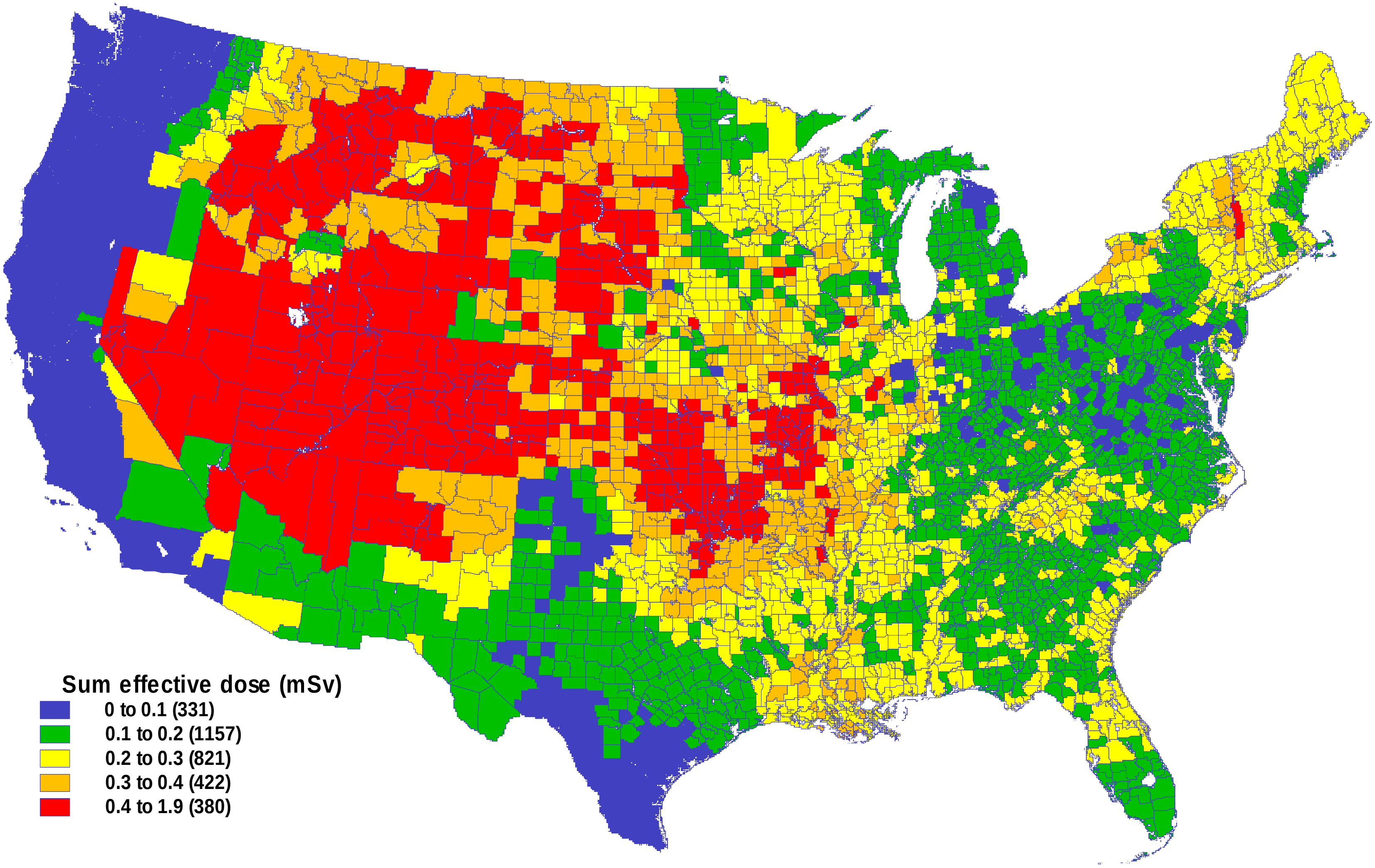

Fig. 26. Map of the effective dose by geographical area for the tests conducted from 1951 through 1962.

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[††] 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. As a

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.

[††] 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

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. A surprisingly large contribution is attributed to the two explosions that occurred in 1962 during Operation Storax;

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

almost all of the later was due to Project Sedan, a large cratering experiment.[‡‡] 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. 3–19, 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[§§] 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

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[‡‡] See the following footnote concerning Sedan.

[§§] 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

have been high. 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:

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

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

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

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

	Per caput effective dose commitment, µSv

Radionuclide	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.

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.

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. 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

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

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.

U.S. Congress. Radiation standards, including fallout. Washington: U.S. Government Printing Office; Hearings before the Subcommittee on Research, Development, and Radiation, Joint Committee on Atomic Energy; 87th Congress; 1962.

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 Stated 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 on page 58] 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.

Appendix F

External Dose Estimates from Global Fallout

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

Harold L. Beck

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DRAFT

Abstract

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

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

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

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

Introduction

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

1. Prepare crude estimates of the doses *from external irradiation* received by the American people as a result of the above-ground tests carried out in the 1950s and early 1960s *by the U.S. in the Pacific and by the USSR in Kazakhstan and on Arctic Islands*. These dose estimates would be:
    - based on a review of the readily available open literature and information. It is not expected that sophisticated computer models should be developed or used for this purpose nor that a formal uncertainty analysis be carried out;
    - averaged over states or groups of states of the continental U.S., with indications on how the high-risk populations would be identified. However, if feasible, primary dose estimates should be made on a county by county basis, and averaged only for presentation purposes;
    - calculated separately for the most important radionuclides produced in these nuclear weapons tests with respect to external irradiation of the U.S. population. Those would include, but would not be limited to Cs-137, Zr-Nb-95, Mn-54, Sb-125, and Ba-La-140;
    - provided in terms of average whole-body dose for gamma irradiation. The dose to the skin for beta irradiation should also be indicated, however, since this dose is expected to be small compared to the gamma dose, it is not expected that detailed beta dose calculations will be made for each geographical area and month/year of fallout.; calculated by year of fallout and summed over all tests, with a comparison to the results previously obtained for the NTS tests. If feasible, calculations should be carried out by month of fallout.
2. Provide an electronic database with the deposition densities and estimated doses of the important fallout radionuclides, by month of fallout and geographical area (county, state or group of states). From the point of view of external irradiation, the important radionuclides include those listed above. In addition, the deposition densities of Sr-90, Sr-89, I-131, Fe-55, and Pu-239 should be eastimated, as they are important from the point of view of internal irradiation.

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

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

In a previous report (Beck, 1999), this author estimated the external exposure of the population of the continental U.S. from Nevada Weapons Tests. The mostly low yield (<100 kT) weapons tests conducted at the NTS injected almost all of their debris into the troposphere where it was deposited mostly within the continental U.S.A.(Beck, 1999). In contrast, the mostly high yield (thermonuclear tests with yields greater than 1 MT accounted for over 90% of the fission products produced) tests carried out by the US, UK and USSR in the Pacific and at various sites in the USSR injected most of their debris into the stratosphere (UNSCEAR, 1982,1993). The total fission yield of these tests was about 150 MT (see Table 1) compared to about 1 MT for NTS tests. However, because of the long residence times for the transfer of air between the stratosphere and troposphere (on the order of 1 year), the fallout from these high yield tests was relatively depleted of short-lived radionuclides. Thus the total deposition in the continental U.S.A. of short-lived radionuclides such as I-131 was considerably lower than that from NTS tests.

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

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

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

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

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

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

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

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

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

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

Table 1:Estimated Fission Yields*-MT

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

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

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

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

- In equilibrium with parent

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

Methodology

General

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

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

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

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

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

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

f) The cumulative amount of each radionuclide present in the soil in each county was calculated from the estimated monthly depositions and nuclide half-life, correcting for decay during the month of deposition and decay from one month to another as well as ingrowth of daughter activity (e.g. Nb-95 from Zr-95).

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

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

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

Precipitation estimates

Monthly precipitation has been measured at over 8000 US Weather Service cooperative monitoring sites and data is available for most sites beginning in about 1900. This data is available on the world wide web (http://www.ncdc.noaa.gov/ol/climate/online/coop-precip.html). Not all sites were in operation at all times and even for sites in operation continuously, data was often missing for some or all months during a given year. Since there are about 3000 counties in the continental U.S., the average number of monitoring sites per county was about 3. However, some counties had a large number of sites (10 or more) while precipitation was not measured at all in other counties.

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

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

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

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

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

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

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

A similar variation with longitude is illustrated by Fig 4. Here the cumulative activity per cm of rain for cumulative Sr-90 measured in soil samples at sites in the latitude band 35-45 degrees is shown. Data from the cumulative deposition of Sr-90 from 1958-65 as measured in deposition in the HASL pot and column sites are also plotted. These data indicate a clear trend of a relatively constant specific activity in the eastern U.S. and then a steep increase as one approaches the mountainous area of western Colorado, Utah and Wyoming. The specific activity reaches a peak of about a factor of two at approximately the longitude of Salt Lake City but drops precipitously to less than northeastern U.S. levels as one reaches the West Coast. The result of this increase in specific activity is that sites such as Salt Lake City, where the average annual rainfall is about ½ that of New York City, received about the same total Sr-90 deposition as New York City. The exact reason for apparent steep gradient with longitude is not known but may be due to a combination of factors including the relatively high latitudes and increased thunderstorm activity during the months of peak stratosphere to troposphere air transfer (Hardy et al., 1968).

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

Specific activity of Sr-90 at NE US sites

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

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

Prior to 1954, there were no reported measurements of Sr-90 from which to make specific activity measurements. However, soil sample data were available for a few sites in the eastern U.S. These provided a crude estimate of the total deposition of Sr-90 from "global" fallout up to 1954. Almost all of this deposition was assumed to have occurred in 1953, primarily as a result of the high yield US tests carried out in the Pacific in late 1952. The monthly variation in specific activity during the year was assumed to be the same as that measured in NYC during 1954.

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

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

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

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

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

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

Because the variation with longitude and latitude is not uniform, counties near the boundary of quadrangles where the default specific activity estimates differ significantly will have larger uncertainties in Sr-90 deposition estimates than counties in sections of the US where the gradations from quad to quad are smaller. Clearly, as discussed later, a more sophisticated model might be developed, particularly if additional data can be located to better define the actual variations with latitude and longitude and with time. However, it is likely that the variations in precipitation within a county discussed earlier are a larger contributor to the total uncertainty in deposition in these areas than the crude estimates of geographical variation in specific activity.

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

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

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

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

In addition to the comparisons shown in figs. 6a-6f, the annual depositions for the years 1958-65 predicted by the model were compared to those at the measured sites for about 30 measurement sites with a significant amount of measured data. On average, the agreement in annual Sr-90 deposition was better than "10% although for some sites, there were differences in the calculated and measured total deposition density estimates of as much as "50% for some years.

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

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

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

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

Site	Soil Sample Date	Cumulative Deposition Density (Bq.m2)	
		Soil Sample	Model
Clallam County, WA	9/64	1150-4200 (6 sites)	2290
	9/65	1300-6440	2440
Puyallup, WA	9/64	2110	1850
	9/65	2180	2110
Mandan, ND	10/64	3000	1440
Bozeman, MT	9/64	2780	1630
Orono, ME	6/64	2110	2410
	7/65	2180	2480
St. Paul. MN	10/64	2740	1890
Corvalis, OR	9/64	1630	1920
	9/65	1920	2070
Burlington, VT	6/64	1960	2440
	7/65	2220	2590
Rapid City, SD	9/64	3590	3150
	9/65	3590	3480
Boise, ID	9/64	2150	1630
	9/65	2550	1810
Ithaca, NY	9/64	2040	2440
	10/65	2110	2590
Amherst, MA	6/64	2000	2660
	7/65	2330	2890
S. Wellflect, MA	6/64	2780	2920
	7/65	2890	3030
Logan, UT	9/64	1520	2590
	9/65	1810	2740
Desmoines. IO	9/64	2780	2960
	8/65	3030	3180
Kingston, RI	6/64	2780	3030
	7/65	3330	3180
Brigham City, UT	9/64	3440	2370
	9/65	3370	2550
New York City	12/64	2590	2590
Salt lake City, UT	9/64	3740	3260
	9/65	3850	3550

		Soil Sample	Model
Site	Soil Sample Date	Cumulative Deposition Density (Bq.m2)	
Heber, UT	9/64	2330	2740
	9/65	2550	2960
Rosemont, NB	9/64	2890	2370
	9/65	3110	2850
Columbus, OH	8/64	2890	2180
	8/65	2960	2370
Derby, CO	9/64	2180	1700
	9/65	2290	1920
Healdsburg, CA	9/64	1920	2070
	9/65	1920	2220
Cedar City, UT	9/64	1260	1330
	9/65	1410	1550
Norfolk, VA	2/64	2110	2220
	2/65	2740	2290
	2/66	2810	2370
Tulsa, OK	10/64	1850	2330
Florence, SC	2/65	2890	2220
	3/66	2810	2220
Los Angeles, CA	9/64	810	1000
	9/65	850	1110
Atlanta, GA	2/64	2000	2510
	3/65	2740	2590
	3/66	2110	2660
El Centro, CA	9/64	570	110
	9/65	670	110
Newton, MS	3/65	1890	2260
Tifton, GA	3/65	2000	2290
Jacksonville, FL	2/65	2260	2370
	3/66	2150	2520
New Orleans, LA	3/65	2260	2520
	3/66	1890	2630
Ft. Lauderdale, FL	2/65	1850	2070
	3/66	2370	2070

Soil data from Meyer et al., 1968.

Ratios of deposition to Sr-90, Sr-89

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

Because of the sparseness of actual data, a critical assumption was required for this preliminary study: i.e. that the ratios of the various radionuclide deposition densities for any given month did not vary significantly across the US. Considering that most of the fallout deposited in the continental U.S. was from debris originally injected into the stratosphere where it had time to mix and equilibrate, this assumption is probably reasonable for the nuclides with half-lives greater than about a month. However, it may not be reasonable for nuclides with shorter half-lives for several reasons. First, some significant fraction of the fallout during months of testing, particularly for tests held at latitudes comparable to the U.S., may be from debris injected into the troposphere. The fallout would then vary across the U.S. because of decay in transit as the debris traversed the country. If debris from the stratosphere was transferred preferentially to the troposphere at specific longitudes, as indicated by figure 4, again one might expect a variation with longitude in deposition. Debris injected into the troposphere tends to remain in a band close to the latitude of injection. However, some of the debris injected into the troposphere from US tests in the Pacific at low latitudes might have diffused to higher latitudes and impacted the southern latitudes of the US more than the more northerly latitudes. Unfortunately, except for Sr-89 with a half-life of 50 d, there is insufficient data upon which to base a geographical variation in deposition for these nuclides. In general, the Sr-89 to Sr-90 ratios do not indicate any significant geographical variation. Measurements of short-lived nuclides have been reported in precipitation and in air at only a few scattered sites across the US and only during years after 1957.

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

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

Although the model is not able to accurately predict the actual deposition density of a particular short-lived nuclide, it served as a useful guide to the expected ratio of depositions for nuclides of about the same half life. Thus, for example, for periods when no measurements of Zr-95 were reported anywhere in the US, but measurements of Sr-89 were available, the model estimates of the ratio of Zr-95 to Sr-89 as a function of time were used to estimate the Zr-95/Sr-90 deposition density ratio from the average measured Sr-89/Sr-90 ratio. Similarly, where Ce-144 data were available, but not Ru-106 data, the model deposition-density ratios of Ru-106/Ce-144 and the measured ratios of Ce-144/Sr-90 were used to estimate the Ru-106/Sr-90 ratio. A similar procedure was used to estimate I-131 deposition density from the sparse Ba-140 measurements. Ratios of Nb-95 to Zr-95 were estimated based on the estimated age of the Zr-95 being deposited and the relative half-lives of Zr-95 and Nb-95[2]. Since the half-lives of Cs-137 and Sr-90 are similar (Table 2), the ratios of deposition were assumed to be equal to the production ratio for this report.[3] For periods where no data were available for a particular radionuclide the author made rough estimates using the production ratios shown in Table 2, and the model calculations as a guide. In all cases, where actual credible data was available, the actual data was used.

Again, the author's judgement was used to evaluate available data and thus the final estimates of the isotopic ratios presented in Appendix 1 of this report are a synthesis if the available data, the model predictions, and the authors professional judgement. Recommendations for estimating the uncertainty in and improving the estimates of isotopic ratios are discussed later in this report. The estimated ratios of Zr-95 to Sr-90 deposition density versus time are shown in figure 7. Note that the ratio approaches the ratio of production rates given in Table 2 during the Fall of 1961. This is expected since

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

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

the stratospheric reservoir of Sr-90 was relatively depleted due to the moratorium on atmospheric testing from 1959 through most of 1961. At other times, the large inventory of Sr-90 in the stratosphere from earlier tests reduces the ratio below the production ratio even during months of heavy testing.

Deposition densities of radionuclides contributing to external radiation exposure

The deposition density of each of the radionuclides listed in Table 2 was thus estimated for each county and month by multiplying the estimated Sr-90 deposition density for that county and month by the monthly isotopic ratio estimates in given in Appendix 1. The estimates for the more important contributors to external dose, Zr-Nb-95 and Cs-137 are probably quite reasonable since Zr-95 was measured in precipitation or air at several sites in 1958 and 1961-62 and Sr-89 was measured at a relatively large number of sites (HASL, 1958-72). Furthermore, the model Sr-89/Zr-95 ratios agree reasonably well with the measurements for periods where both were measured simultaneously, supporting the use of the model ratios at other times. Similarly, the estimates for Ce-144 and Ru-106 are also considered reasonably valid. The deposition of Cs-137 as estimated from the production ratios is in reasonable agreement with available data. Ru-103 was not generally measured but Ce-141 measurements were occasionally reported. The use of the model and available Ce-141 data to infer Ru-103 deposition is probably reasonably valid. The most uncertain estimates are for Ba-140 and I-131, both for reasons discussed above regarding geographical variations and due to the sparseness of available data. No actual data on I-131 deposition density was available for this report and thus I-131 deposition densities were estimated from available Ba-140 data. Scattered Ba-140 measurements in precipitation are available for Pittsburgh, Westwood, NJ, Houston, Richmond CA, and Fayetteville, Arkansas at various times and a rough ratio to Sr-89 could be inferred from these measurements that was consistent with the ratio suggested by the Bennett model.

External radiation exposure

For the author’s previous report on external exposure from NTS fallout, conversion factors from Beck (1980) were used to convert cumulative deposition density[4] to exposure rate in air assuming the radioactivity was distributed in the soil with a relaxation length of about 0.1 cm for the first 20 days. From 20 d to 200 d, a relaxation length of 1 cm was used, while for times greater than 200 days, a relaxation length of 3 cm was used. This report uses a similar model, multiplying the deposition on the ground less than 1 month by the conversion factor corresponding to a relaxation length of 0.1 cm. A relaxation length of 1 cm is used for the activity remaining in the soil that was deposited within the period 1-6 months while a relaxation length of 3 cm was used to calculate the exposure rate from the activity that had been present for greater than 6 months. The corresponding deposition-density to exposure conversion factor for each of these relaxation lengths is from Beck (1980). Since the penetration into the soil would be

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

slower in more arid regions, maintaining the 0.1-cm relaxation length for the first 30 d provides a slightly conservative estimate of the exposure for sites with greater precipitation. Table 6 illustrates the dependence of the exposure rate in air on the various relaxation lengths. Note that the exposure rate is reduced by about 1/3 as the activity penetrates to a relaxation length of 1 cm and about ½ as the activity penetrates to a relaxation length of 3 cm from 0.1 cm. This accentuates the importance of the first few weeks after deposition with respect to total external radiation exposure to an even greater degree than previous calculations based only on radionuclide decay. For a discussion of available data on nuclide penetration with depth on the soil see Beck (1999).

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

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

Whole-body effective dose

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

Thus the dose to adults exposed outdoors is about 2/3 the outdoor exposure. However, most people spend most of their time indoors and thus their exposure is reduced greatly due to attenuation of the radiation by building materials. The amount of shielding (i.e. the shielding factor) will depend on the type of structure. In general, based on a review of the available literature, it is estimated that heavily constructed buildings made of brick or concrete will provide a shielding factor of about 0.2 ± 20% (1 s,d,) while lightly constructed buildings will provide a shielding factor of about 0.4. ± 20% (NCRP, 1999). These estimates are fairly conservative and allow for a small amount of radioactivity that may be tracked into the home from contamination of shoes, etc. Assuming that on average most persons spend about 80% of their time indoors (UNSCEAR, 1993; NCRP, 1999) with an average shielding factor of 0.3, their whole body effective dose would be 0.66 * (0.2 + 0.8 * 0.3) = 0.29 x Outdoor exposure. However, the UNSCEAR estimated that persons who work outdoor spend on average only 40% of their time indoors and the most exposed outdoor worker spends only about 30% of his/her time indoors. The NRC (1977) made a similar estimate of 40% of time spent indoors for the maximum exposed individual. Assuming only 30% indoors in a lightly shielded structure for the maximum exposed outdoor worker, the dose to the most exposed individuals would be
0.66 * (0.7 + 0.3 * 0.4) = 0.54 x Outdoor exposure or almost twice that of the average exposure. Conversely, the UNSCEAR (1993) estimated indoor workers spend only about 10% of their time outdoors while other estimates indicate some individuals spend even less time outdoors. Assuming 5% as a reasonable estimate for the least exposed individual living in a well shielded house and/or working in a well-shielded building, the minimum exposed individual would receive a dose of about 0.66 * (0.05 + 0.95 * 0.2) = 0.16 x outdoor exposure, or about ½ that of the average dose.

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

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

Beta-ray skin dose

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

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

Discussion of Results

Fallout deposition

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

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

As can be seen from Table 7, the deposition density of long-lived radionuclides from “global” fallout is about a factor of 10-15 greater than that from NTS fallout. However, the total deposition of short-lived nuclides such as I-131 was much less for “global” fallout than for NTS fallout. The “global” to NTS fallout ratios of population-weighted deposition density differ from the total deposition ratios reflecting the more uniform deposition of “global” fallout across the country. As shown in Beck (1999), the deposition of NTS fallout generally declined as the distance from NTS increased. The higher relative proportion of “global” fallout in the more populous (and higher rainfall) eastern U.S. resulted in a relatively higher per capita exposure from “global” fallout for the same total continental U.S. deposition.

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

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

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

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

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

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

Exposure and dose

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

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

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

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

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

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

A large number of fission products are produced in a nuclear explosion. However, only a relatively few account for most of the external exposure. Table 10 shows the largest contributors to total integrated exposure (% of total integrated exposure from nuclide and decay products). The global fallout percentages vary only slightly with location bit vary significantly from year to year as shown in figure 14. Figure 15 shows the per capita dose that resulted from each radionuclide as a function of time. The short-lived radionuclides have been grouped. As can be seen, during periods of testing the shorter-lived isotopes contribute relatively more to the dose while for years with no testing the longer-lived radionuclides are dominant. In contrast to the doses from NTS fallout, very short-lived radionuclides such as Te-I-132 and I-131 were insignificant contributors to exposure rates while Zr-Nb-95 accounted for a large portion of the exposure. For NTS fallout, Zr-Nb-95 was significant only at large distances from the NTS (Beck, 1999). Most of the cumulative dose from "global" fallout was due to Zr-Nb-95 and the longer-lived nuclides. Cs-137 and Zr-Nb-95 accounted for about 70% of the cumulative population exposure (see Table 9). In contrast, Cs-137 contributed only a small amount of (about 2%) of the integral dose from NTS fallout (Beck, 1999).

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

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

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

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

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

Location	Date	Measurement (: R/h)*	Model estimate (: R/h)*
Butte, MT	9/27/62	2.3	1.2
Missoula, MT	9/27/62	1.6	1.6
Ellensburg, WA	9/29/62	0.5	1.4
Seattle, WA	9/29/62	2.2	1.8
Clallam Cty, WA	10/1-2/62	2.0 (avg. of 5 sites)	1.8
Corvalis, OR	10/3/62	1.0	2.3
Crater Lk, OR	10/4/62	2.9	1.9
Richmond, CA	10/5/62	0.7	0.5
	10/12/63	1.4	1.2
Felton, CA	10/6/62	1.1	0.9
Santa Cruz, CA	10/6/62	1.0	0.9
Sunnyvale, CA	10/6/62	0.7	0.7
	10/12/63	0.4	1.4
Reno, NV	10/7/63	1.0	2.4
Winnemucca, NV	10/8/62	1.2	0.9
Elko, NV	10/8/62	1.8	2.2
	10/8/63	2.5	2.6
Wendover, UT	10/8/62	1.9	2.2
Salt Flats nr. Wend.	10/9/62	3.1	2.2
	10/16/63	1.7	1.8
Rawlins, WY	10/10/63	1.6	1.5
Laramie, WY	10/10/62	4.1	2.5
	10/8/63	3.6	1.8
Ft. Collins, CO	10/10/62	2.1	2.6
Denver, CO	10/10/62	1.6 (avg. of 5 sites)	2.2
	10/19/63	1.0 (avg. of 6 sites)	1.8
Colo. Springs, CO	10/11/62	2.7 (avg. of 2 sites)	2.3
	10/20/63	1.6 (avg. of 4 sites)	2.2
La Junta, CO	10/11/62	2.0	1.7
Dodge City, KS	10/12/62	3.1	2.4
	10/21/63	2.2	1.8
Wichita, KS	10/12/62	3.6	3.5
Kansas City, MO	10/13/62	4.1	3.6
Hannibal, MO	10/13/62	4.1	4.5
Springfield, IL	10/14/63	3.8	2.3
Franklin Pk., IL	10/22/63	2.5	2.5
Argonne Lab	10/15/62	2.5	2.8
	10/3/63	3.1 (2 sites)	2.8
Somerset, PA	10/16/62	3.6	3.6
	10/1/63	6.8	2.3
Carlisle, PA	4/5/63	4.4	3.8
	10/1/63	1.9	1.8
Decatur, AL	4/7/63	6.0	6.0
Memphis, TN	4/8/63	5.0	5.3
Little Rock, Ak	4/9/63	6.6	3.9
Houston, TX	4/10/63	5.6	1.8
Galveston, TX	4/10/63	0.5	1.2
Lake Chas., LA	4/14/63	5.2	3.1
Bay Minette, LA	4/13/63	4.6	3.2
Macon, GA	4/16/63	4.3	4.4
Aiken, SC	4/17/63	6.6	4.7

Location	Date	Measurement (: R/h)*	Model estimate (: R/h)*
US25&SC19, SC	4/17/63	4.2 (5 sites)	4.7
Nr. Warrenton, NC	4/18/63	4.1	3.8
Madison, WI	9/22/62	2.6	3.0
Spring Valley, MN	9/22/62	2.6	3.8
	10/3/63	2.4	3.4
Sioux falls, SD	9/23/62	5.1 (2 sites0	4.0
	10/5/63	3.6	2.6
Chamberlain, SD	9/23/62	4.6	4.2
	10/6/63	3.6	2.9
Murdo, SD	9/24/62	3.6	5.0
	10/6/63	3.7	3.0
Rapid City, SD	9/24/62	3.8 (2 sites)	5.3
	10/17/63	2.8	3.8
Spearfish, SD	9/24/62	3.7	6.6
Sundance, WY	9/25/62	2.3	5.2
	10/7/63	2.7	3.1
Moorecroft, WY	9/25/62	2.3	5.2
	10/7/63	2.7	3.1
Pelham, NY	8/63	3-5 (multiple msmts.)	3.9

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

The doses discussed above are from gamma irradiation. As discussed in Beck (1999), the ICRU (1997) estimated the beta skin dose rate from a plane source of fission products to be about 8-16 times the total effective dose. In Beck (1999), the ratio of dose rates for a 0.1-cm relaxation length for early arrival times was estimated to be about 3-5. The age (arrival time) of “global” fallout compared to NTS fallout was very long and most of the dose was delivered over a long period of time during which the longer-lived radionuclides penetrated further into the soil. It can thus be assumed that the beta skin dose from “global” fallout was even less significant than that estimated for NTS fallout. This is particularly true since most of the global fallout was deposited during rain and the assumption of a 0.1-cm relaxation length for the first 30 days is thus probably conservative. Only a relatively few longer-lived nuclides emitting higher energy beta rays such as Y-90, the daughter of Sr-90, contribute significantly to the dose.

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

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

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

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

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

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

In addition to estimating the uncertainties in the various deposition and exposure estimates, the estimates themselves might be improved if additional data can be located, particularly data on the ratios of the deposition of the various nuclides as a function of location in the US. Additional data could also be used to develop a more sophisticated, higher resolution, model of the distribution of Sr-90 specific activity with latitude and longitude. This might be accomplished using a technique such as kriging to provide estimates of specific activity that vary smoothly across the country. A more sophisticated model would also attempt to account for the impact of "dry" deposition at arid locations. A thorough review and assessment of the vast amount of other scattered sources of data might also allow the estimates of isotopic ratios for particular months to be improved. It may also allow improvements to the atmospheric model, which would then allow one to more confidently utilize the model for periods with no data. Because the current effort was limited in scope and resources, only a small subset of the vast literature could be evaluated and utilized.

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

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

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

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

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

Summary and Conclusions

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

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

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

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

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

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

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

Figure 12: Total dose received by typically exposed adults from “global” fallout, 1953-2000. Average for each county.

Figure 13: Dose received by typically exposed adults for each county during 1962.

Figure 14: Fraction (%) of total annual population dose from each radionuclide; 1953-1972.

Figure 15: Monthly variations in Per Capita Dose from specific radionuclides. The short-lived radionuclides (I-131, Ba-La-140, Ru-103, and Ce-141) are grouped together.

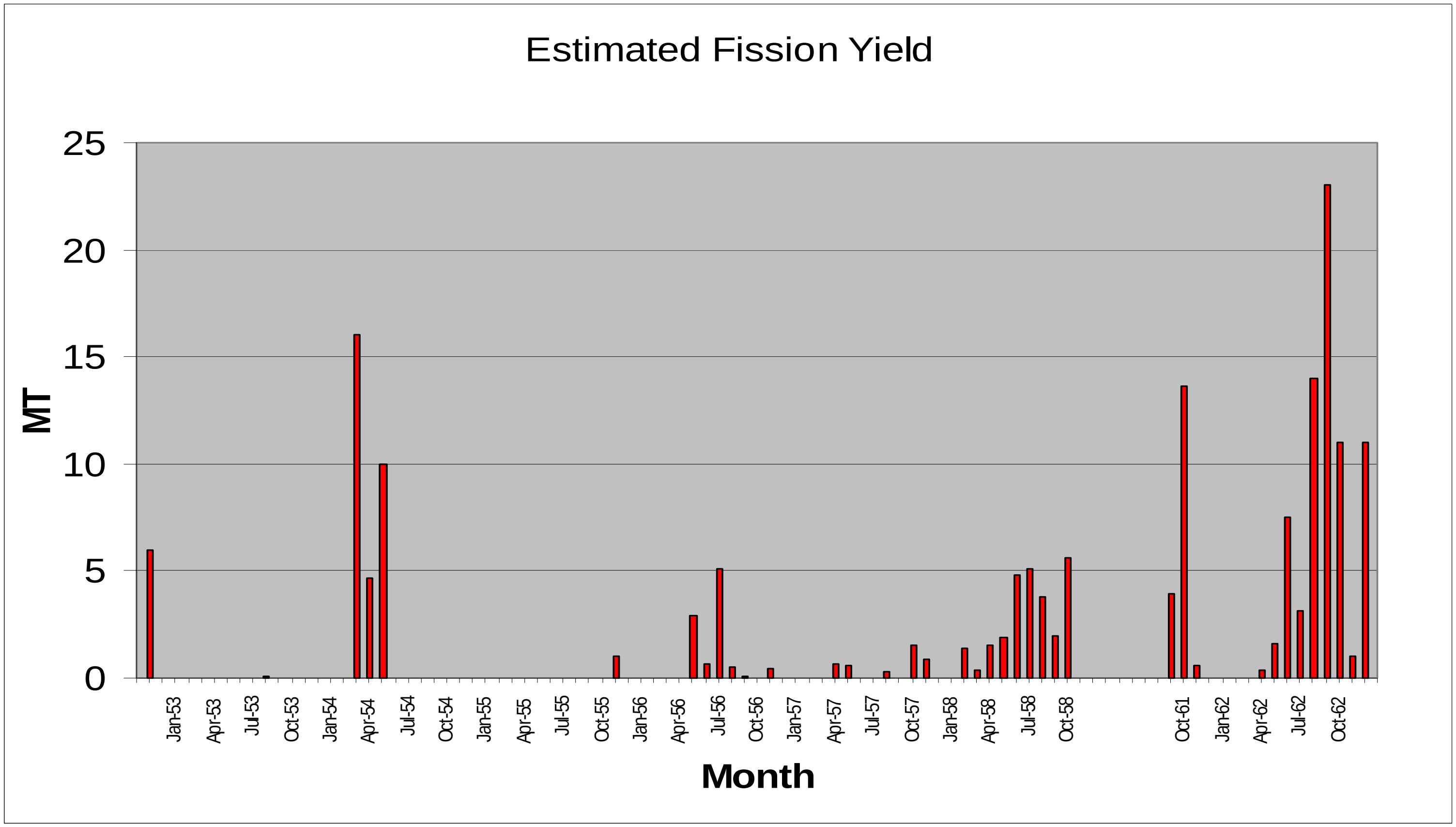

Estimated Fission Yield
25
20
15
10
5
0
MT
Jan-53
Apr-53
Jul-53
Oct-53
Jan-54
Apr-54
Jul-54
Oct-54
Jan-55
Apr-55
Jul-55
Oct-55
Jan-56
Apr-56
Jul-56
Oct-56
Jan-57
Apr-57
Jul-57
Oct-57
Jan-58
Apr-58
Jul-58
Oct-58
Oct-61
Jan-62
Apr-62
Jul-62
Oct-62
Month

Figure 1.

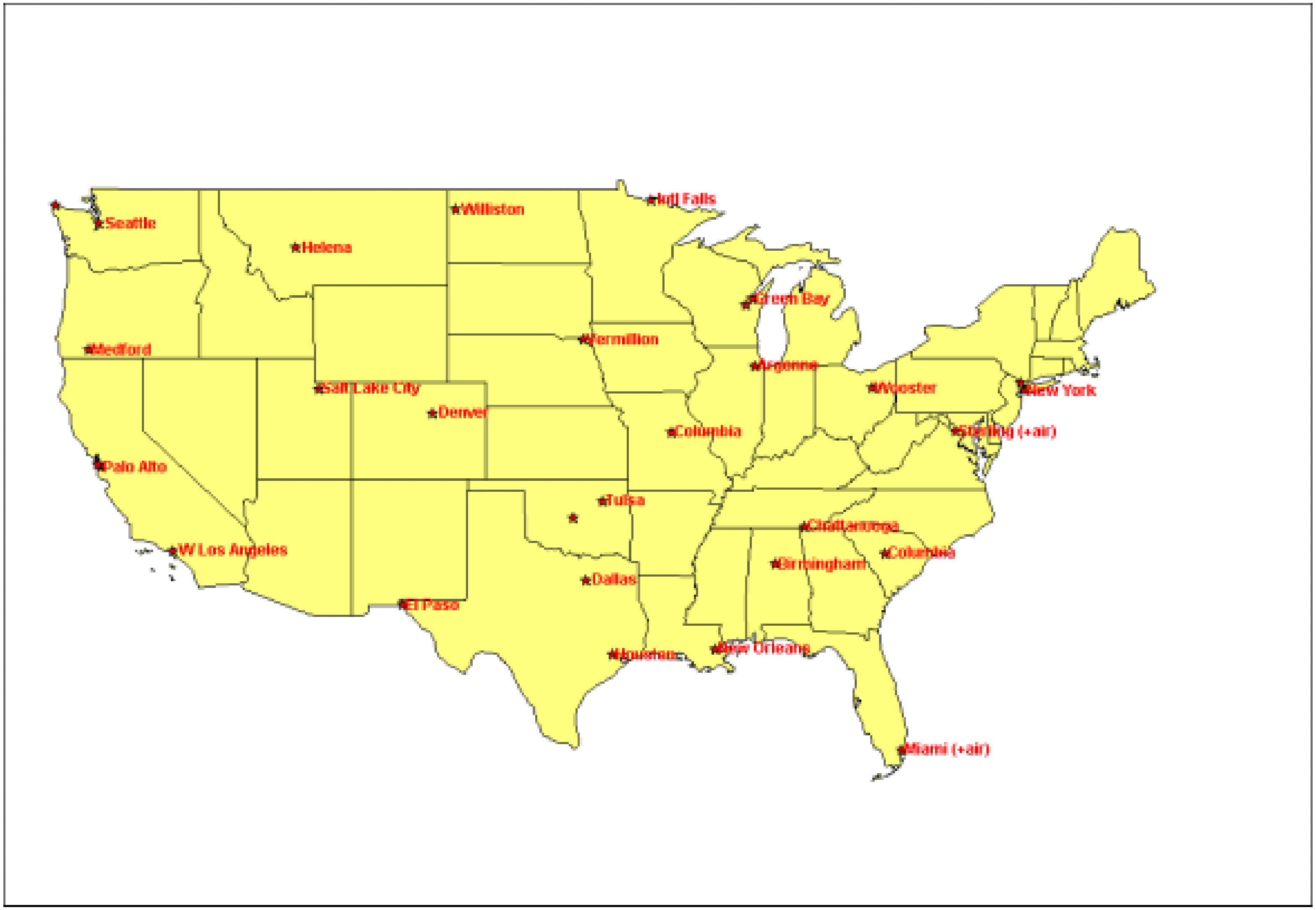
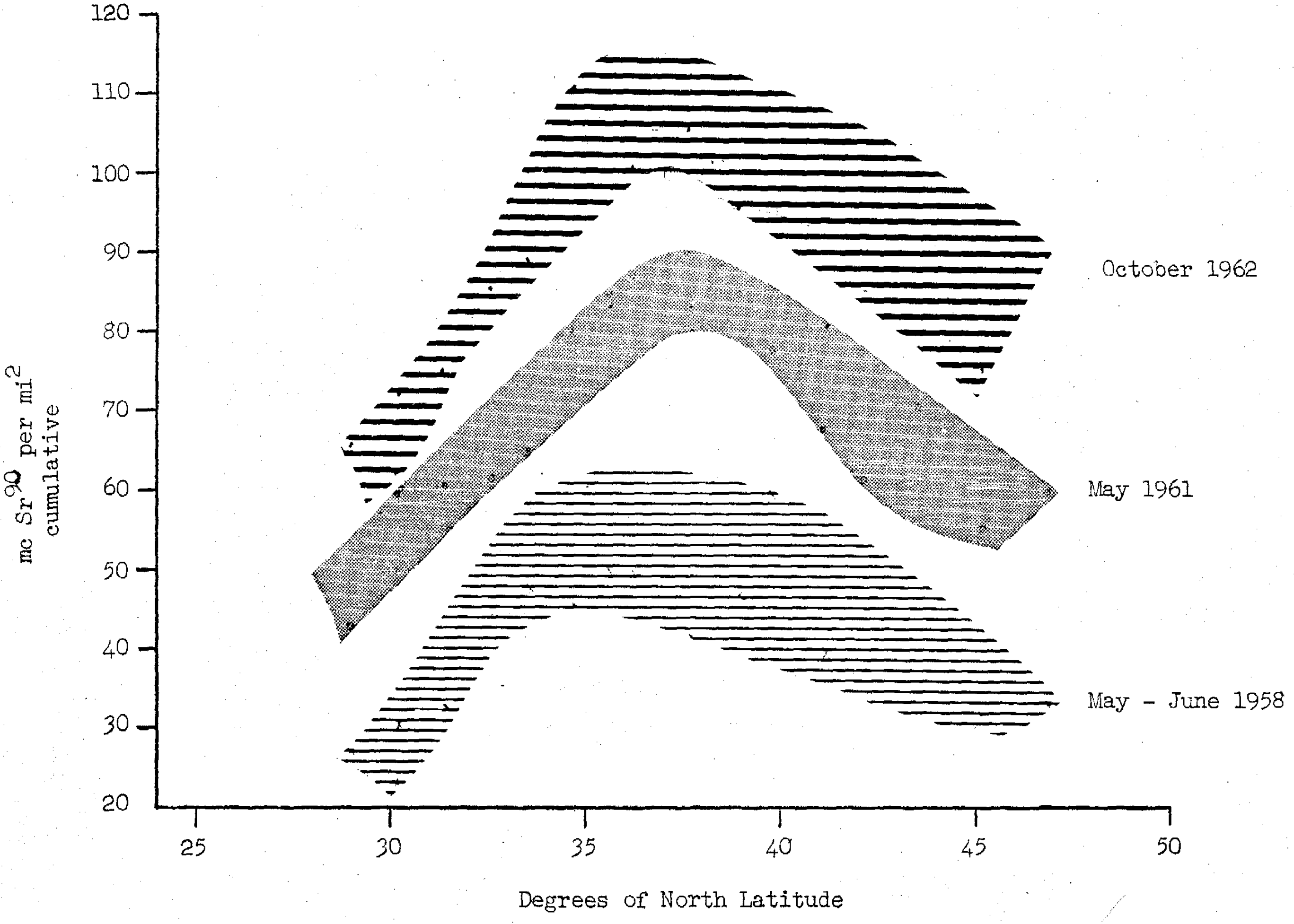

Intl Falls
Williston
Seattle
Helena
Green Bay
Vermillion
Medford
Argonne
Salt Lake City
Wooster
New York
Denver
Columbia
Sterling (+air)
Palo Alto
Tulsa
Chattanooga
W Los Angeles
Columbia
Birmingham
Dallas
El Paso
New Orleans
Houston
Miami (+air)

Figure 2.

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



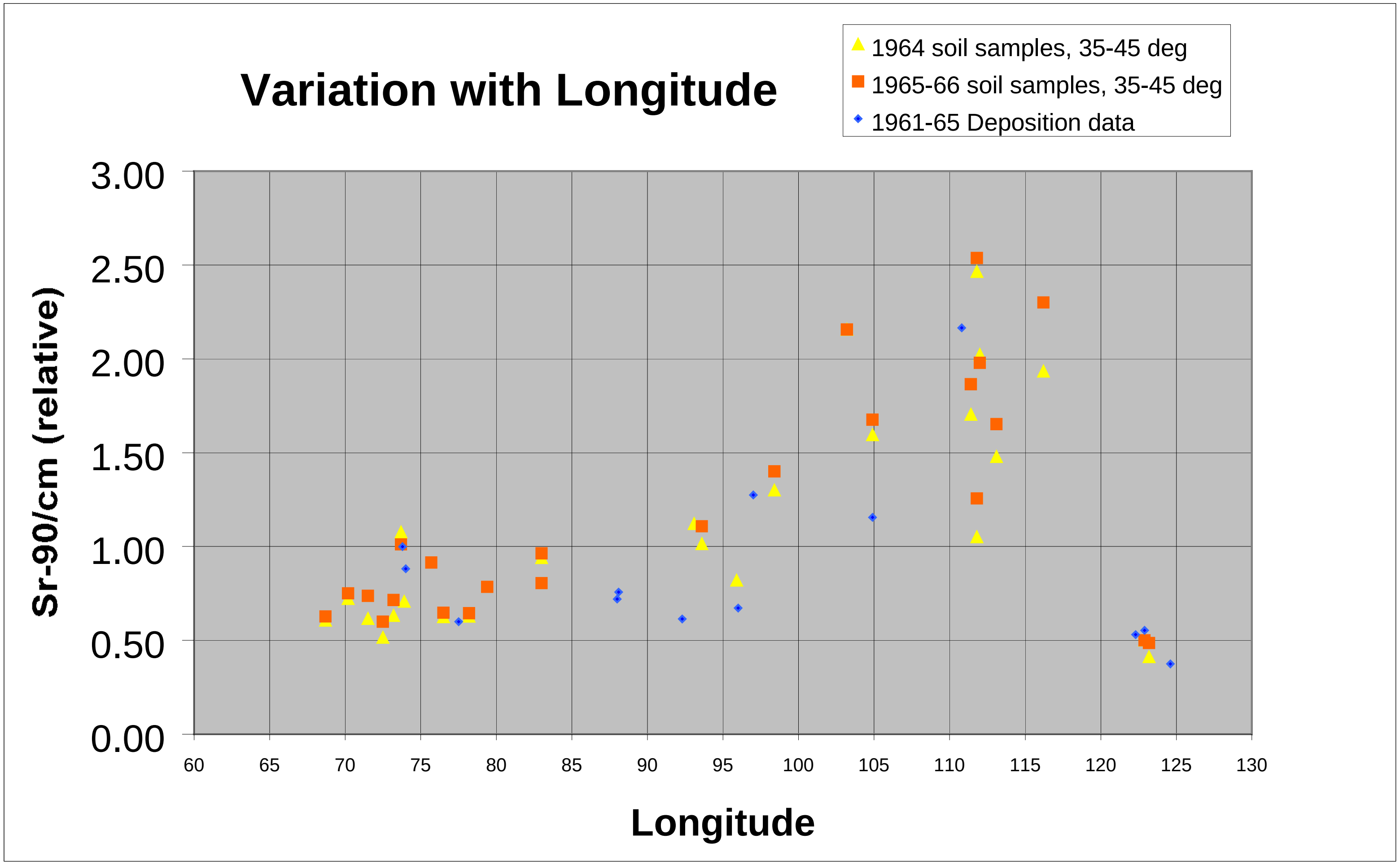
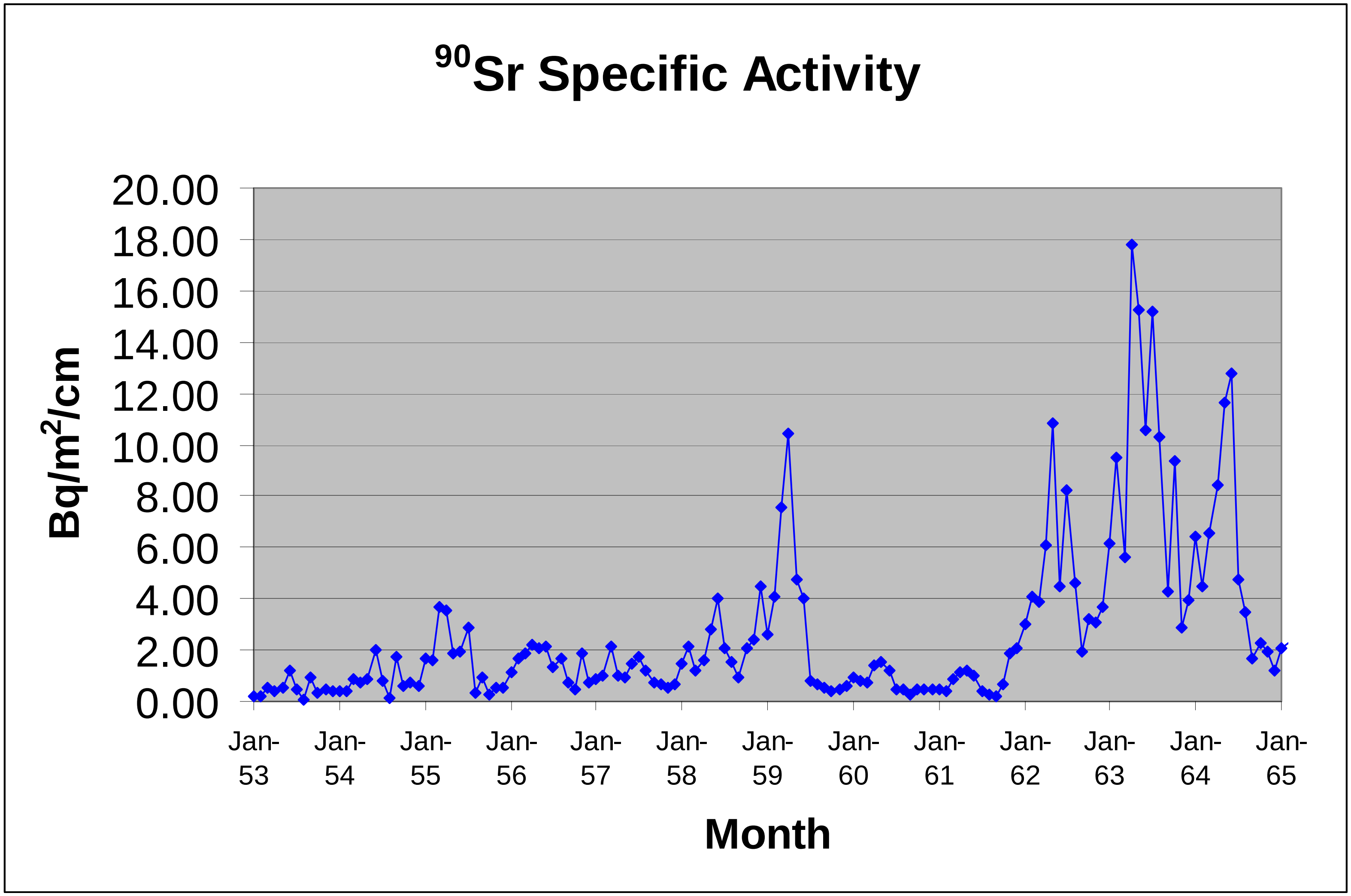

Variation with Longitude
▲ 1964 soil samples, 35-45 deg
■ 1965-66 soil samples, 35-45 deg
◆ 1961-65 Deposition data
Sr-90/cm (relative)
3.00
2.50
2.00
1.50
1.00
0.50
0.00
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
Longitude

Figure 4.



^{90}Sr Specific Activity
Bq/m^2/cm
20.00
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
Jan-53
Jan-54
Jan-55
Jan-56
Jan-57
Jan-58
Jan-59
Jan-60
Jan-61
Jan-62
Jan-63
Jan-64
Jan-65
Month

Figure 5.

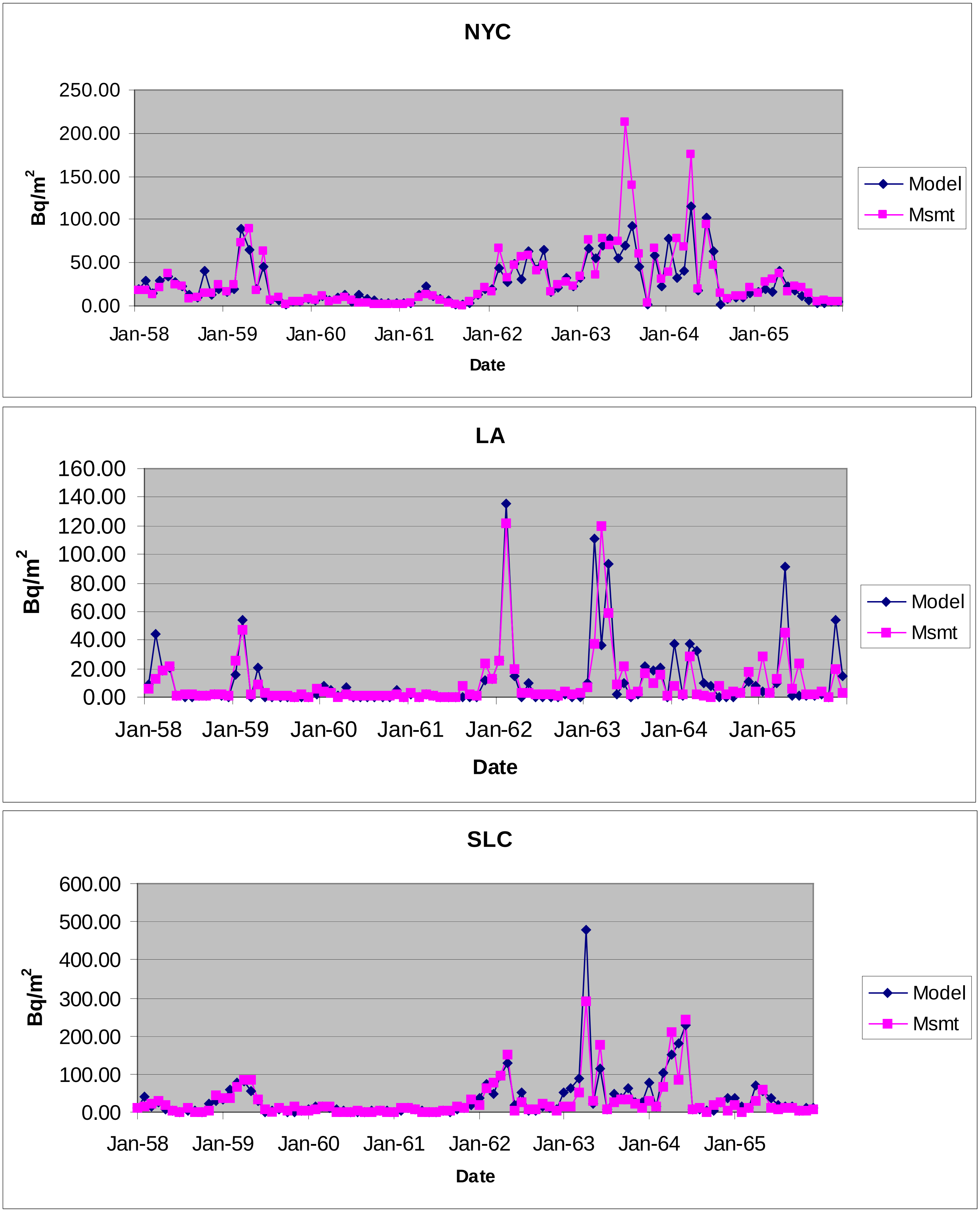
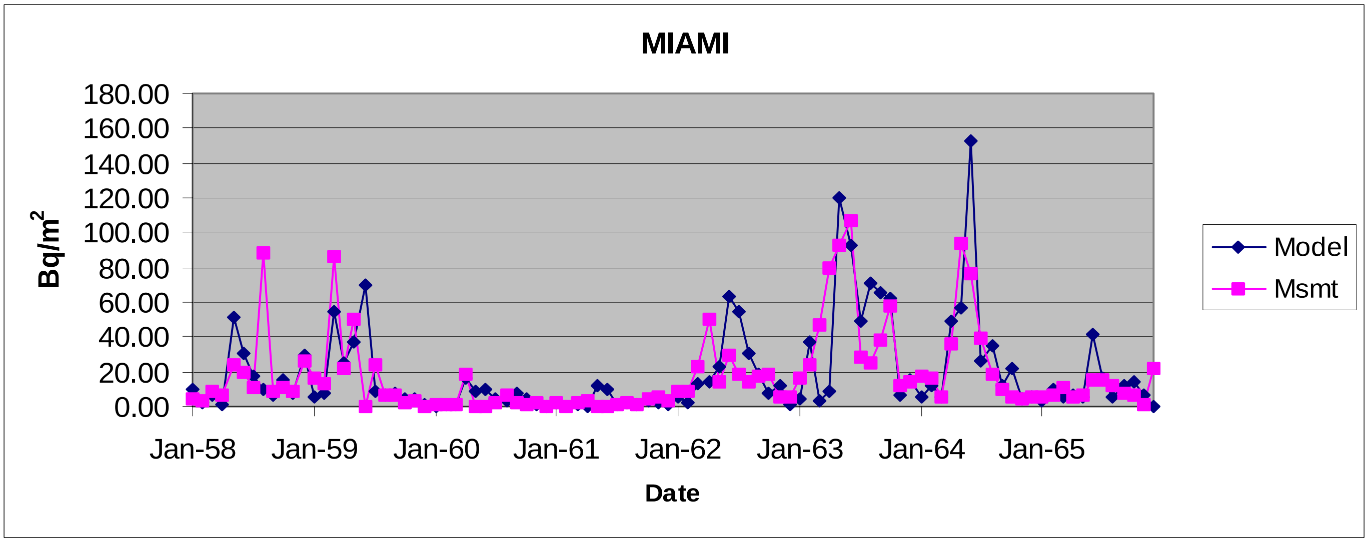
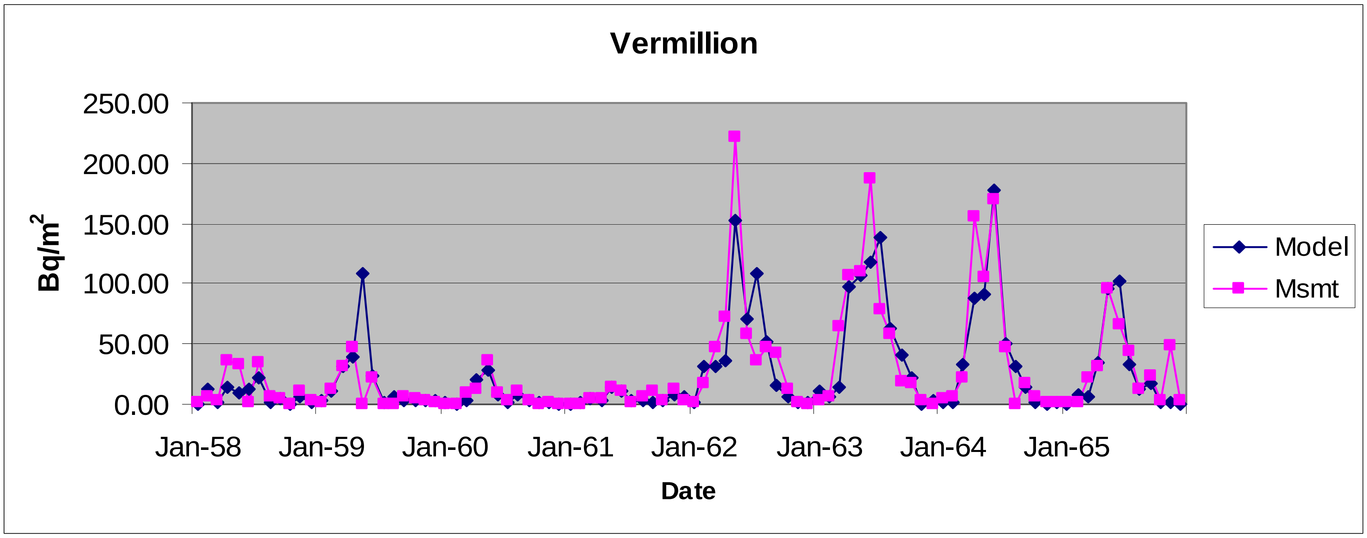

NYC
250.00
200.00
150.00
100.00
50.00
0.00
Bq/m^2
Jan-58
Jan-59
Jan-60
Jan-61
Jan-62
Jan-63
Jan-64
Jan-65
Date
Model
Msmt
LA
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
Bq/m^2
Jan-58
Jan-59
Jan-60
Jan-61
Jan-62
Jan-63
Jan-64
Jan-65
Date
Model
Msmt
SLC
600.00
500.00
400.00
300.00
200.00
100.00
0.00
Bq/m^2
Jan-58
Jan-59
Jan-60
Jan-61
Jan-62
Jan-63
Jan-64
Jan-65
Date
Model
Msmt

Fig 6


MIAMI
Bq/m2
180.00
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
Jan-58
Jan-59
Jan-60
Jan-61
Jan-62
Jan-63
Jan-64
Jan-65
Date
Model
Msmt


Vermillion
Bq/m2
250.00
200.00
150.00
100.00
50.00
0.00
Jan-58
Jan-59
Jan-60
Jan-61
Jan-62
Jan-63
Jan-64
Jan-65
Date
Model
Msmt

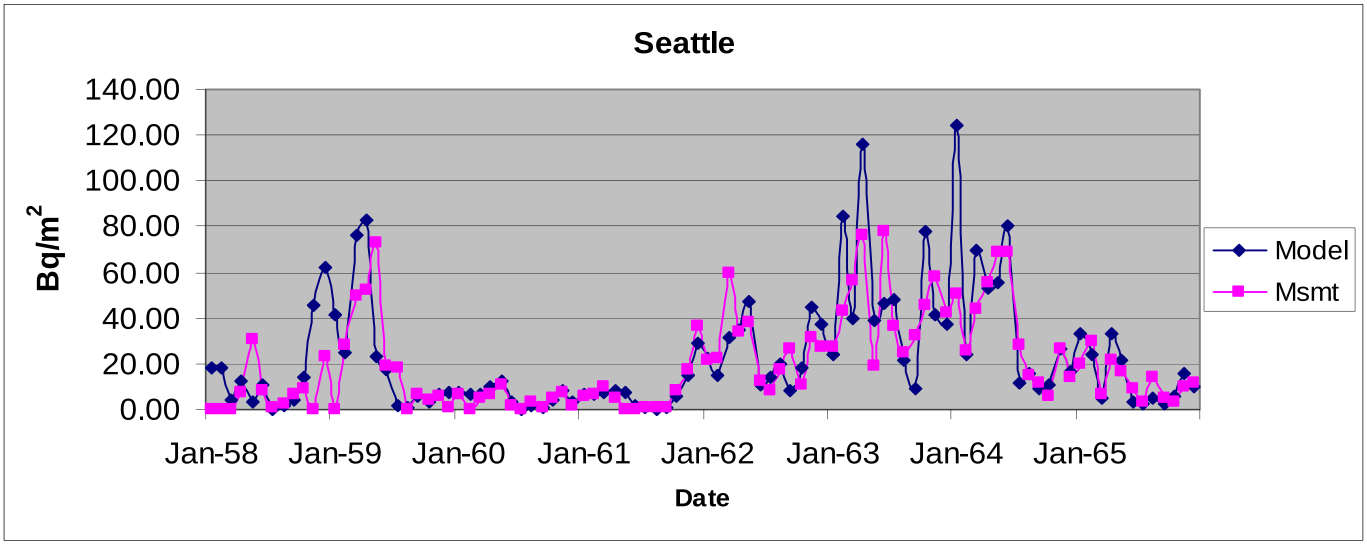
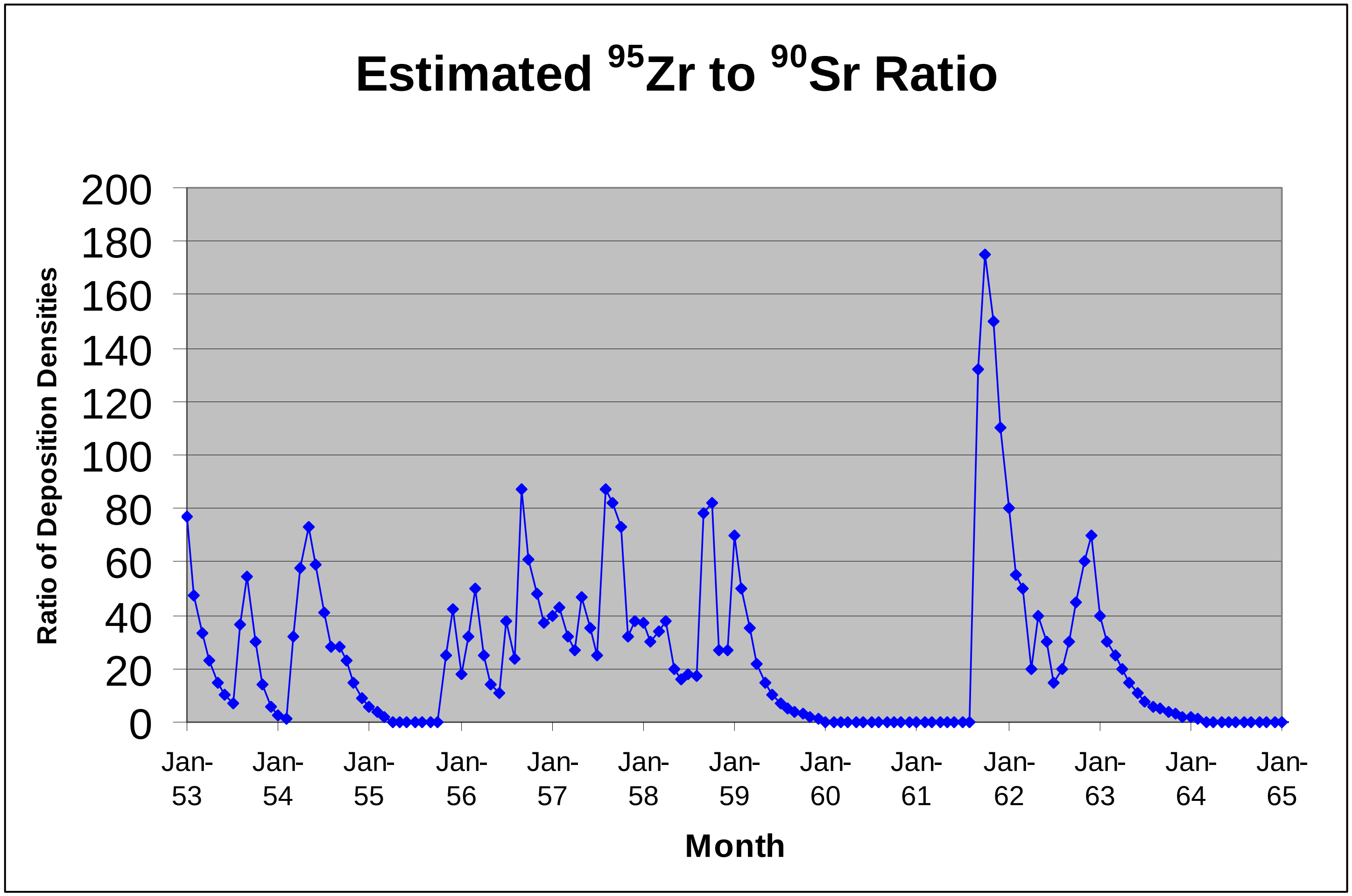

Seattle
Bq/m2
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
Jan-58
Jan-59
Jan-60
Jan-61
Jan-62
Jan-63
Jan-64
Jan-65
Date
Model
Msmt

Figure 7.



Estimated ^{95}Zr to ^{90}Sr Ratio
Ratio of Deposition Densities
200
180
160
140
120
100
80
60
40
20
0
Jan-53
Jan-54
Jan-55
Jan-56
Jan-57
Jan-58
Jan-59
Jan-60
Jan-61
Jan-62
Jan-63
Jan-64
Jan-65
Month

Figure 8.

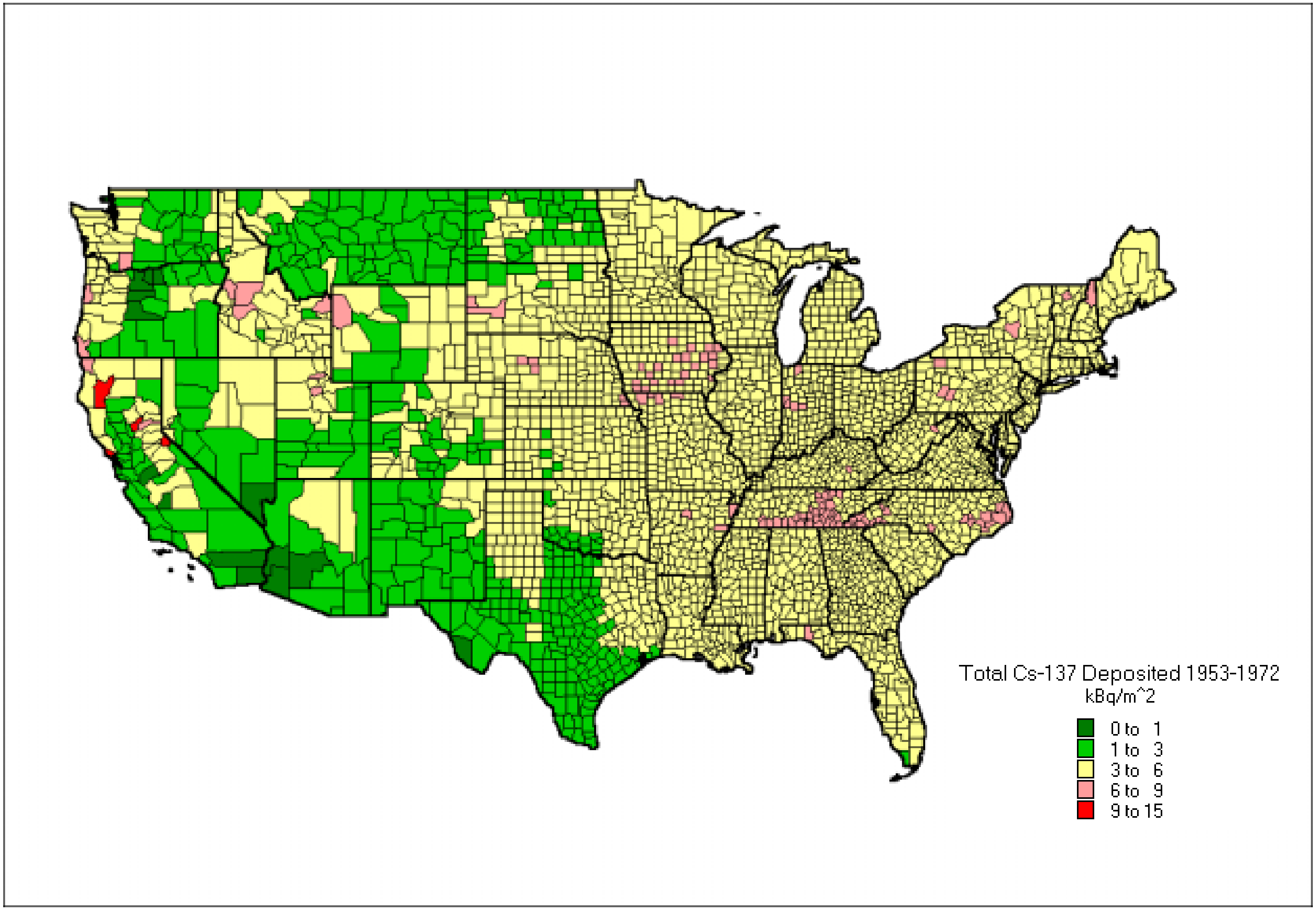

Total Cs-137 Deposited 1953-1972
kBq/m^2
0 to 1
1 to 3
3 to 6
6 to 9
9 to 15

Figure 9.

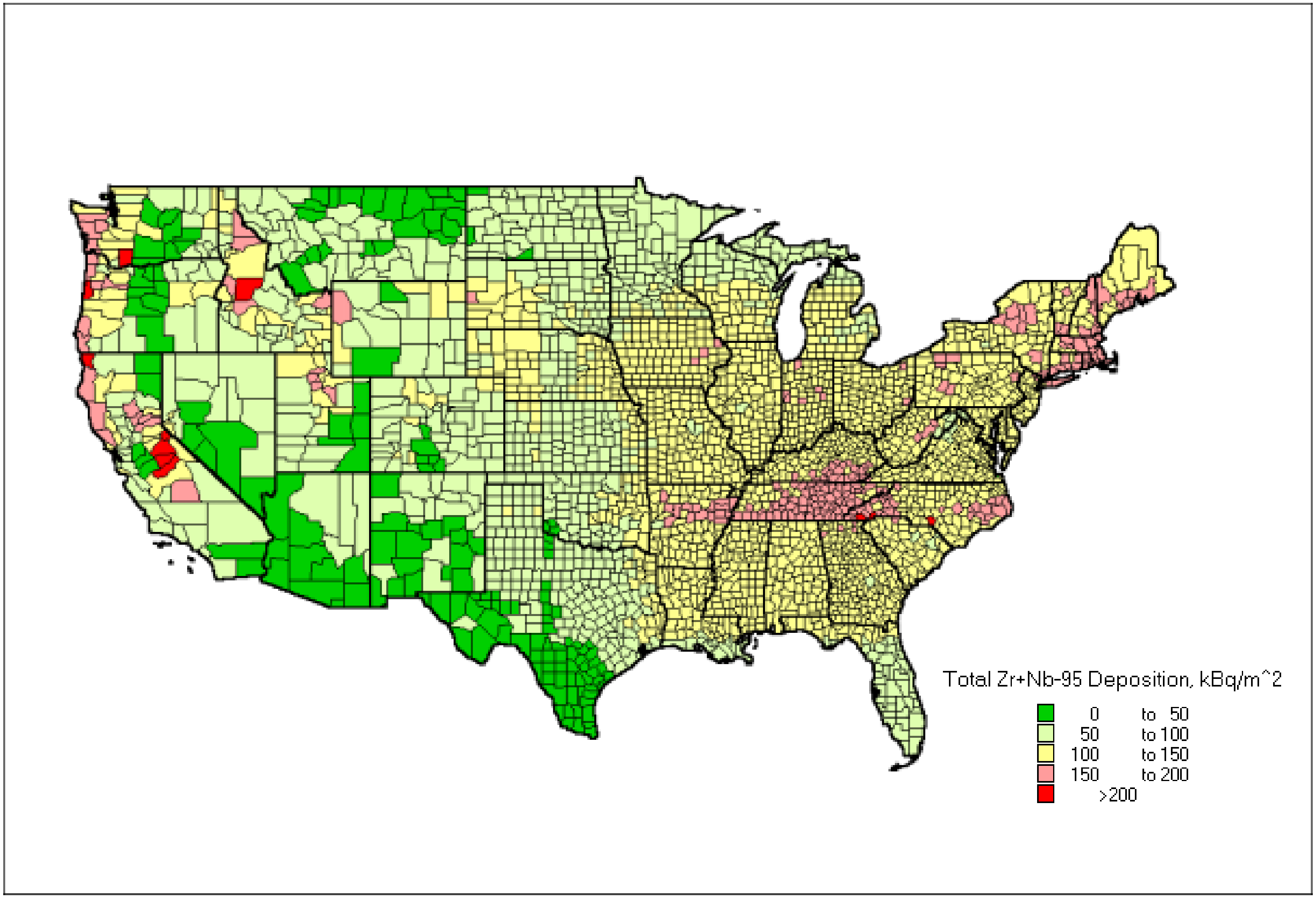

Total Zr+Nb-95 Deposition, kBq/m^2
0 to 50
50 to 100
100 to 150
150 to 200
>200

Figure 10.

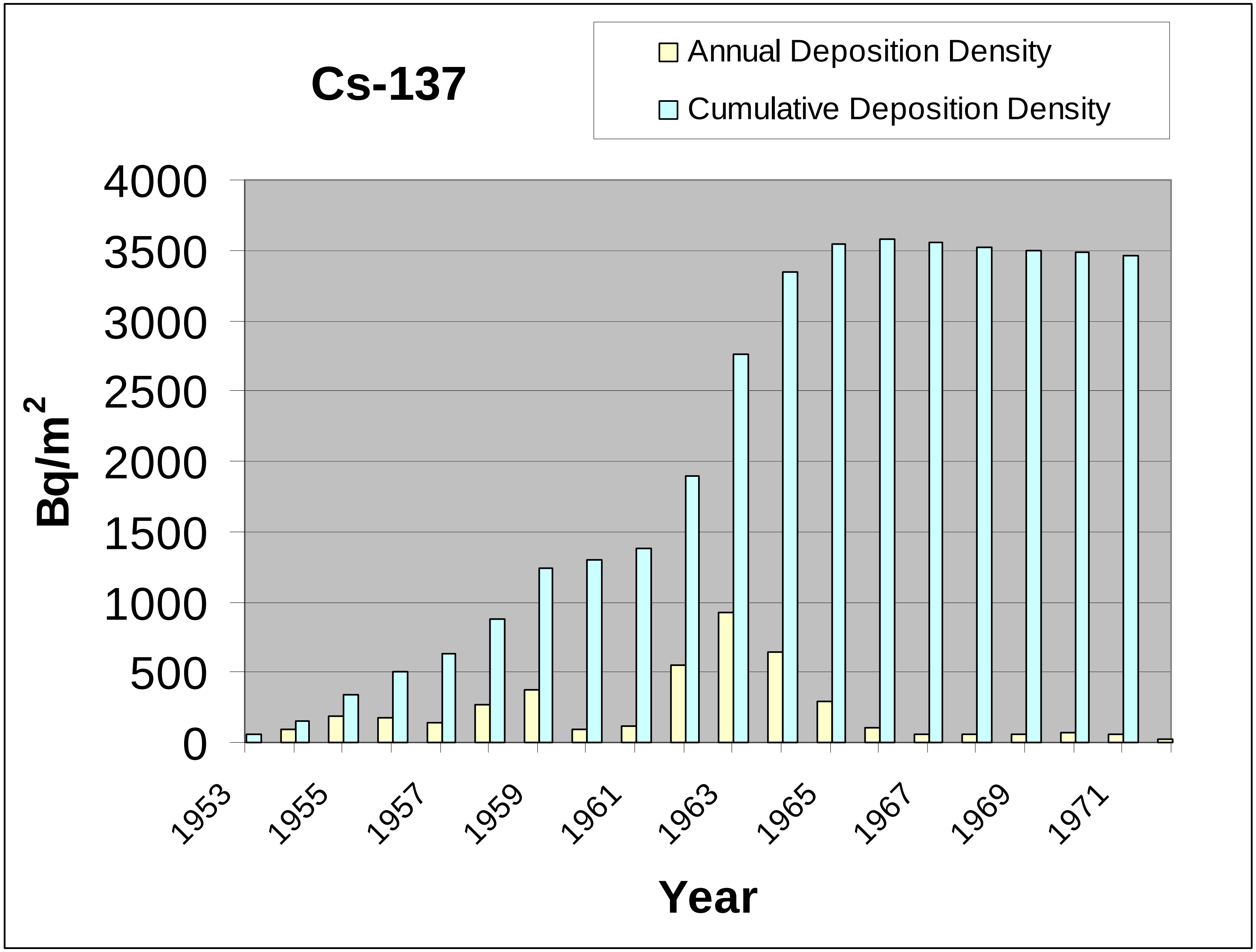

Cs-137
Annual Deposition Density
Cumulative Deposition Density
4000
3500
3000
2500
2000
1500
1000
500
0
Bq/m^2
1953
1955
1957
1959
1961
1963
1965
1967
1969
1971
Year

Figure 11.

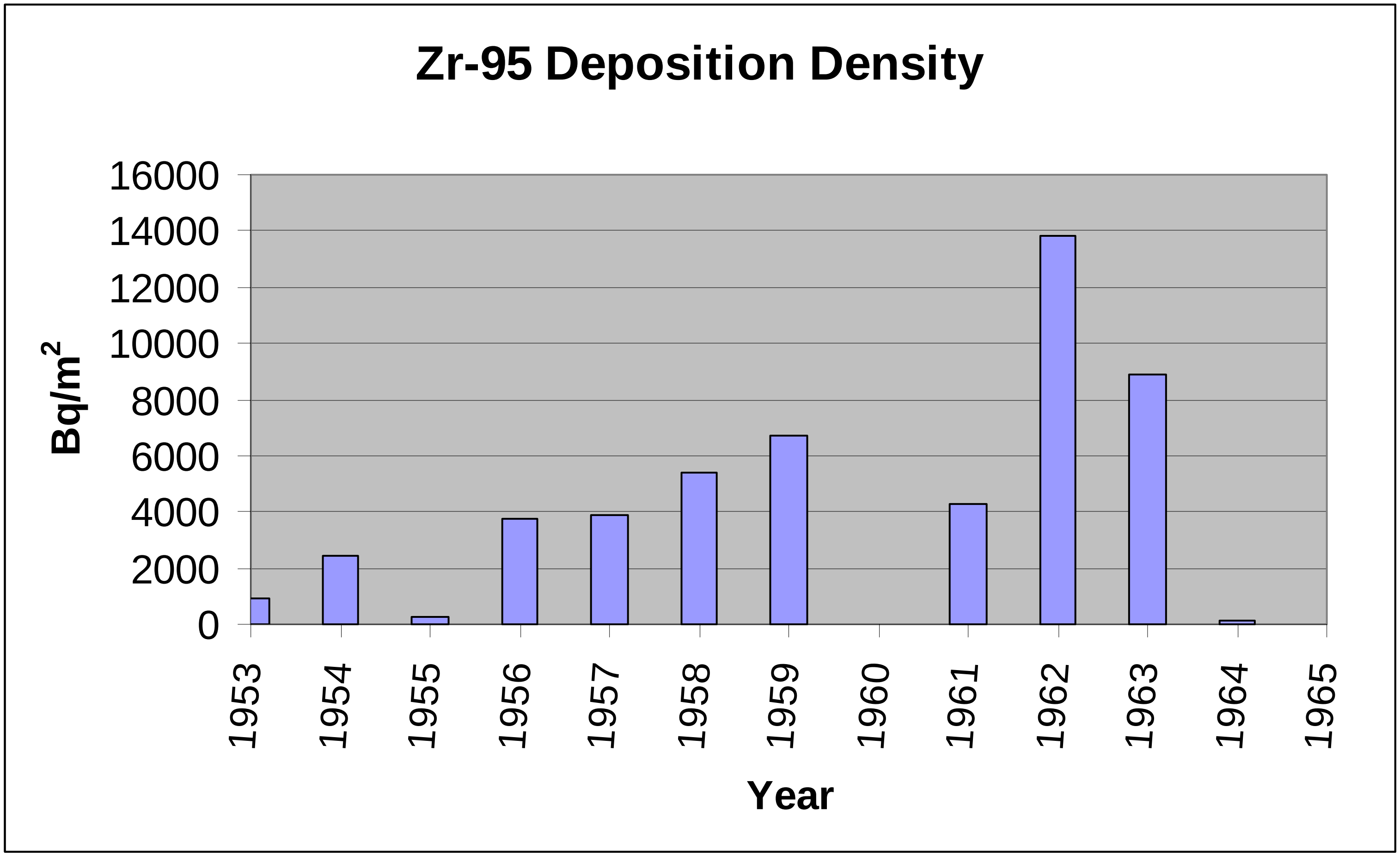

Zr-95 Deposition Density
Bq/m2
16000
14000
12000
10000
8000
6000
4000
2000
0
1953
1954
1955
1956
1957
1958
1959
1960
1961
1962
1963
1964
1965
Year

Figure 12.

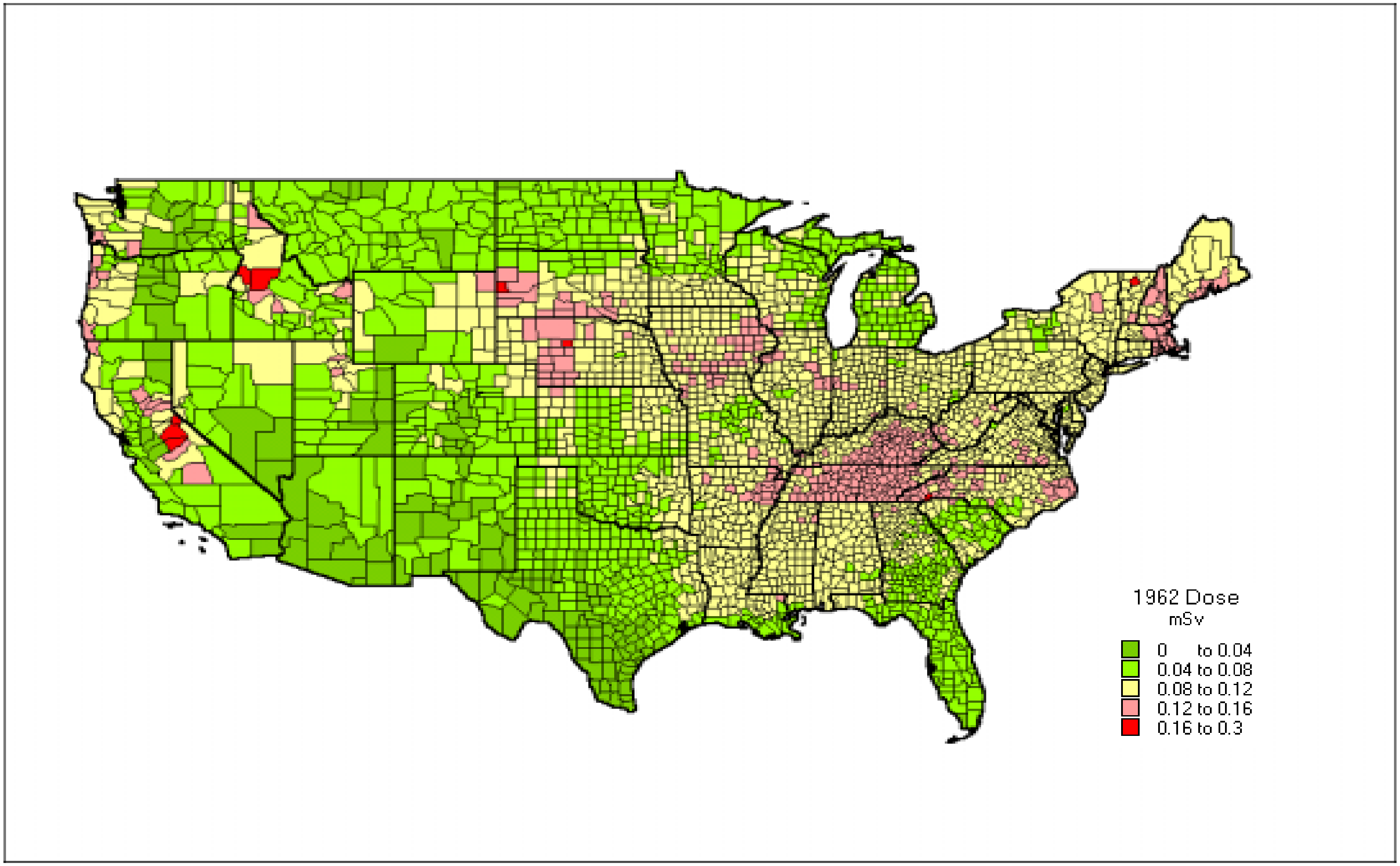
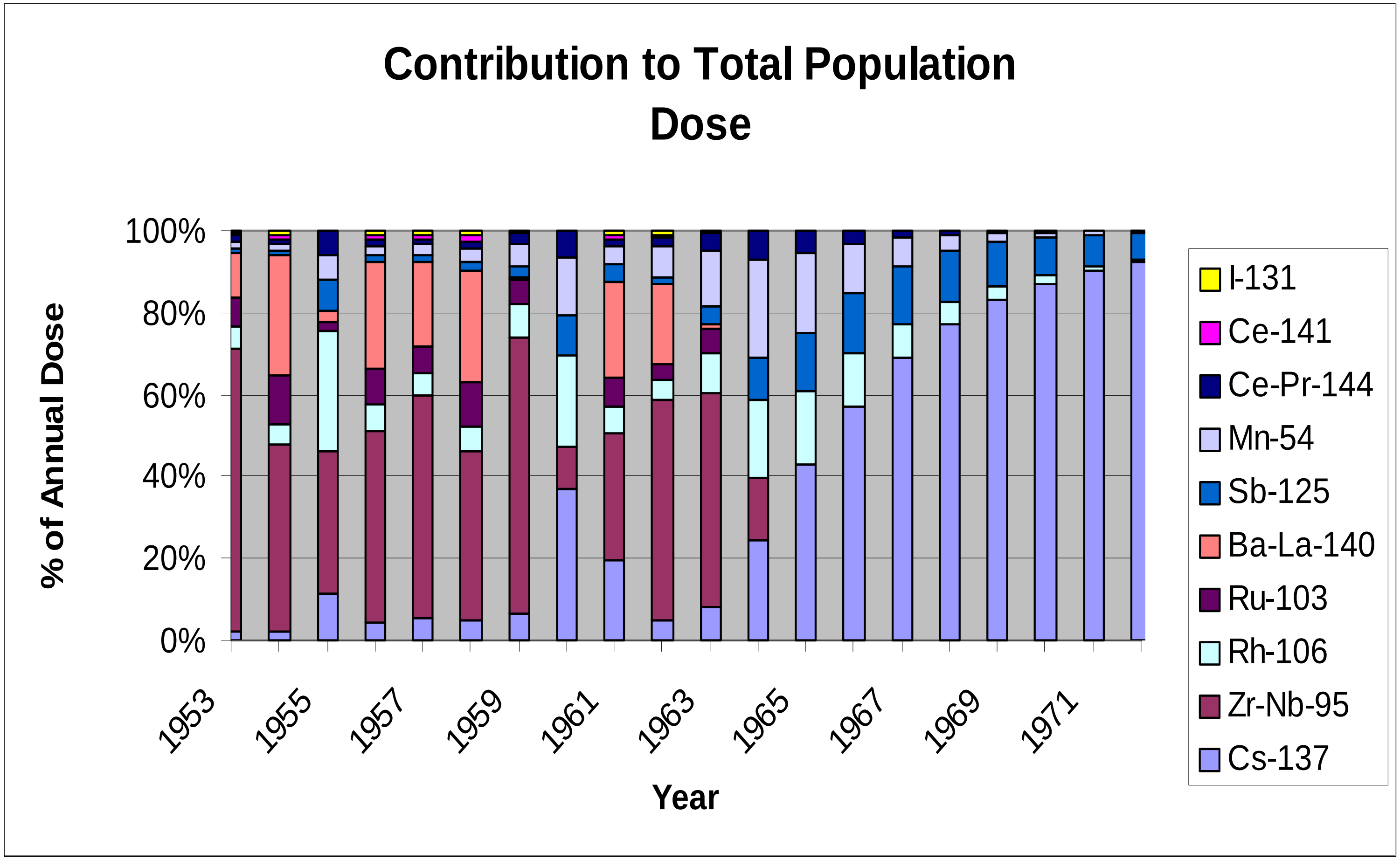


Figure 13.



Contribution to Total Population Dose
% of Annual Dose
100%
80%
60%
40%
20%
0%
1953
1955
1957
1959
1961
1963
1965
1967
1969
1971
Year
I-131
Ce-141
Ce-Pr-144
Mn-54
Sb-125
Ba-La-140
Ru-103
Rh-106
Zr-Nb-95
Cs-137

Figure 14.

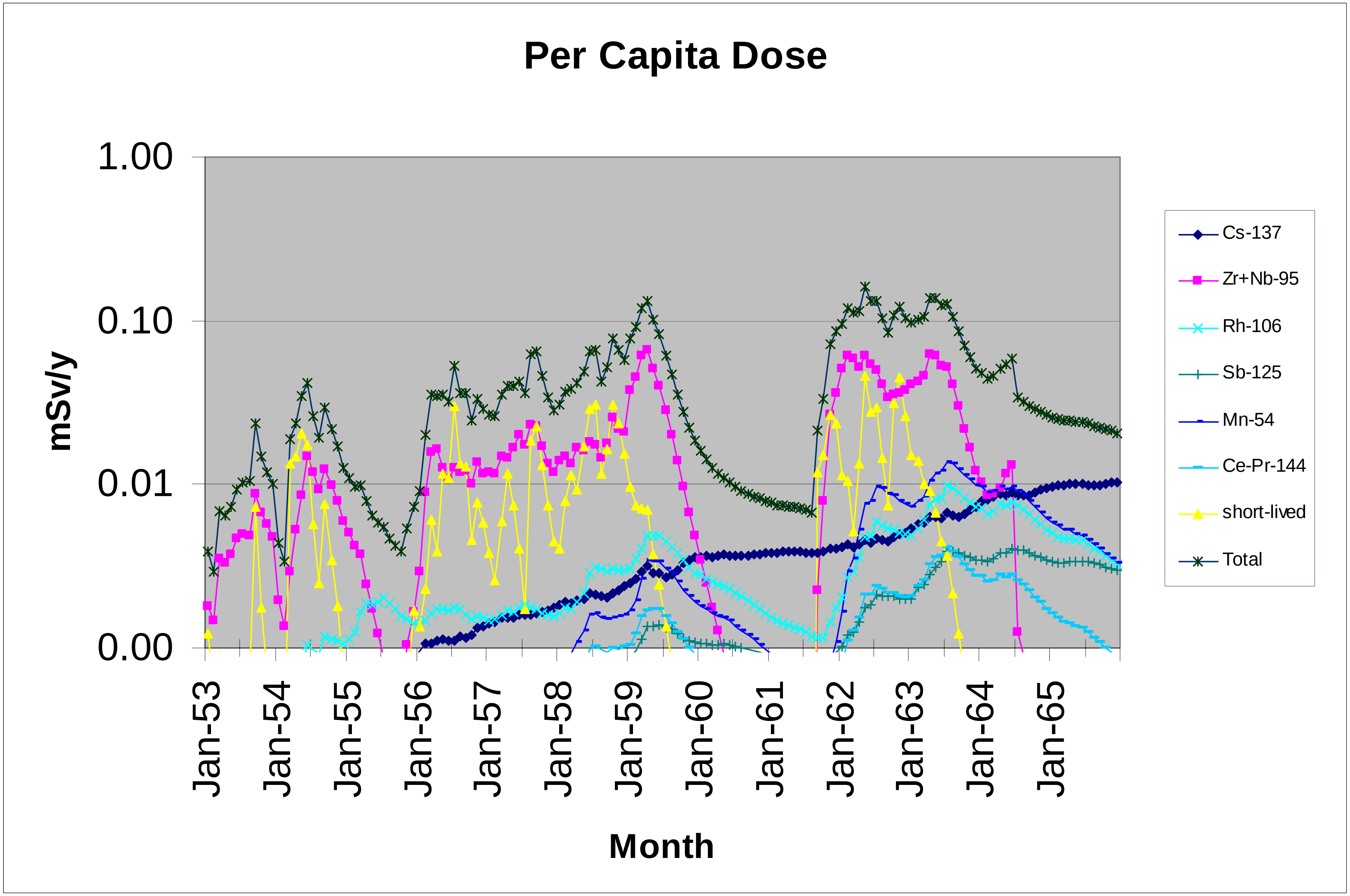

Per Capita Dose
1.00
0.10
0.01
0.00
mSv/y
Jan-53
Jan-54
Jan-55
Jan-56
Jan-57
Jan-58
Jan-59
Jan-60
Jan-61
Jan-62
Jan-63
Jan-64
Jan-65
Month
Cs-137
Zr+Nb-95
Rh-106
Sb-125
Mn-54
Ce-Pr-144
short-lived
Total

Figure 15.

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Appendix 1: Nuclide Ratios Used in This Preliminary Assessment

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

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

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

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

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

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

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

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

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

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

Appendix G

Internal Dose Estimates from Global Fallout

Radiation Dose to the Population of the Continental United States from the Ingestion of Food Contaminated with Radionuclides from High Yield Weapons Tests Conducted by the U.S., U.K., and U.S.S.R. between 1952 and 1963

Final Report

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

Report to the National Cancer Institute
Purchase Order No. 263-MQ-008090

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Radiation Dose to the Population of the Continental United States from the Ingestion of Food Contaminated with Radionuclides from High Yield Weapons Tests Conducted by the U.S., U.K., and U.S.S.R. between 1952 and 1963

Part I. Estimates of Dose

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

Report to the National Cancer Institute
Purchase Order No. 263-MQ-008090

ABSTRACT

According to a Congressional request to the Department of Health and Human Services a feasibility study is being conducted to study the health consequences to the American peoples of nuclear weapons tests. This report concerns calculations of the dose from the consumption of food contaminated by radionuclides deposited or distributed with global fallout, which originated from high yield tests conducted in the Northern Hemisphere by the U.S., the U.K. and the U.S.S.R. Such tests were conducted in 1952–1958 and 1961–1962. Results of this part of the feasibility study indicate that such doses can be calculated, as have similar doses from the tests conducted at the Nevada Test Site. The methods of calculation for ^{90}Sr, ^{131}I, and ^{137}Cs 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. For ^{90}Sr and ^{137}Cs doses were calculated on a yearly basis for 1953 through 1972 for each county in the contiguous U.S. for adults and for persons born on 1 January 1951; doses during the latter years were well beyond the time period of the actual tests, but these long-lived radionuclides were still being deposited from the reservoir in the stratosphere. Doses from ^{131}I were estimated only on a country-average basis, as county-by-county deposition levels were not available; doses from ^{131}I were estimated for the 1953–1963 years. Doses from ^{3}H and ^{14}C were calculated with the use of specific activity models, and calculations were carried out for the actual doses received in 1952–2000. Detailed results are provided in a CD that accompanies this report. Summary results in the form of coded maps are provided for ^{90}Sr and ^{137}Cs. The total estimated collective effective dose from the five radionuclides considered is estimated to be 66,000 person Sv; the collective dose to the thyroid is 210,000 person Sv. The estimated per caput effective dose is 400 μSv. These doses are somewhat smaller than the doses previously estimated to have occurred in the contiguous U.S. from the atmospheric tests conducted at the Nevada Test Site. The more important radionuclides in global fallout (on an effective dose basis) were ^{14}C and ^{137}Cs, whereas the dose from the Nevada tests is dominated by ^{131}I.

A comparison is made of the doses calculated with the current method with doses that can be derived from measurements of global fallout radionuclides in milk as reported by the U.S. Public Health Service's Pasteurized Milk Network for the time period of 1960–1963 first quarter. The results are in good agreement for ^{90}Sr and ^{131}I; calculated results for ^{137}Cs are higher than those based upon the milk measurements, but this is expected as a substantial fraction of dose from ^{137}Cs arises from the consumption of meat.

A list is provided of major references concerning the occurrence of global fallout and calculations of dose from these radionuclides.

The presently available calculations of dose from ^{131}I in global fallout are limited and are not available on a county-by-county basis. Recommendations are provided on how to improve this situation by the use of measured values of global fallout in milk, other foods, cattle thyroids, and air.

PREFACE

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 large atmospheric nuclear weapons tests conducted by the U.S. and the U.K. in the Pacific and by the former U.S.S.R., primarily near the Arctic Circle. Such doses are commonly referred to as resulting from "global fallout."

The tasks to be performed under the terms of the purchase order are:

1. "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 sites outside the continental U.S. including the Marshall Islands, Kazakhstan, and Russia. These estimates would be:

   – "Based on a review of the readily available literature and information found in scientific journals and published reports; it is not expected that sophisticated computer models should be developed or used for this purpose. For the purposes of this assessment, an electronic database of fallout deposition will be provided by NCI;

   – "Averaged over states or latitudinal bands of the continental U.S., with indications on how the high-risk populations could be identified. However, if feasible, primary calculations should be carried out on a county by county basis, and averaged only for presentation purposes;

   – "Calculated separately for the most important radionuclides produced in nuclear weapons tests. These would include, but would not be limited to H-3, C-14, Sr-90, Cs-137, and I-131. Estimates of dose from Sr-90 and Cs-137 will use the deposition databases provided by NCI while estimates of dose from H-3 and C-14 will use methods published by other investigators and by UNSCEAR in its 1993 report as well as in previous reports. Estimates of dose from I-131 will also use the data provided by NCI though the dose estimates to be reported will be limited to a nationwide collective dose estimate.

   – "Provided in terms of absorbed doses for some of the most radiosensitive organs and tissues (red bone marrow, gastro-intestinal tract, and thyroid).

   – "Calculated by year of testing in the 1950s and 1960s, and summed over the most significant tests worldwide (other than those tests conducted at the Nevada Test Site), with a comparison to the published UNSCEAR latitudinal averages for all tests.

   – "Calculated for persons born on 1 January 1951 and residing continuously in the counties of birth. This calculation will use age-corrected coefficients.

2. "For selected areas of the continental U.S. and for selected years of fallout, compare the internal dose estimates calculated in item 1 for Sr-90, Cs-137, and I-131 with those derived from the measurements of fallout radionuclides in foodstuffs.

3. “Provide a list of the most significant references regarding: (1) the networks of measurements of fallout radionuclides in air and foodstuffs, and (2) the assessment of the doses from internal radiation.
4. “The report to be provided shall discuss limitations on presently calculating county-specific dose estimates from global sources of I-131 and shall discuss feasibility for future work and methods that might be implemented in such work.”

The funds made available to accomplish this work consisted of $24,900. Thus, it was necessary to find very efficient means to accomplish this complex task.

INTRODUCTION

In previous reports (Anspaugh 2000; Beck 1999) doses were estimated for the 48 contiguous states from fallout derived from the tests of nuclear weapons-related devices at the Nevada Test Site (NTS). Results in Beck (1999) were for external exposure and dose, and results in Anspaugh (2000) were for doses from the ingestion of contaminated foods. The latter report was based upon estimates of deposition density as calculated by Beck (1999) for 19 radionuclides. These radionuclides were selected for analysis on the basis of screening calculations that had been performed previously by Ng et al. (1990) for the Off-Site Radiation Exposure Review Project (ORERP); these screening calculations indicated that 21 radionuclides were estimated to be responsible for about 95% of the total dose from the ingestion pathway for the radionuclides released at the NTS. Doses were not calculated in Anspaugh (2000) for two (^{135}I and ^{239}Np) of the 21 radionuclides, as estimates of deposition density were not available[*] at the time when the calculations were made. Most of the 19 radionuclides had relatively short half lives, but were more important in a dosimetric sense than the long-lived radionuclides due to the rapid entry of local and regional fallout into food chains.

For global fallout the radionuclides of concern are different for several reasons. The first is that global fallout by definition consists of radioactive debris that is globally dispersed due to its injection into the high atmosphere by large explosions. Due to its injection at high altitudes, global fallout typically does not return to earth for one or more years. During this time the short-lived fission products decay to small levels, and, except for unusual occurrences, the short-lived radionuclides of interest for NTS fallout are not of concern. Two radionuclides, ^{90}Sr and ^{137}Cs, have long half lives (about 30 y each) and do not decay appreciably before they return to earth. Historically, these radionuclides have been studied extensively due to their presence in global fallout and due to concern about adverse health effects from the ingestion of these two radionuclides.

Another factor of importance is that global fallout originates from high yield weapons that typically derive much of their yield from fusion reactions. These explosions produce or “spill” large amounts of ^{3}H, and the intense neutron flux also produces large amounts of ^{14}C through the reaction ^{14}N(n,p)^{14}C. Because ^{3}H and ^{14}C enter their respective hydrogen and carbon

---

[*] Estimates of deposition density for ^{239}Np are now available from Beck (personal communication). If more detailed studies are to follow the current feasibility studies, the dose from ^{239}Np should be included.

cycles and do not deposit in the same manner as do radionuclides associated with particulate matter, the usual methods of calculating deposition and dose are not appropriate; rather the specific activity approach has been used (UNSCEAR 1993). In order to calculate the dose from ^{3}H and ^{14}C it is necessary to derive source terms (the activity created per unit fusion-explosion energy) and to estimate the fusion yields as a function of time. In general there is little movement of radionuclides across the hemispheric boundary, so it is also important to know the fusion yield in the northern hemisphere for this assessment. Most of the fusion yields occurred in the northern hemisphere, but with substantial amounts near the equator. The conservative assumption is made here that the resulting radionuclides remained in the northern hemisphere.

The fusion yields estimated to have occurred in the northern hemisphere as a function of time are indicated in Table 1. These values were derived from total yield values reported in UNSCEAR (1993), DOE (1994), and Mikhailov et al. (1996); and with subtraction of the fission yields derived by Beck (2000).

Due to widespread concern about global fallout and its effects on man, scientists from many countries have studied fallout beginning in the 1950's. Such concern was a primary reason that led to the formation of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), which has studied global fallout over many years and has issued a number of assessments of dose with primary interest on calculating global averages of dose. In its most recent assessment of global-fallout dose the UNSCEAR (1993) provided the estimates indicated in Table 2 of the doses from the ingestion of food contaminated by global fallout.

Table 1. Estimated fusion yields exploded in the northern hemisphere as a function of time. Values are estimated from total yields in UNSCEAR (1993), DOE (1994), and Mikhailov et al. (1996); minus the fission yields estimated by Beck (2000). Explosions close to the equator are conservatively considered to have injected their debris into the northern hemisphere only.

Year	Fusion yield, megatons
1952	5.0
1953	0.36
1954	17
1955	0.88
1956	13
1957	3.9
1958	31
1959	0
1960	0
1961	69
1962	99
Total	240

Table 2. Effective dose commitments estimated by UNSCEAR (1993) for the northern temperate zone (40°–50° latitude) from radionuclides produced by the testing in the atmosphere of large

nuclear weapons. Estimates below are for "global" fallout and arise primarily from the injection of radionuclides into the upper atmosphere of the northern hemisphere.

Radionuclide	Dose commitment, μSv
^{3}H	48
^{14}C	78[a]
^{55}Fe	14
^{89}Sr	2.3
^{90}Sr	170
^{131}I	79
^{137}Cs	280
^{140}Ba	0.42
^{238}Pu	0.0009
$^{239+240}Pu$	0.50
^{241}Pu	0.004
^{241}Am	1.5
Sum	670

[a] The UNSCEAR (1993) value of 2600 μSv over all time was multiplied by a factor of 0.03, the portion estimated to be delivered in 50–70 y.

On the basis of the data in Table 2, and in accordance with the requirements for the purchase order, the radionuclides selected for examination during this feasibility study include ^{3}H, ^{14}C, ^{90}Sr, ^{131}I, and ^{137}Cs. These radionuclides account for all but a small fraction of the estimated dose to man from global fallout. The prominence of ^{131}I on the list may be surprising, as its half life is only eight days. The appearance of ^{131}I in global fallout has tended to be sporadic, but contaminated milk in the U.S. had been observed on a number of occasions (e.g., Dahl et al. 1963; Terrill et al. 1963). Possible mechanisms for these sporadic occurrences have been suggested by Machta (1963) and include

- The subsidence of large air masses contaminated with debris from U.S.S.R. tests at its Novaya Zemlya site near the Arctic Circle, and
- The penetration of large thunder storms into the upper troposphere and stratosphere that resulted in the scavenging of fresh debris from the U.S. tests in the Pacific.

The assessment of dose from ^{14}C is particularly difficult, due to its long half life of 5730 y. The UNSCEAR (1993) has assessed the intergenerational dose due to this radionuclide, and under such considerations it is the most significant radionuclide in global fallout. The relative importance of ^{14}C is much less, if the dose during the first 50–70 y is considered. Further, the carbon cycle is complex (as evidenced by the current controversy over global warming due to the release of carbon dioxide), and dose assessments must rely on complicated models. Thus, the projections of dose into the future for this radionuclide are only approximate, but estimates of dose through the present time are firmly based upon measurements of ^{14}C in food, water, and humans.

Estimates of dose from ^{3}H are considered to be more reliable, as this radionuclide has a much shorter half life of 12 y, and the hydrogen cycle is not as complicated as that of carbon. As for ^{14}C, estimates of dose through the present time are firmly based upon measurements of ^{3}H in food, water, and humans.

The purpose of this report is to fulfill the requirements of the purchase order referenced in the Preface. The estimates of dose (Task 1) from global fallout for the radionuclides indicated above are summarized in Part I of this report, as are the methods used to perform the calculations. An accompanying CD-ROM contains the detailed results of the calculations on a county-by-county basis for ^{90}Sr and ^{137}Cs; more details of the results for ^{3}H, ^{14}C, and ^{131}I are also provided on the CD, but results for these radionuclides are available only as averages over the continental U.S. Part II of this report contains all other information requested (Tasks 2, 3, and 4).

METHODS

The methods of dose calculation used in this report for ^{90}Sr, ^{131}I, and ^{137}Cs are similar to those used previously for the calculations of dose from tests at the NTS (Anspaugh 2000). The specific activity approach is used to calculate doses from ^{3}H and ^{14}C; the methods used for ^{3}H and ^{14}C are similar to those used by the UNSCEAR (1993).

Nuclear events of interest

This report includes doses from all high yield nuclear events that took place within the northern hemisphere during the years from 1952 through 1963; such tests were stopped in 1963 by the U.S., the U.K., and the U.S.S.R. Tests at the NTS are not included in this report, as such tests were not high yield, and doses from the ingestion of contaminated foods from NTS tests have been included in a previous assessment (Anspaugh 2000).

Because tests of high yield weapons inject much of their debris into the stratosphere from which it devolves slowly over time, it is not generally possible to identify global fallout with a particular test. Rather, doses have been calculated on a monthly basis for ^{90}Sr, ^{131}I, and ^{137}Cs and on a yearly basis for ^{3}H and ^{14}C.

Internal dose from ^{90}Sr and ^{137}Cs

Doses from ^{90}Sr and ^{137}Cs were estimated by a process similar to that used for radionuclides from NTS fallout (Anspaugh 2000). The basic calculation is shown in eqn (1):

$$D = P \times I \times F_g \, , \qquad (1)$$

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}.

Deposition density. Values of deposition density, P, for ^{90}Sr were furnished by Beck (2000) on behalf of the National Cancer Institute (NCI) on a county-by-county basis averaged over each month for the years of 1953 through 1972.[†] Values for the deposition density for ^{137}Cs were derived from those of ^{90}Sr by multiplying the ^{90}Sr results by a factor of 1.5, as recommended by Beck (2000) [a similar relationship has been used by UNSCEAR (1993)].

Integrated intake. Monthly average values of integrated intake, I, were derived from Whicker and Kirchner (1987) by interpolation of the date-specific values in that publication. The age-related values used in this study are shown in Figs. 1 and 2 for ^{90}Sr and ^{137}Cs, respectively.

Values of integrated intake are complex functions of age- and season-dependent intake rates of different foods and the season-dependent radioecological movement of radionuclides through foodchains. Whicker and Kirchner (1987) developed the PATHWAY model to estimate integrated intake for the ORERP studies. The food-consumption rates used in the PATHWAY

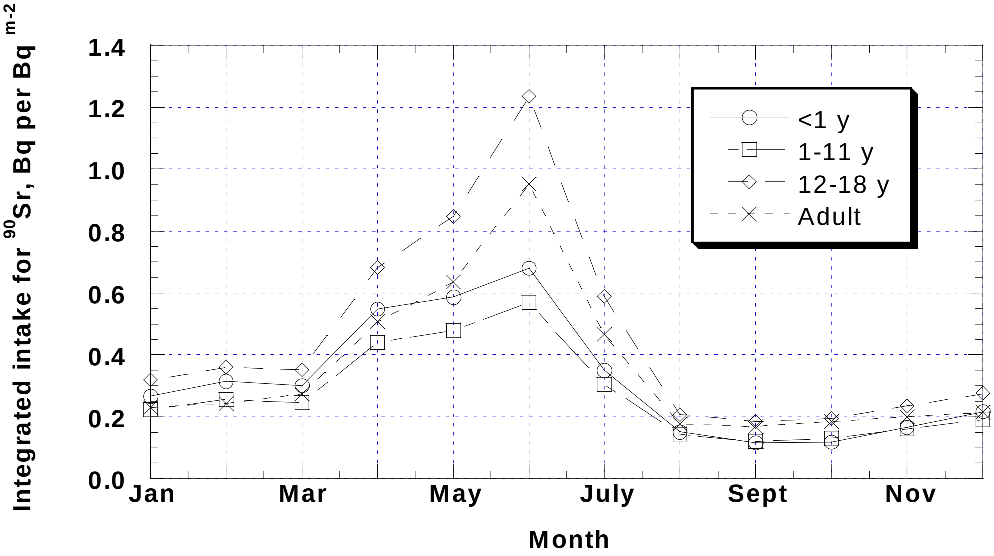

Fig. 1. Monthly average values of integrated intake of ^{90}S for four age groups. Data were derived from Whicker and Kirchner (1987).

[†] These years do not match the years of testing indicated on the previous page. Fallout from the 1952 tests occurred mainly in 1953 and afterward; fallout from the tests in the early 1960's was still measurable in 1972.

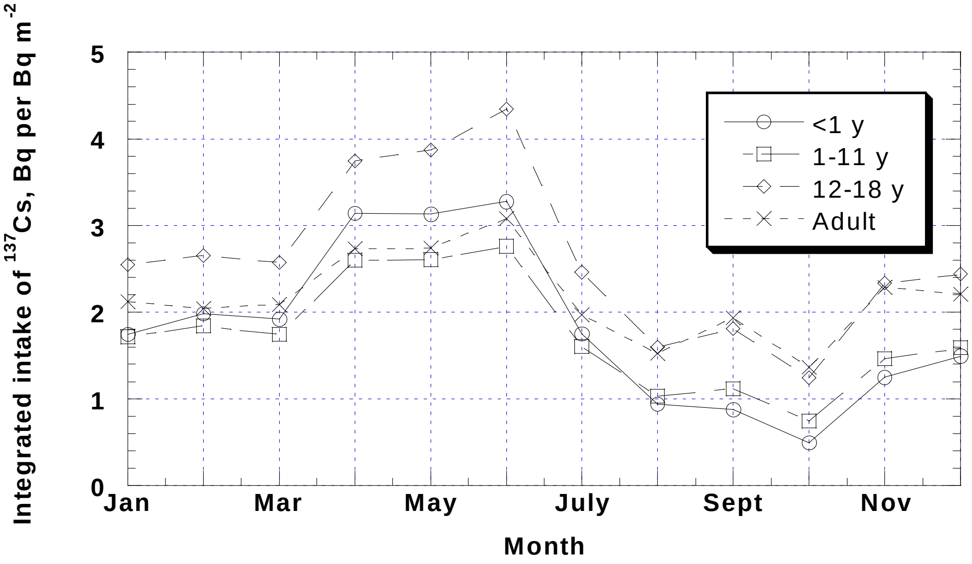

Fig. 2. Monthly average values of integrated intake of ^{137}Cs for four age groups. Data were derived from Whicker and Kirchner (1987).

model are shown in Table 3. The fractions of different food types that are assumed to be locally produced are indicated in Fig. 3, and the consumed fraction of non-leafy vegetables and fruits assumed to be freshly produced is shown in Fig. 4.

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

- Initial retention of radionuclides by vegetation;
- Loss of radionuclides from vegetation as a function of time;

Table 3. Food-consumption rates used in the PATHWAY code (Whicker and Kirchner 1987). Estimates are based primarily on data summarized by Rupp (1980) for rural families.

Food type	Food-consumption rates by age group, fresh kg day^{-1}			
	<1 y	1–11 y	12–18 y	≥19 y
Milk	0.800	0.623	0.635	0.360
Milk products	0.144	0.074	0.143	0.062
Beef	0.044	0.113	0.210	0.277
Poultry	0.003	0.017	0.028	0.030
Eggs	0.017	0.026	0.036	0.053
Leafy vegetables	0.002	0.021	0.036	0.062
Stored fruits and vegetables	0.207	0.266	0.356	0.360
Grains	0.025	0.025	0.151	0.137

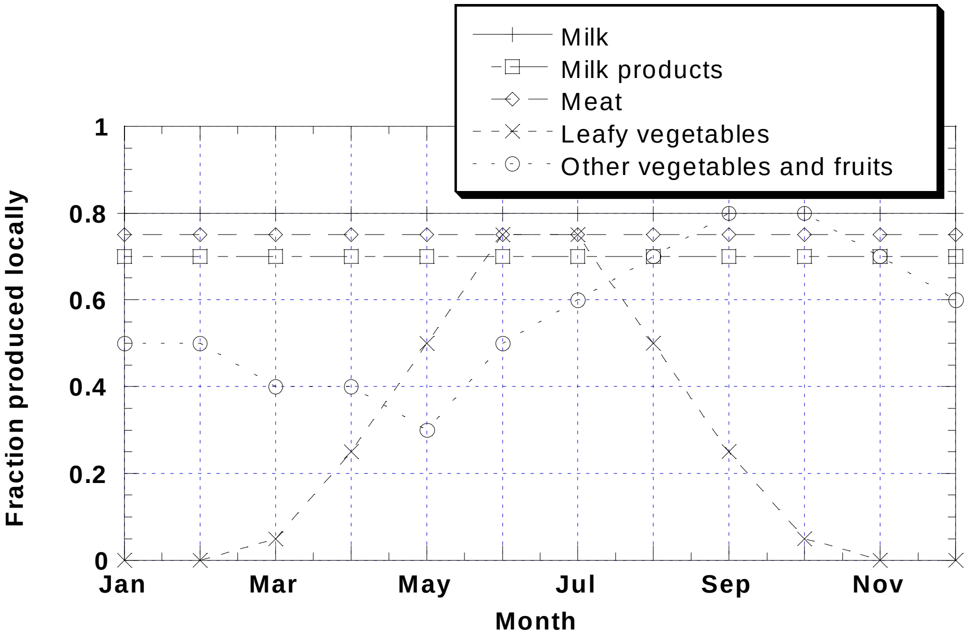

Fig. 3. Fraction of food that is assumed to be locally produced for several different food categories. Values for eggs are the same as those for milk. From Whicker and Kirchner (1987).

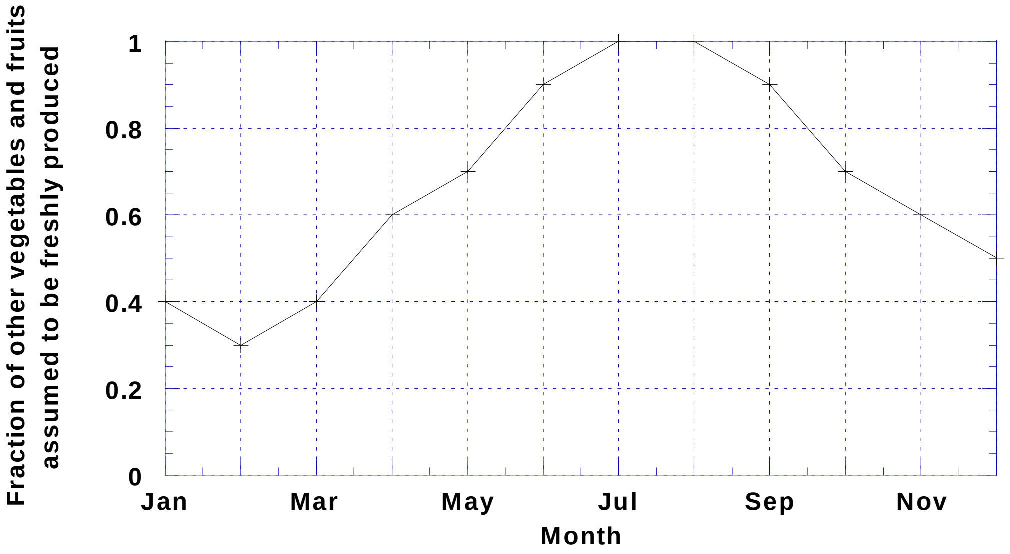

Fig. 4. Consumed fraction of non-leafy vegetables and fruits assumed to be freshly produced. From Whicker and Kirchner (1987).

- Dilution of radionuclide concentration in fresh vegetation by plant growth;

- Movement of radionuclides 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.

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}. Its value 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.

Although the 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 of radionuclides in rainfall, except during conditions of very light rain 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-coefficient 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; such values are commonly referred to as coefficients of committed dose.

ICRP (1998) is the 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). For the assessment for doses from tests at the NTS (Anspaugh 2000) the ICRP coefficients were converted to geometric means, so that uncertainties could be propagated in a consistent manner. As the deposition-density values provided by Beck (2000) for global fallout do not have attached uncertainty values, the dose coefficients used for this assessment have been used directly from ICRP (1998). The dose coefficients used in this study are indicated in Table 4.

For ^{90}Sr, dose coefficients for the unlisted organs are essentially the same as the dose coefficient for the thyroid; as ^{90}Sr (and its progeny) is a "pure" beta-emitting radionuclide that

Table 4. Age-dependent dose coefficients for members of the public used in this study for ^{90}Sr and ^{131}I. Values are from ICRP (1998)

ICRP	Dose coefficient for the indicated radionuclide and organ, Sv Bq^{-1}

[‡] 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].

age category	^{90}Sr Bone Sur[a]	^{90}Sr Colon[b]	^{90}Sr Red marr[c]	^{90}Sr Thyroid	^{90}Sr Effective	^{137}Cs Colon	^{137}Cs Effective
3 mo	2.3×10^{-6}	1.2×10^{-7}	1.5×10^{-6}	1.2×10^{-8}	2.3×10^{-7}	3.8×10^{-8}	2.1×10^{-8}
1 y	7.3×10^{-7}	8.9×10^{-8}	4.2×10^{-7}	5.5×10^{-9}	7.3×10^{-8}	2.3×10^{-8}	1.2×10^{-8}
5 y	6.3×10^{-7}	4.5×10^{-8}	2.7×10^{-7}	2.9×10^{-9}	4.7×10^{-8}	1.5×10^{-8}	9.6×10^{-9}
10 y	1.0×10^{-6}	2.6×10^{-8}	3.7×10^{-7}	1.8×10^{-9}	6.0×10^{-8}	1.3×10^{-8}	1.0×10^{-8}
15 y	1.8×10^{-6}	1.5×10^{-8}	4.9×10^{-7}	1.1×10^{-9}	8.0×10^{-8}	1.5×10^{-8}	1.3×10^{-8}
Adult	4.1×10^{-7}	1.3×10^{-8}	1.8×10^{-7}	6.6×10^{-10}	2.8×10^{-8}	1.5×10^{-8}	1.3×10^{-8}

[a] Bone surface

[b] Weighted mass average of dose coefficients for the lower and upper large intestine

[c] Red bone marrow

localizes in the bone, the higher doses are to the bone marrow and to the bone surface. The dose coefficient for ^{90}Sr is also somewhat higher for the colon, due to the transit of the beta emitter. On the other hand, ^{137}Cs is distributed throughout the body and delivers most of its dose from the emission of a gamma ray by its short-lived progeny ^{137m}Ba. Thus, while dose coefficients for ^{137}Cs for the colon are nearly twice as high as the effective dose coefficient, the dose coefficients for the unlisted organs are approximately the same as the effective dose coefficient.

Age groups. Doses were calculated on a county-by-county basis for adults and for an individual who was born on 1 January 1951.

Dose from ^{131}I

For ^{131}I calculations were also based on eqn (1). Beck (2000) did not provide county-by-county estimates of deposition density for ^{131}I, as more analysis would be required beyond that possible for this feasibility study. Rather, rough estimates of deposition density were provided on a population-weighted basis for the entire country. As for ^{90}Sr and ^{137}Cs, monthly averages of age-dependent integrated intake values were derived from Whicker and Kirchner (1987). The values used in this study are shown in Fig. 5. Dose coefficients were taken from the ICRP (1998); the values used are listed in Table 5. Calculations were made for adults and for individuals born on 1 January in each of the years from 1951 through 1963. In addition, because the dose from ingestion of ^{131}I varies strongly with age, per caput values of dose were calculating by considering the age distribution of the population in 1960 and by calculating a population-weighted average value of dose. For the latter calculation, age-dependent values of integrated intake and dose coefficients were used.

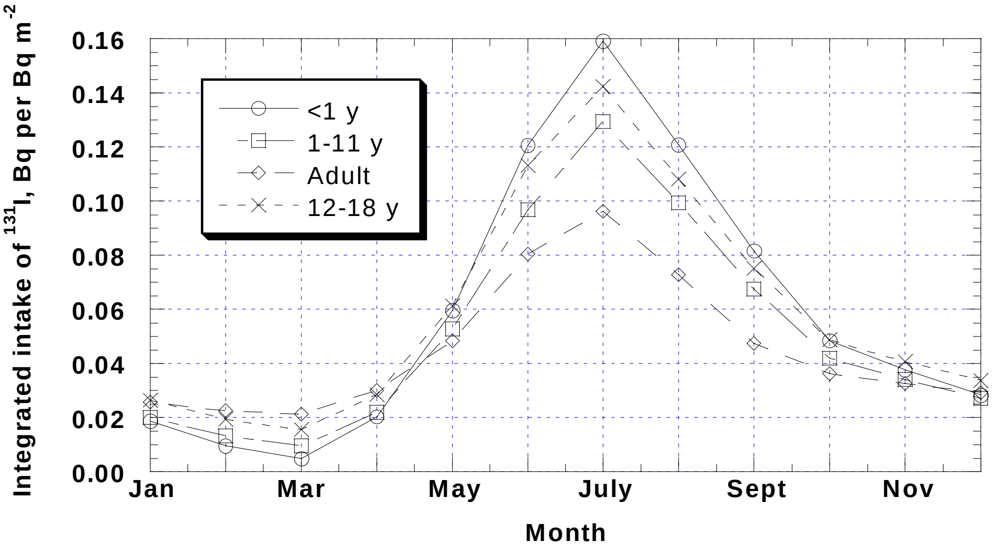

Fig. 5. Monthly average values of integrated intake for four age groups for ^{131}I. Data were derived from Whicker and Kirchner (1987).

Table 5. Age-dependent dose coefficients for ^{131}I used in this study for members of the public. Values are from ICRP (1998)

ICRP age category	Dose coefficient for ^{131}I for the indicated organ, Sv Bq^{-1}				
	Bone surface	Colon	Red marrow	Thyroid	Effective
3 mo	6.1×10^{-10}	2.6×10^{-9}	5.2×10^{-10}	3.7×10^{-6}	1.8×10^{-7}
1 y	4.4×10^{-10}	1.5×10^{-9}	3.7×10^{-10}	3.6×10^{-6}	1.8×10^{-7}
5 y	2.8×10^{-10}	6.5×10^{-10}	2.2×10^{-10}	2.1×10^{-6}	1.0×10^{-7}
10 y	1.9×10^{-10}	2.8×10^{-10}	1.6×10^{-10}	1.0×10^{-6}	5.2×10^{-8}
15 y	1.4×10^{-10}	1.5×10^{-10}	1.2×10^{-10}	6.8×10^{-7}	3.4×10^{-8}
Adult	1.3×10^{-10}	1.2×10^{-10}	1.0×10^{-10}	4.3×10^{-7}	2.2×10^{-8}

Dose from ^{3}H and ^{14}C

Doses for these two globally dispersed radionuclides were calculated on the basis of the specific activity approach. As the fusion yield in the northern hemisphere is an important input to the calculation for both radionuclides, the data shown in Table 1 were used as input values. Another important input is the amount of ^{3}H and ^{14}C created per Mt of fusion. UNSCEAR (1993) gives a value of 740 PBq Mt^{-1} for ^{3}H; a reasonable estimate for ^{14}C is 0.85 PBq Mt^{-1}.

Doses from ^{3}H were calculated with use of the NCRP (1979) model; a rough estimate can also be made on the basis of the estimated natural production rate of 37 PBq per y per hemisphere and the measured concentrations of ^{3}H in surface waters. The annual absorbed dose in tissue from naturally occurring ^{3}H was derived in UNSCEAR (1982) to be 10 nSv. Based upon these values a rough estimate of the average dose commitment from ^{3}H is

$$240\,\mathrm{Mt} \times 740\frac{\mathrm{PBq}}{\mathrm{Mt}} \times 10\frac{\mathrm{nSv}}{\mathrm{y}} \times \frac{1}{37}\frac{\mathrm{y}}{\mathrm{PBq}} = 48{,}000\,\mathrm{nSv} \ . \tag{2}$$

However, this result does not provide any information on how this dose might be delivered over time. Use of the NCRP (1979) model provides a more sophisticated approach that simulates the world's hydrological cycle through the use of seven compartments, which consist of atmospheric water, surface soil water, deep groundwater, surface streams and fresh water lakes, saline lakes and inland seas, ocean surface, and the deep ocean. The use of the hydrological cycle is appropriate, as most of the ^{3}H released is in the form of tritiated water or is soon converted to that form (from HT) in soil. Calculations are then made by considering the specific activity of ^{3}H in the various water compartments and the rate of change among the compartments.

Example results from the NCRP (1976) model of the dose over time from the release of 1 PBq of ^{3}H to the northern hemisphere are shown in Fig. 6. The annual dose falls off rapidly with time due to the mixing of the released ^{3}H into the larger compartments. The summary result of the data shown in Fig. 6 is that the release of 1 PBq of ^{3}H to the atmosphere in the northern hemisphere would result in a dose of 0.38 nSv to each person living in the hemisphere. The latter result is consistent with the value computed from eqn (2) of 0.27 nSv with consideration of the substantial uncertainty in both results.

The dose from the release of ^{14}C can be assessed in a rather similar way, although the carbon cycle is much more complicated. From UNSCEAR (1982, 1993) the natural production rate of ^{14}C is roughly 1 PBq y^{-1}, and the resulting equilibrium specific activity produces an annual effective dose of about 12 µSv. A calculation similar to that of eqn (2) could be made, but it would be potentially misleading due to the very long half life of ^{14}C and the very long time (more than one individual's life time) to achieve equilibrium. Thus, in order to calculate doses over the first 50 y from the release of ^{14}C, a compartment model for the global circulation of carbon was used. The model chosen is that of Titley et al. (1995), which is the latest model that has been widely accepted and which builds upon previously accepted models. The Titley et al. model is complicated and contains 23 compartments with separate compartments of two to four layers in each ocean. Carbon is considered to be in the form of CO_2, which is the form that enters the food chain. The model takes into account temperature changes, photosynthesis in the surface layers of the oceans, and transfer of carbon down the water column.

Example results of model calculations are shown in Fig. 7, which is a plot showing the annual doses from the release of 1 PBq of ^{14}C to the northern hemisphere. The summary result of the data shown in Fig. 7 is that the release of 1 PBq of ^{14}C to the atmosphere of the northern hemisphere would result in a dose of 0.7 µSv to each person living in the hemisphere over the following 50 y.

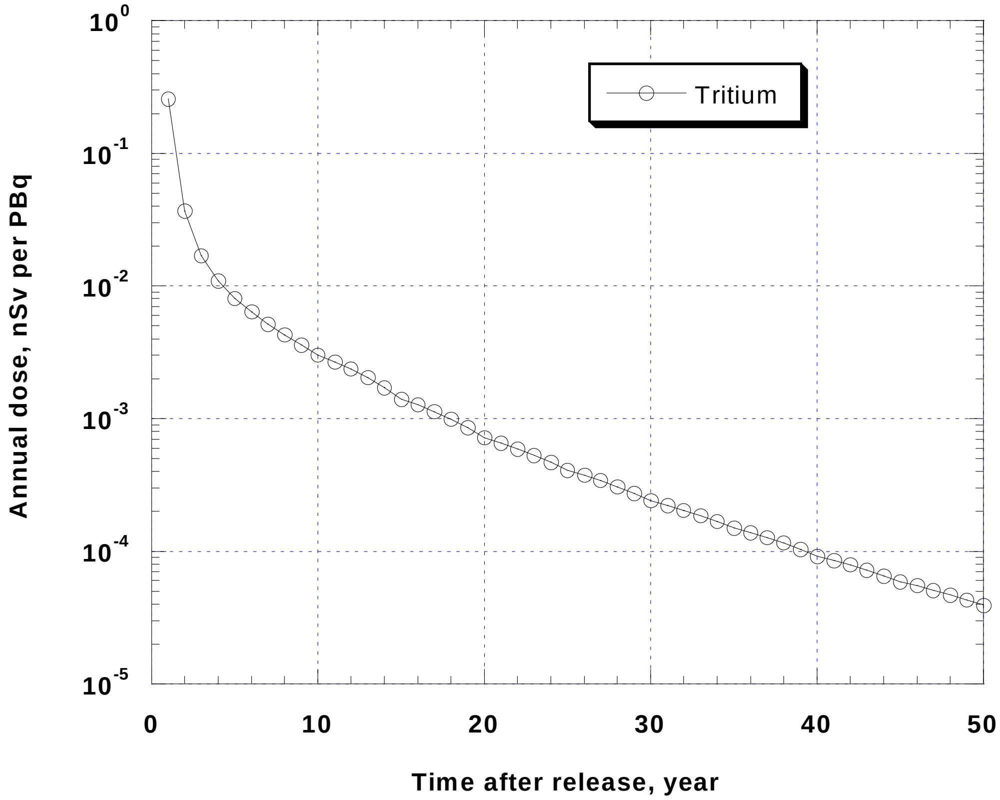

Fig. 6. Annual dose as a function of time following the release of 1 PBq of ^{3}*H to the atmosphere of the northern hemisphere. Results are based upon the NCRP (1979) model of tritium in the hydrological cycle.*

These model results for ^{3}H and ^{14}C are approximate, and no attempt has been made to derive age-dependent values. This is broadly appropriate for these two radionuclides and any other beta-emitting radionuclide that can be assessed using a specific activity approach. Also, as both radionuclides are distributed throughout the body, all organ and effective dose coefficients are presumed to be numerically equal.

Collective dose

Collective doses were also calculated. For ^{90}Sr and ^{137}Cs for which results were available on a county-by-county basis, the adult dose for each county was multiplied by its 1954 population with data supplied by Beck (2000) to give a county specific collective dose for each year (1953–1972). The use of adult doses for this calculation tends to underestimate the true collective dose; however, for ^{90}Sr and ^{137}Cs this effect is not as significant as it is for ^{131}I. Collective doses for each county were also summed to give a collective dose for each year. Finally, doses for all years were also summed to give the total collective dose to the 48 contiguous states.

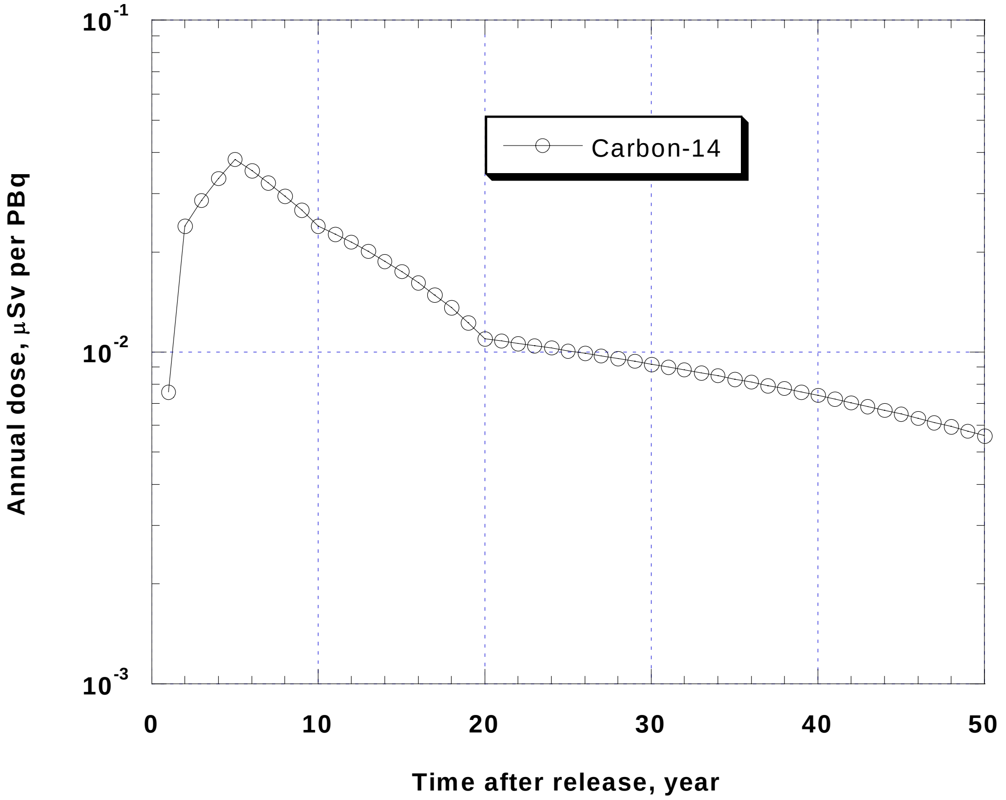

Fig. 7. Annual effective dose following the release of 1 PBq of ^{14}C to the atmosphere of the northern hemisphere. Results are based upon the model of Titley et al. (1995).

For ^{131}I deposition values were not available on a county-by-county basis, but on a population-weighted basis for the entire country. Collective doses were calculated by using the same procedure as mentioned in a previous section for per caput doses. That is, calculations were made with consideration of the age distribution of the population and appropriate values of age-dependent integrated intake and dose coefficient.

For ^{3}H and ^{14}C rough estimates of individual doses were calculated on a country-average basis; such values do not have an age dependence. Collective doses were calculated by simply multiplying the individual doses for the country by the country population in 1954.

RESULTS AND DISCUSSION

The results of the calculations made for this project are provided on a CD that accompanies this report. Information on the CD is organized as follows:

- There is one folder labeled “SrCs” that contains 21 workbooks; 20 are labeled GB1953 through GB1972 and one is labeled GB53-72, which is a summary of the doses for the 20-y period. Each of the 20 workbooks for individual years contains two spreadsheets;

the first is labeled "Sheet1" and contains county-by-county data for estimates of committed dose from ^{90}Sr and ^{137}Cs. Values are provided both for "adults" and for a person born on 1 January 1951. For ^{90}Sr estimates are provided for bone surface, colon, red marrow, thyroid, and effective dose; for ^{137}Cs estimates are provided for colon and effective doses. The second spreadsheet is labeled "Collective" and contains calculated values for collective dose on a county-by-county basis. In addition to data for the parameters indicated above, the sum of collective effective dose from both ^{90}Sr and ^{137}Cs is calculated. The summary workbook "GB53-72" contains similar data in two spreadsheets, but summarized over the entire period of the calculation.

- There is one spreadsheet labeled "GBLI131" that contains all calculations for dose from global fallout due to ^{131}I. Calculations are provided for bone surface, colon, red marrow, thyroid, and effective dose for adults and for persons born on 1 January in the years 1951 through 1963. Collective doses and per caput doses are provided on the same spreadsheet; such calculations were made using the fraction of the population falling into various age groups and appropriate values of age-dependent integrated intake and dose coefficient.
- A final spreadsheet is labeled "TritCarb" and contains estimates of dose for ^{3}H and ^{14}C. Doses are estimated on the basis of the inputs of fission yield from Table 1 and the time dependent annual dose factors from Figs. 6 and 7. Each year's input is tracked separately and summed for each individual year. The calculations extend through the year 2000.

The intent of the following material is to summarize the data contained on the CD in the files mentioned above.

Doses for individuals

^{90}Sr and ^{137}Cs. Estimates of committed dose are available on the CD-ROM for each county in the contiguous U.S.; values are provided for adults and for a person born on 1 January 1951. For ^{90}Sr estimates are given for dose to the bone surface, colon, red marrow, and thyroid and for effective dose. For ^{137}Cs estimates are given for dose to the colon and for effective dose. Reasons for the selections of these organs are discussed in the Methods Section. Such large amounts of data are more easily summarized graphically. Figs. 8–23 provide representative results for three years[§] and the sum of committed doses for the entire 1953–1972 period. Figs. 8–11 are results for the 1955 year. Figs. 8 and 9 present doses to the red bone marrow from ^{90}Sr for an adult and for a person born on 1 January 1951. Figs. 10 and 11 present effective doses from ^{137}Cs for an adult and for a person born on 1 January 1951. This pattern is repeated for the years of 1959 and 1963; the doses were the highest for the latter year. Finally, Figs. 20–23 present

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[§] The 1955, 1959, and 1963 years that are plotted represent local maxima in dose; the committed dose in 1963 (resulting largely from explosions in 1962) was the highest.

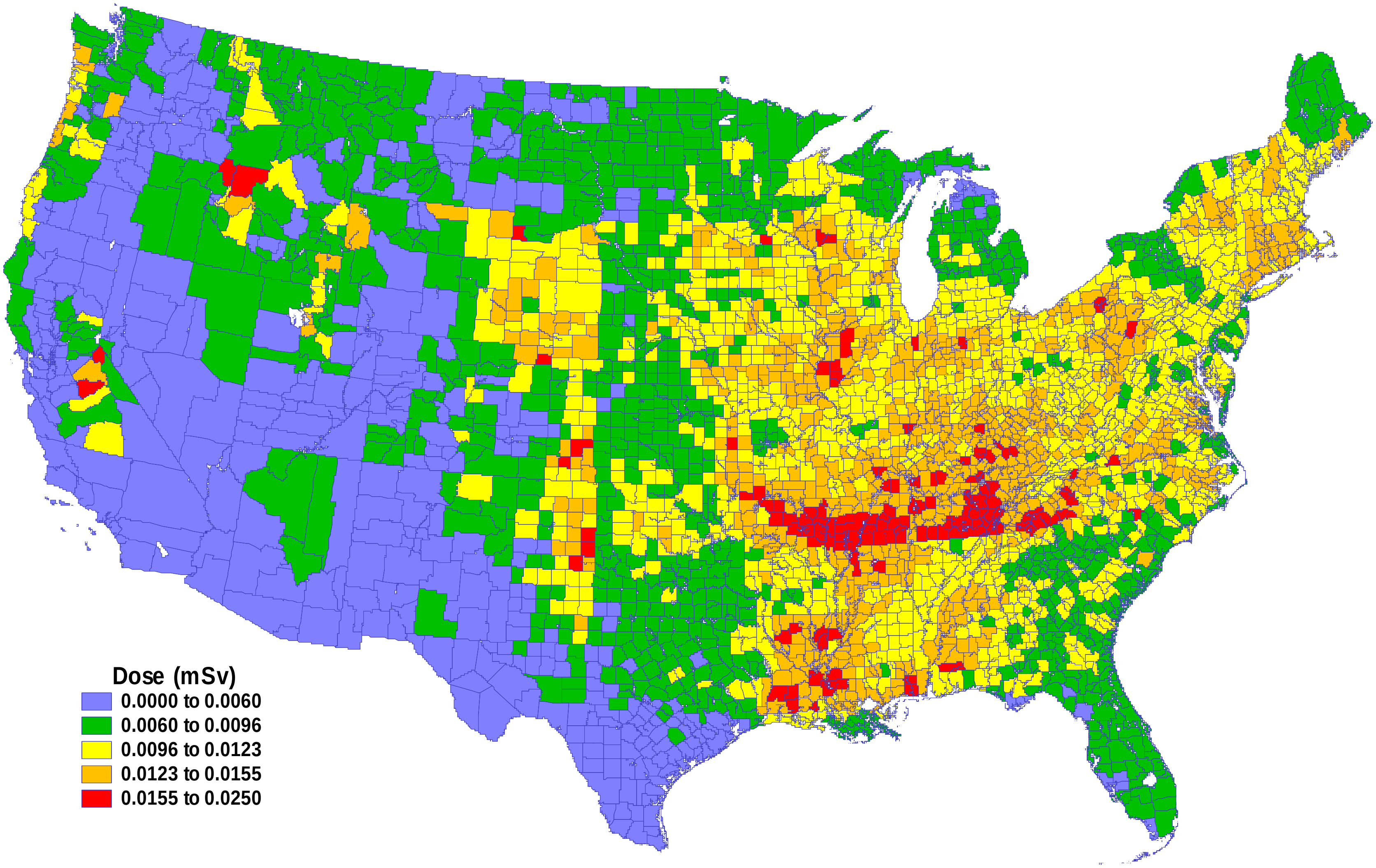

Fig. 8 Map of the commited dose (mSv) for an adult to the red bone marrow from ^{90}*Sr deposited during 1955*

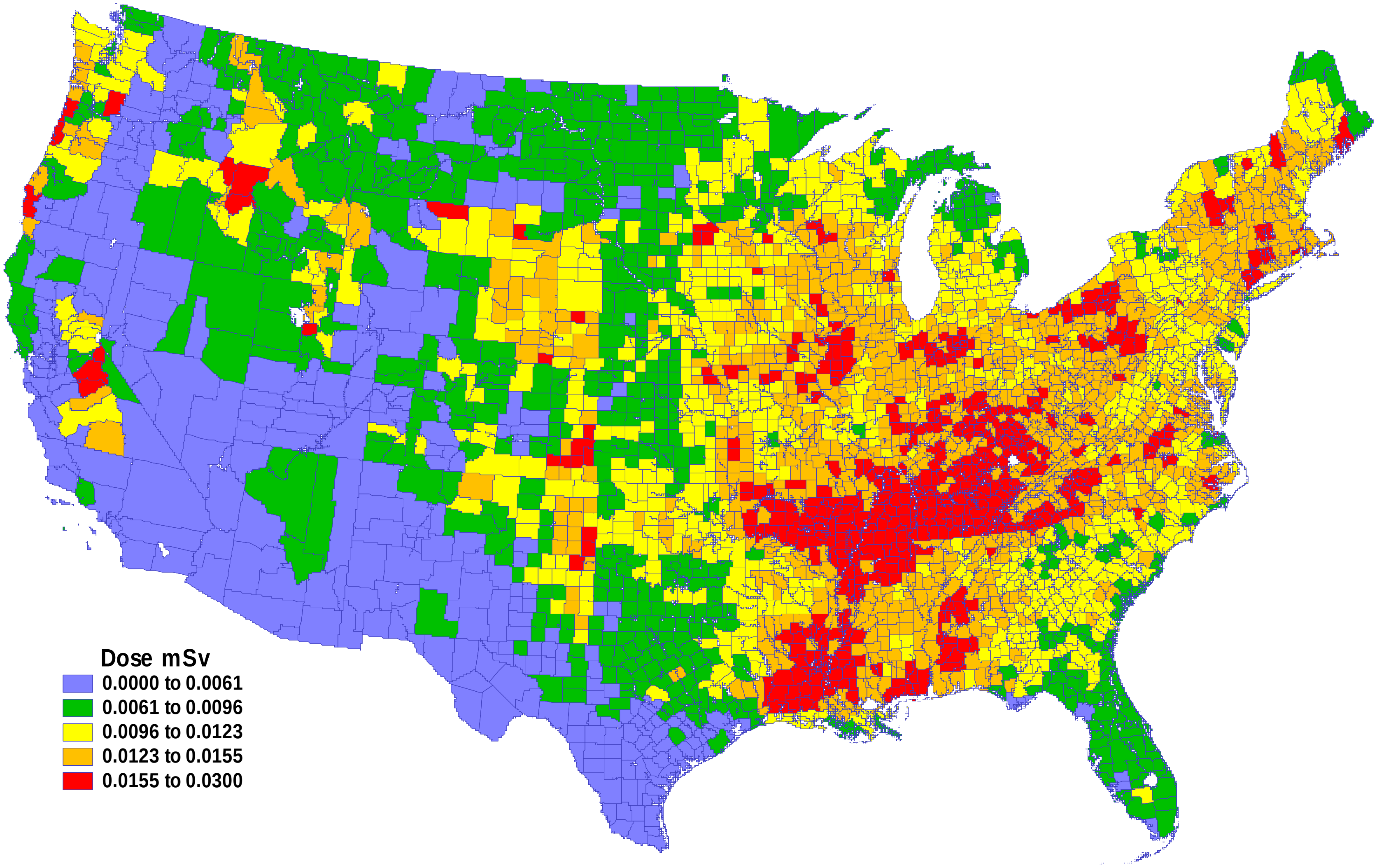

Fig. 9. Map of the committed dose (mSv) for a person born in 1951 to the red bone marrow from ^{90}*Sr deposited during 1955.*

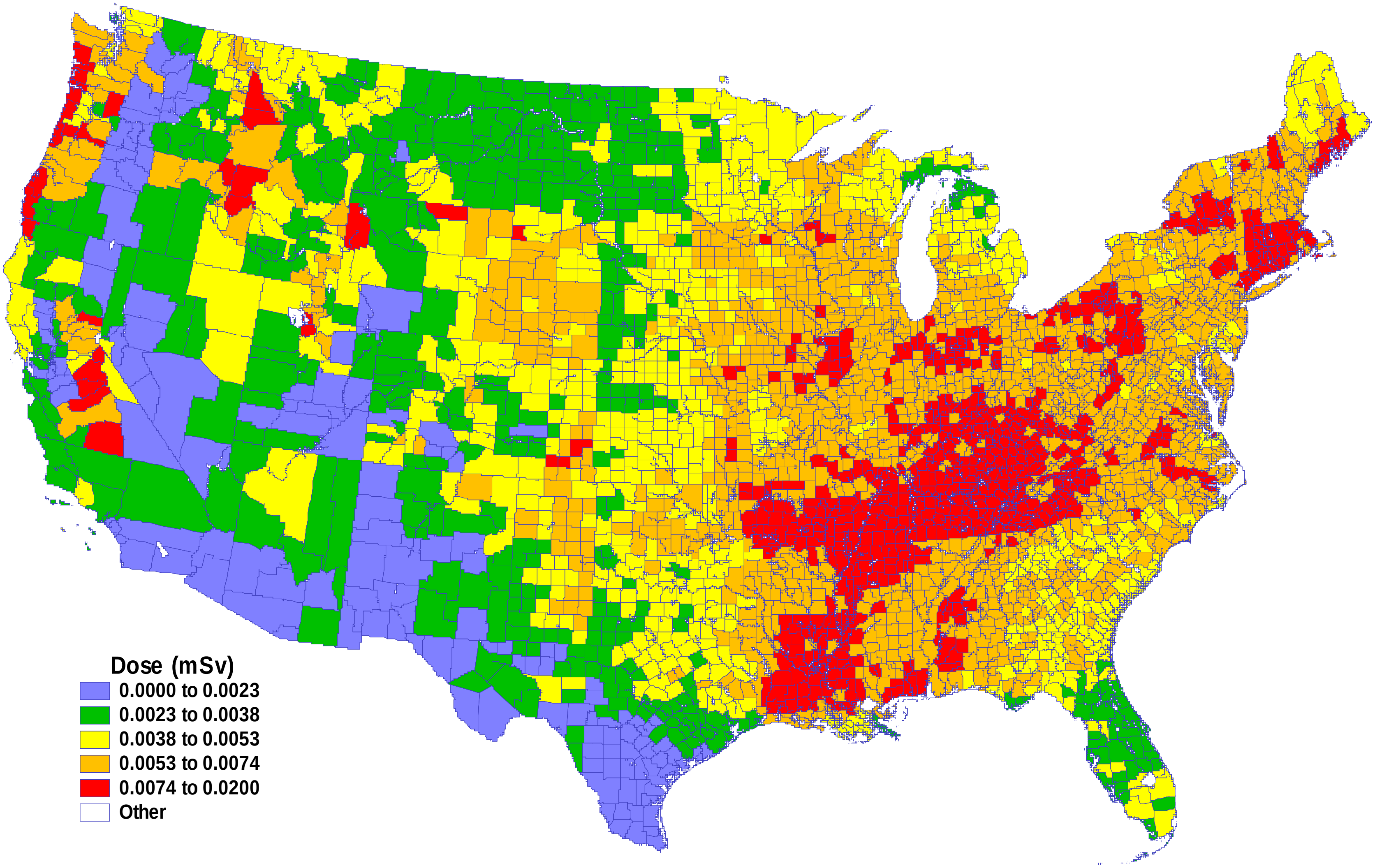

Fig. 10. Map of the committed effective dose (mSv) for an adult from ^{137}Cs deposited during 1955.

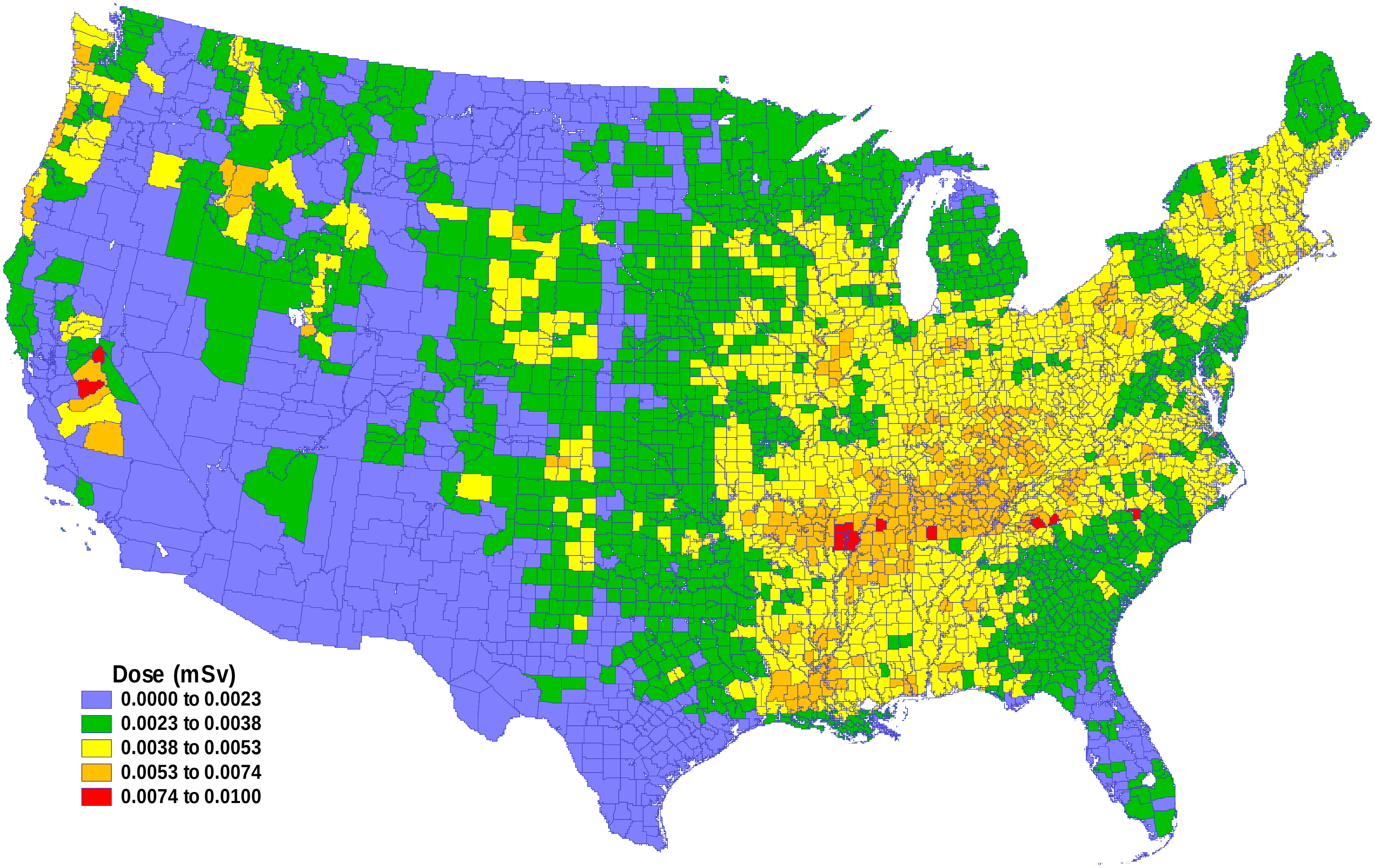

Fig. 11. Map of the committed effective dose (mSv) for a person born in 1951 from ^{137}Cs deposited during 1955.

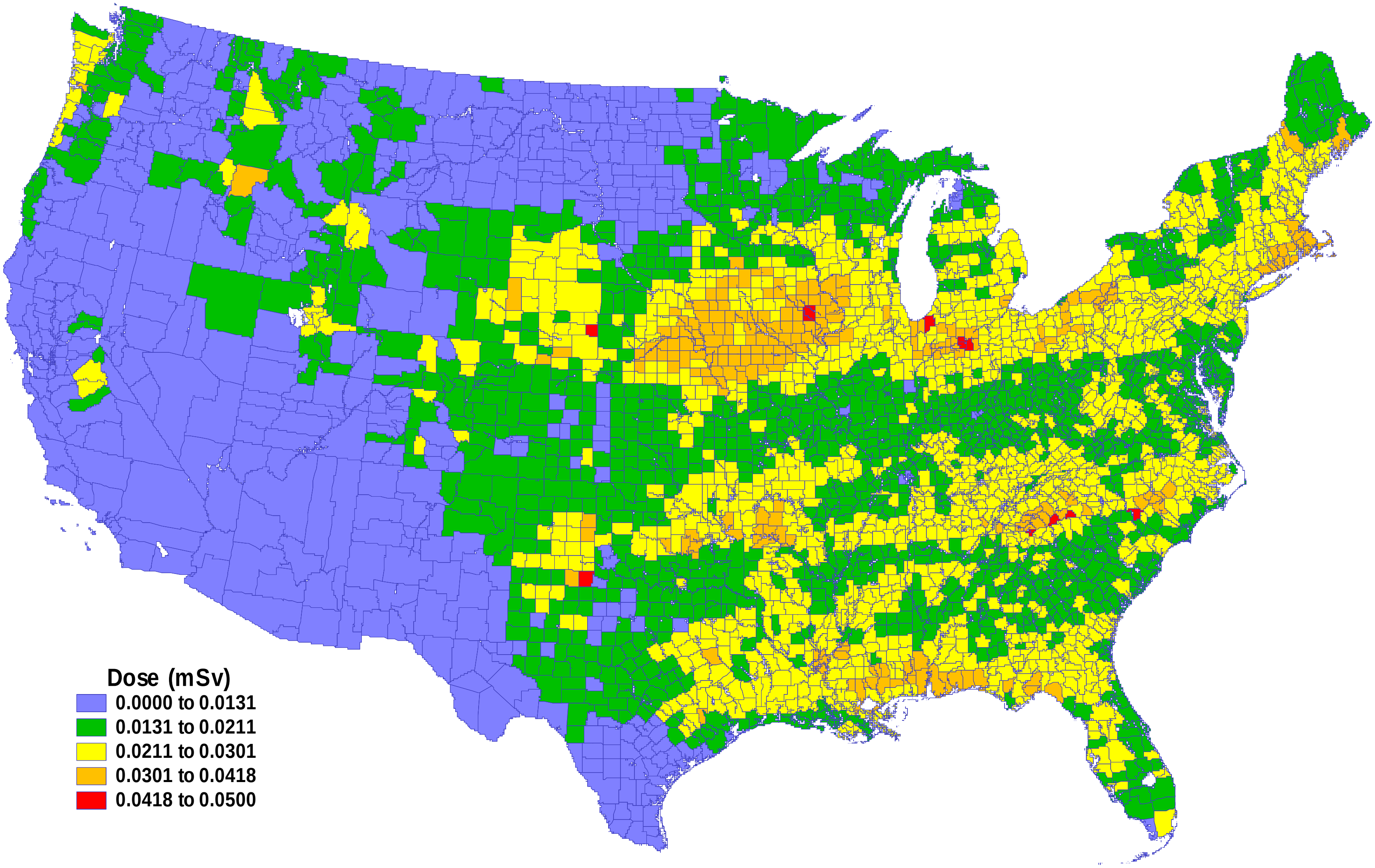

Fig. 12. Map of the committed dose (mSv) for an adult to the red bone marrow from ^{90}*Sr deposited during 1959.*

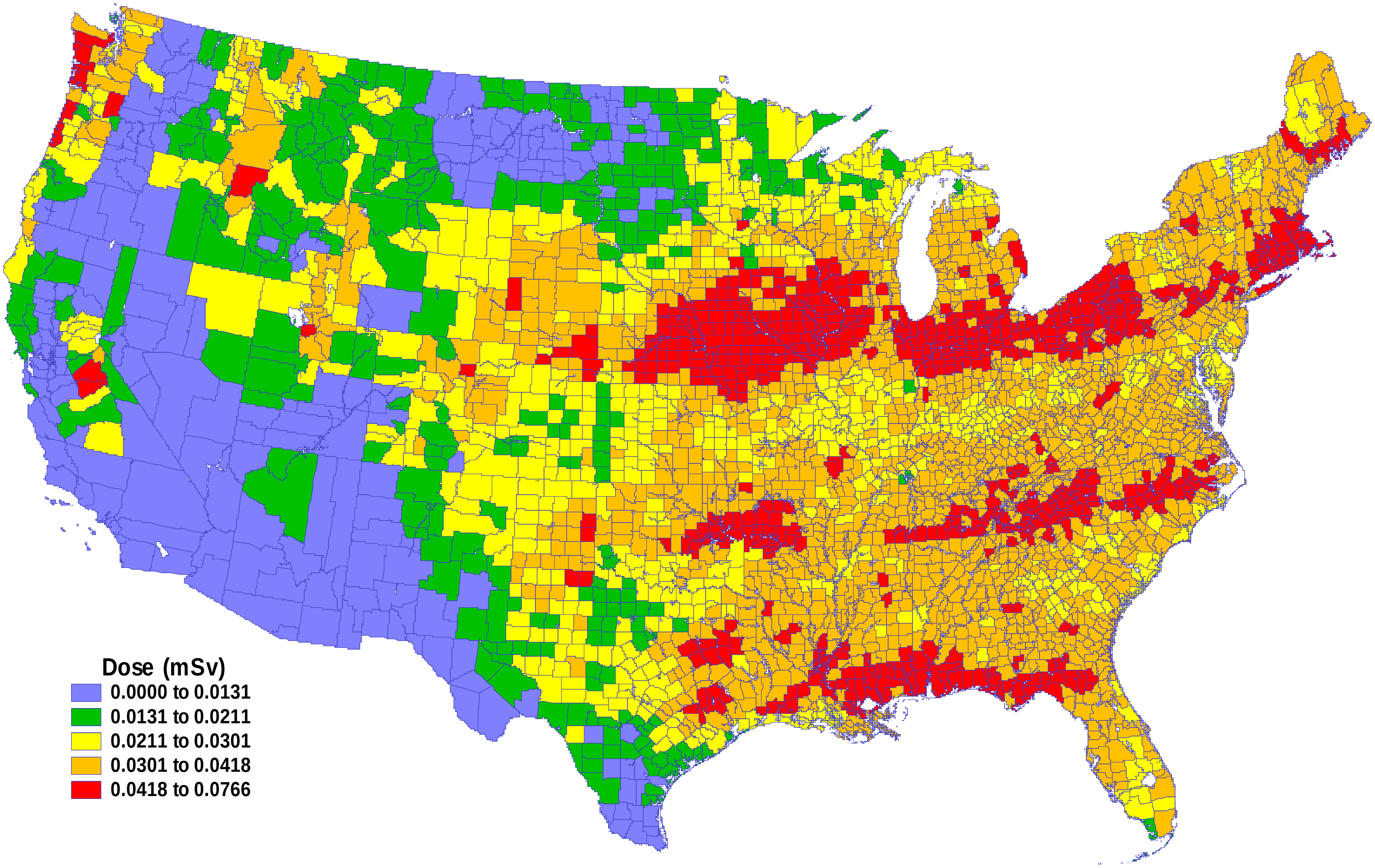

Fig. 13. Map of the committed dose (mSv) for a person born in 1951 to the red bone marrow from ^{90}*Sr deposited during 1959.*

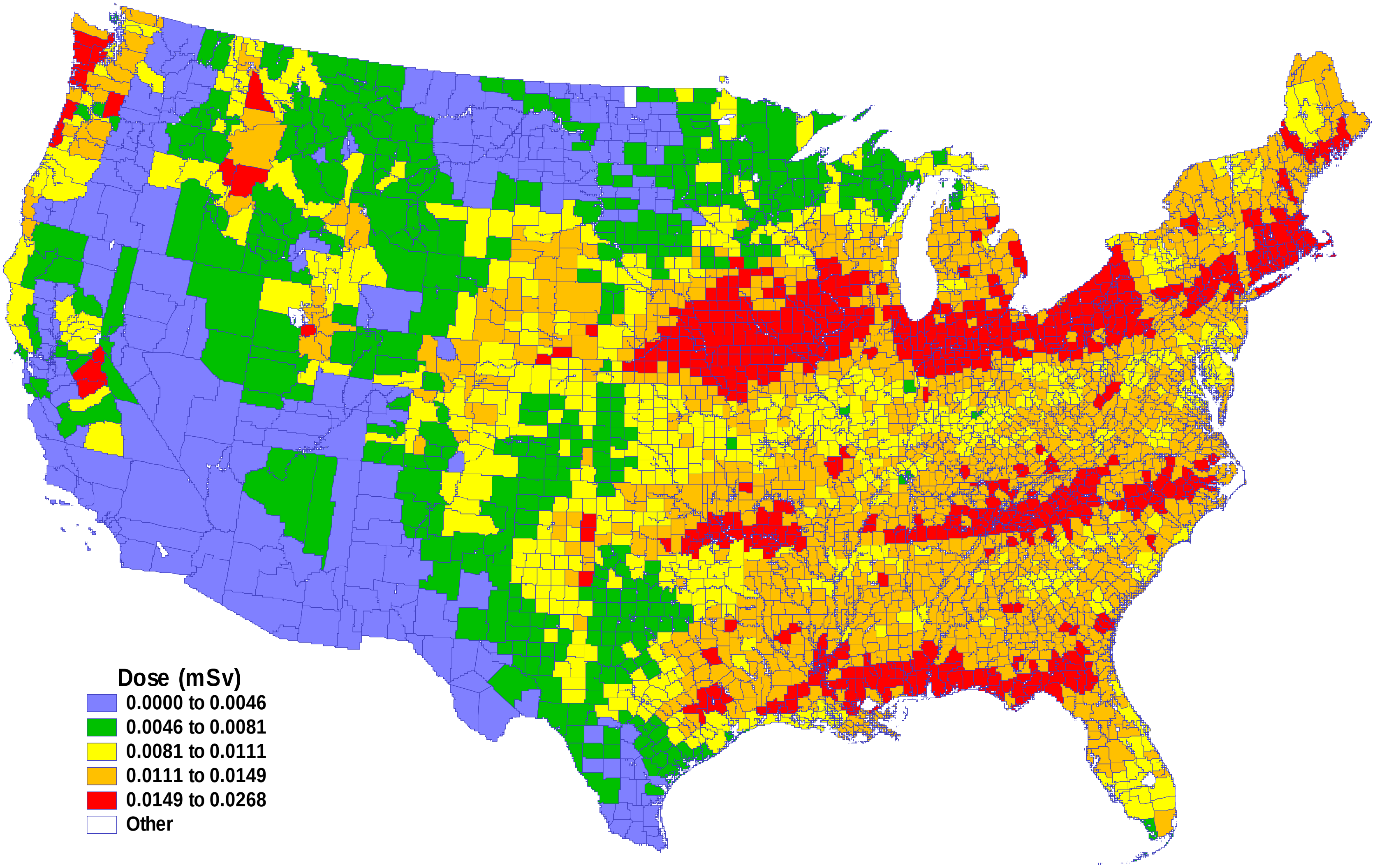

Fig. 14. Map of the committed effective dose (mSv) for an adult from ^{137}*Cs deposited during 1959.*

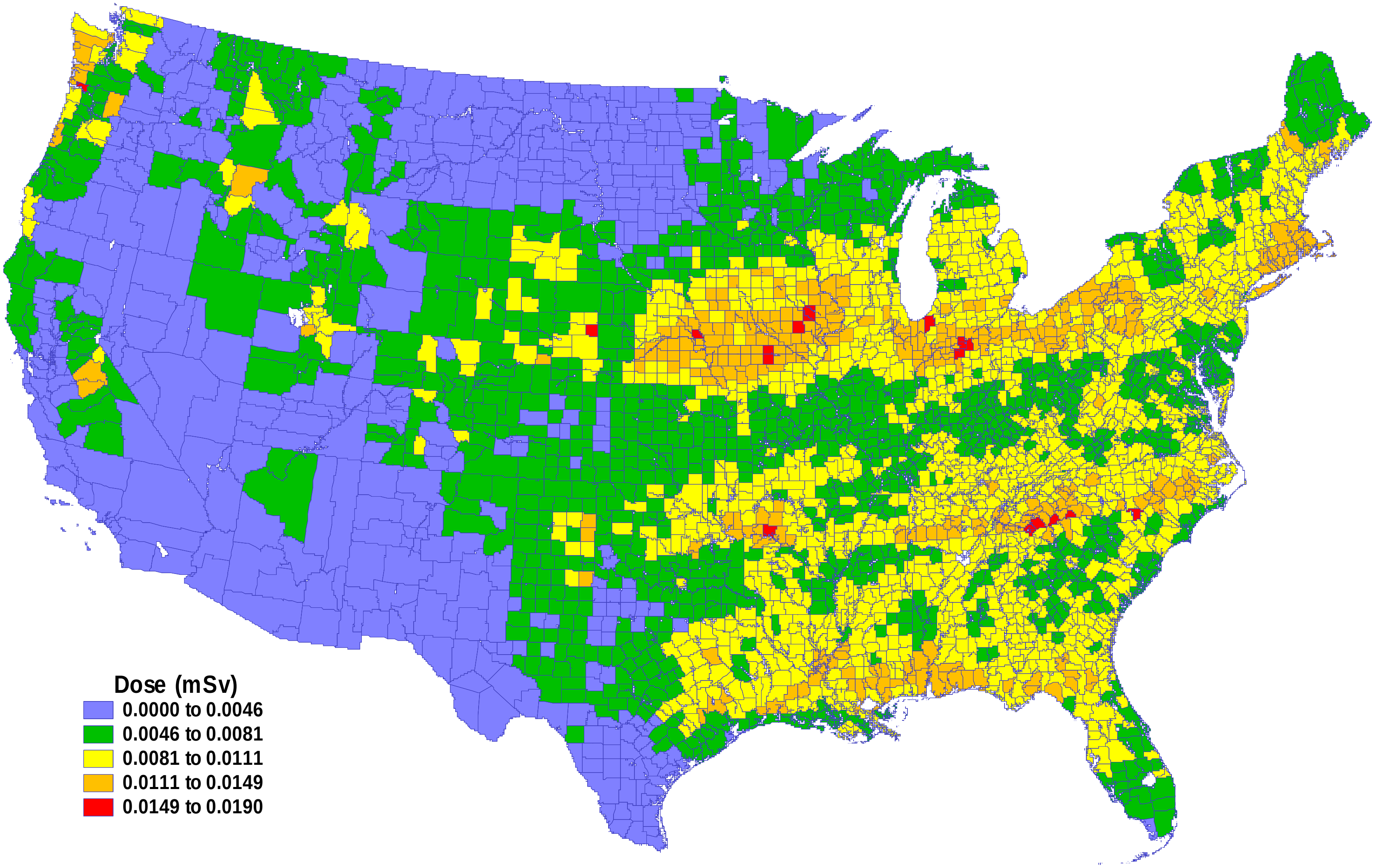

Fig. 15. Map of the committed effective dose (mSv) for a person born in 1951 from ^{137}*Cs deposited during 1959.*

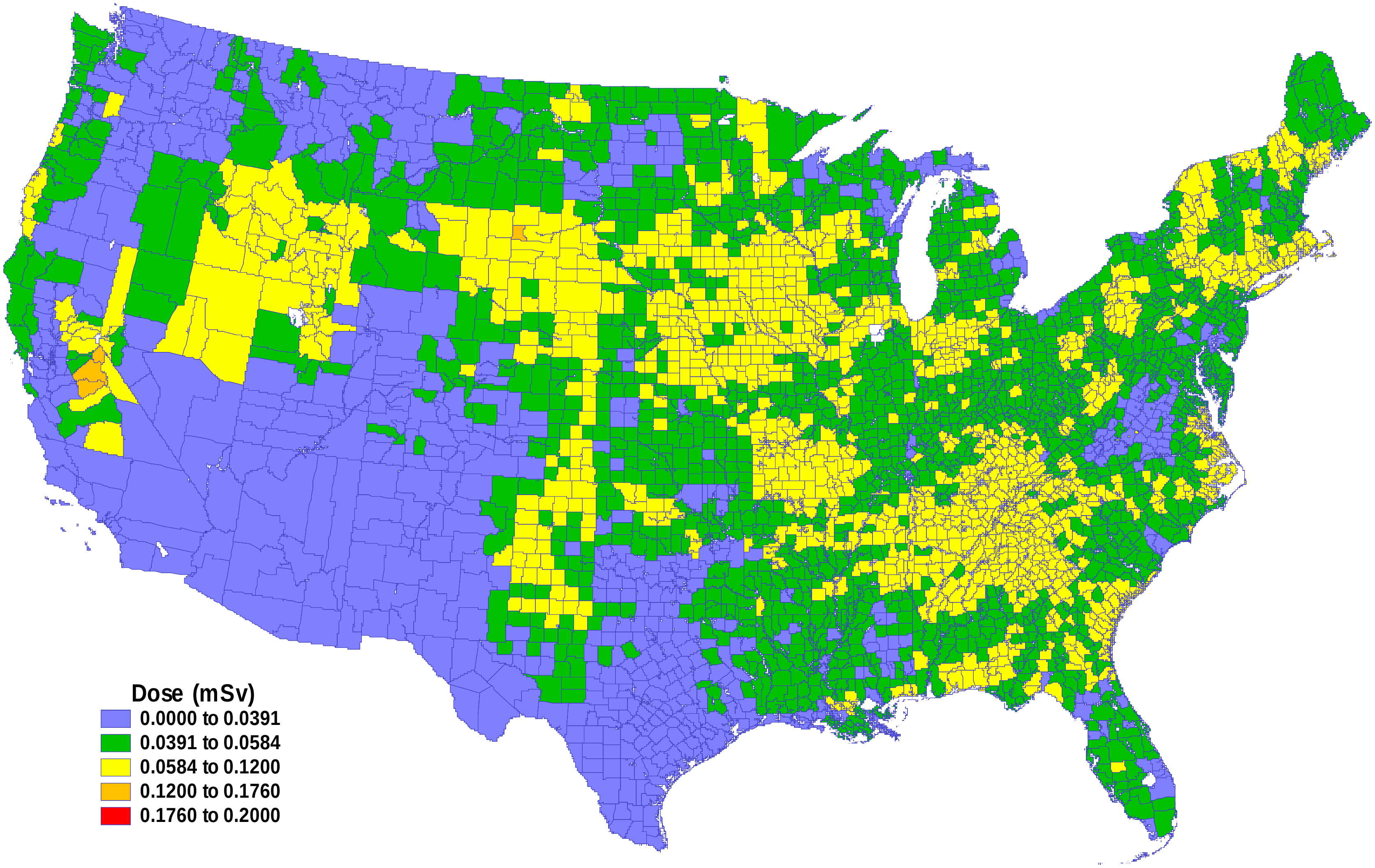

Fig. 16. Map of the committed dose (mSv) for an adult to the red bone marrow from ^{90}Sr deposited during 1963.

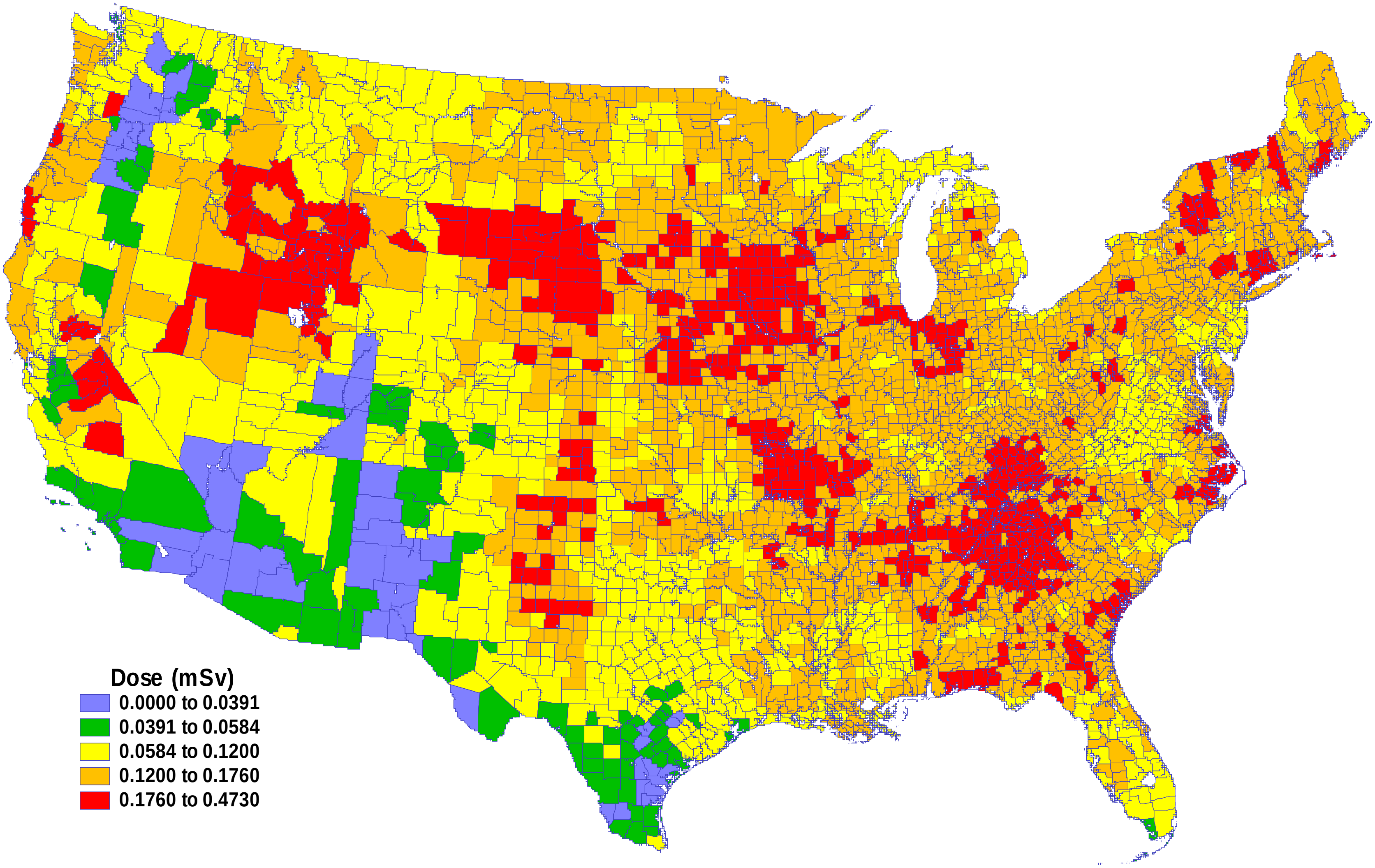

Fig. 17. Map of the committed dose (mSv) for a person born in 1951 to the red bone marrow from ^{90}*Sr deposited during 1963.*

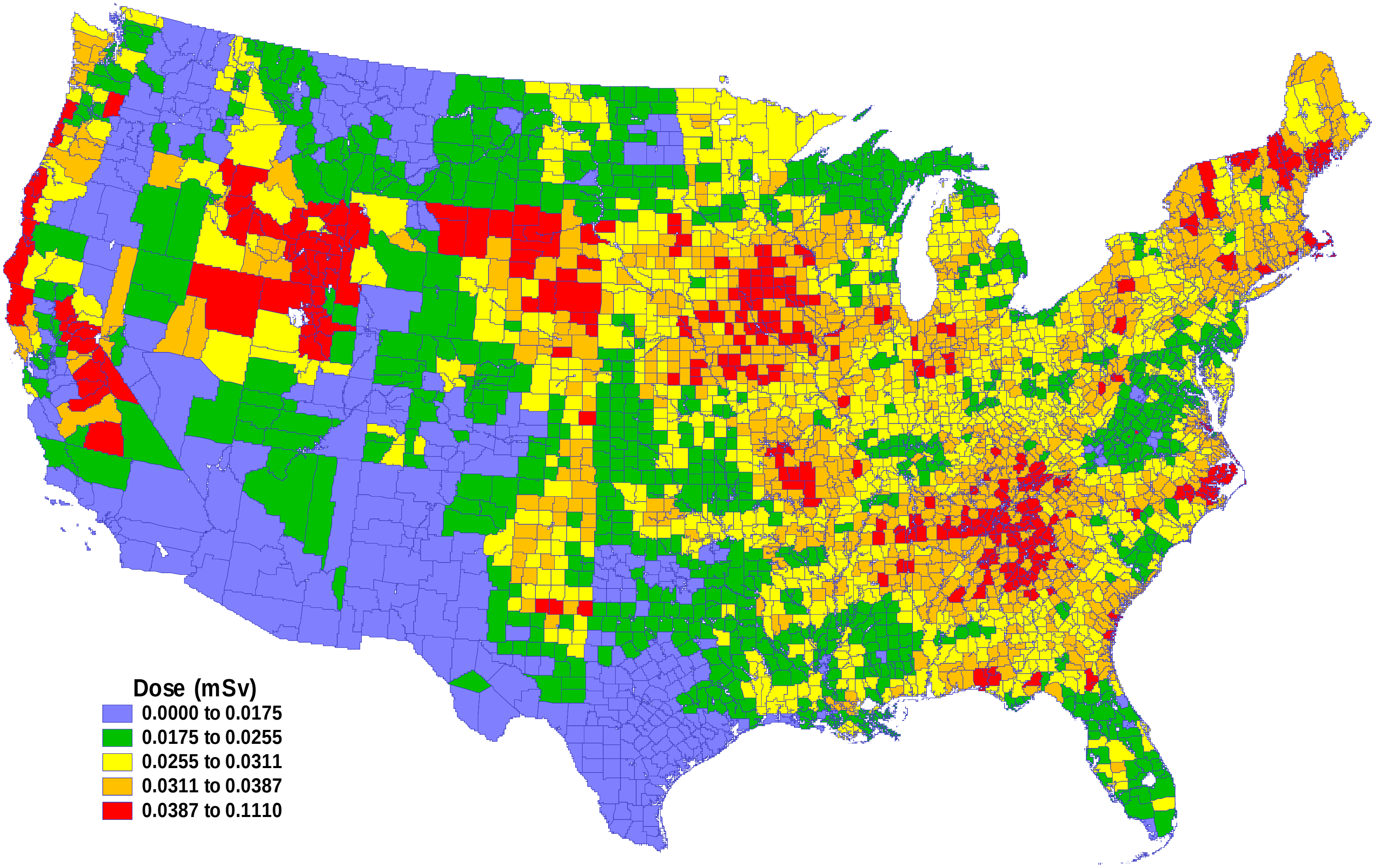

Fig. 18. Map of the committed effective dose (mSv) for an adult from ^{137}Cs deposited during 1963.

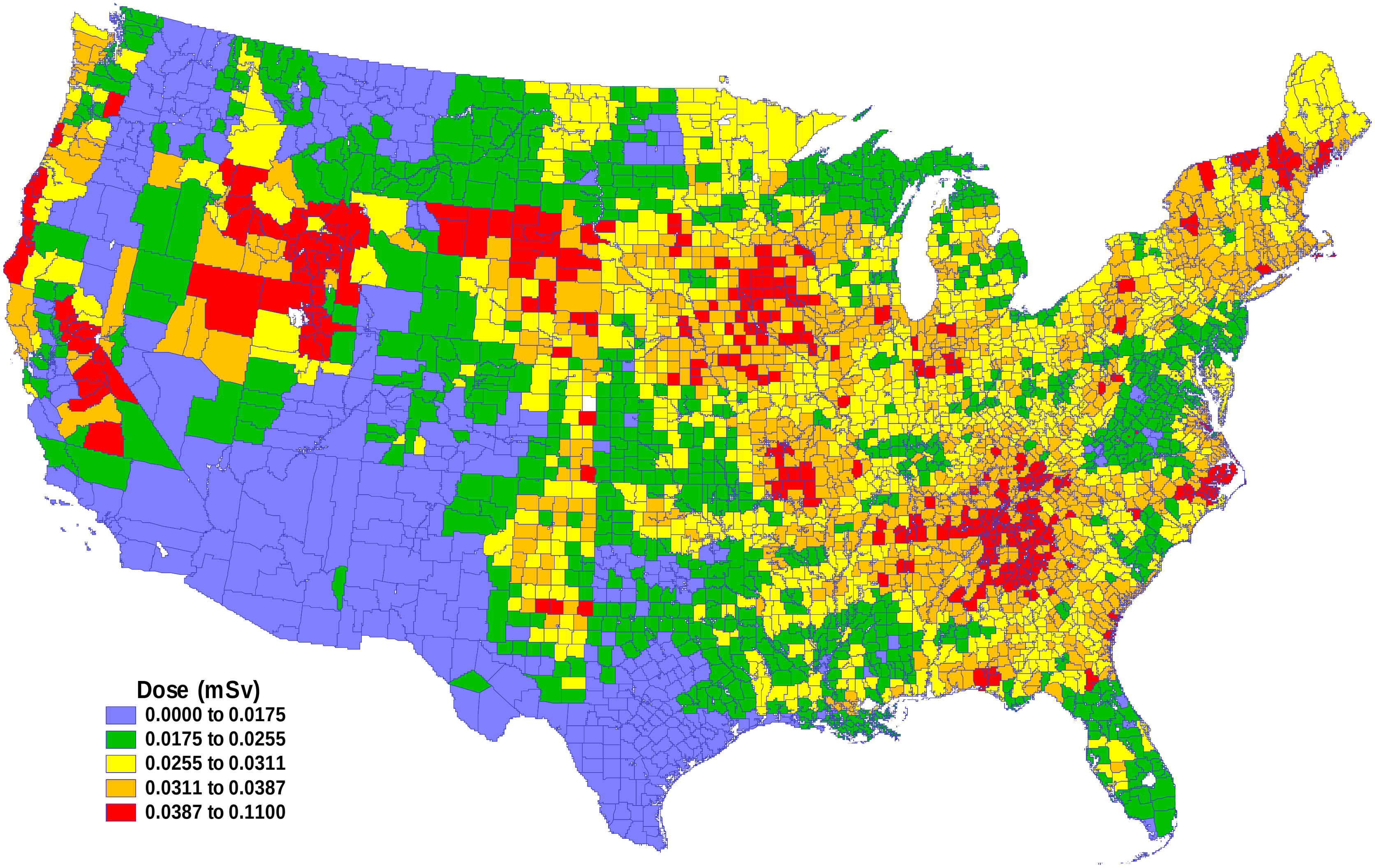

Fig. 19. Map of the committed effective dose (mSv) for a person born in 1951 from ^{137}*Cs deposited during 1963.*

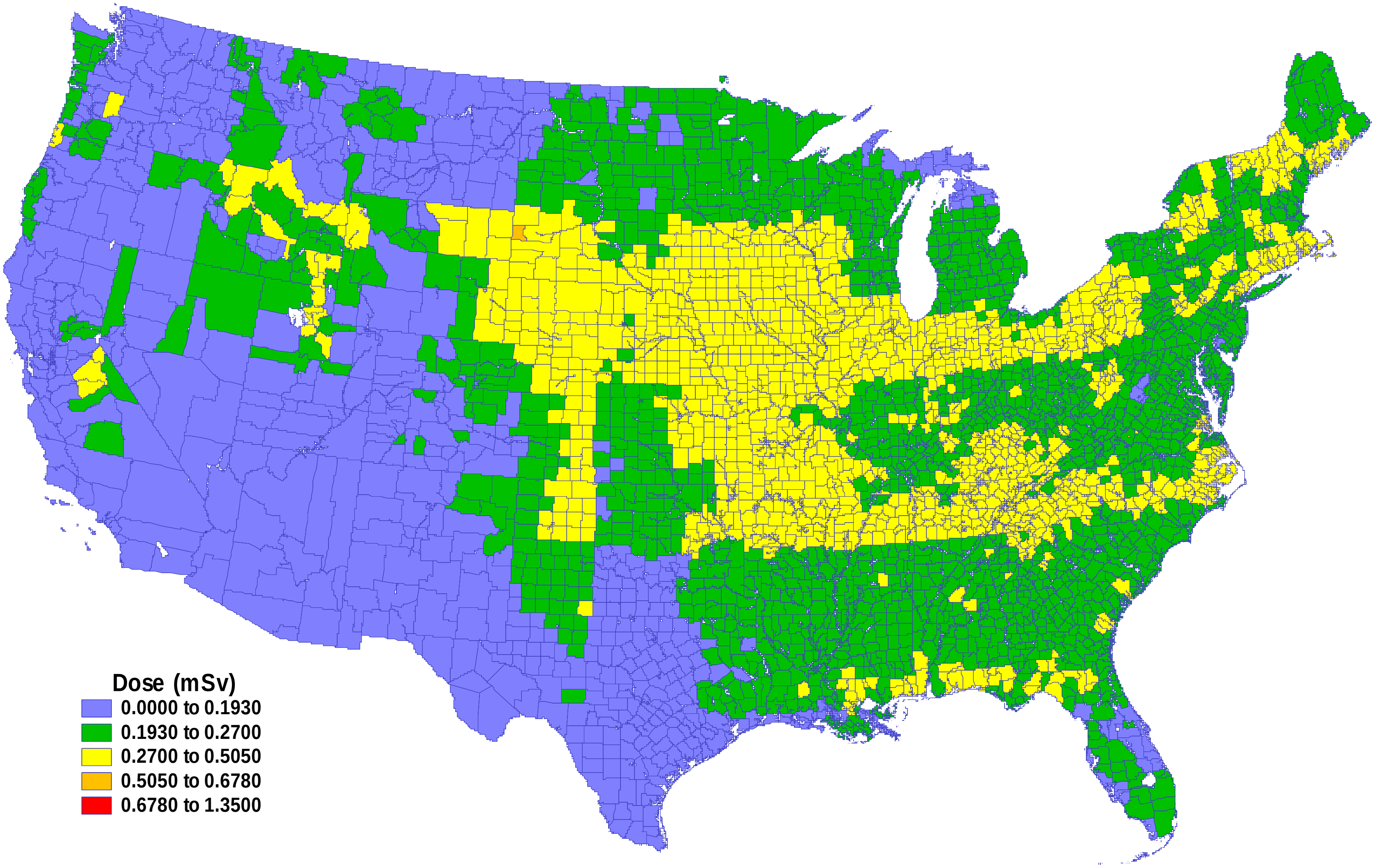

Fig. 20. Map of the committed dose (mSv) for an adult to the red bone marrow from ^{90}*Sr deposited during 1953-1972.*

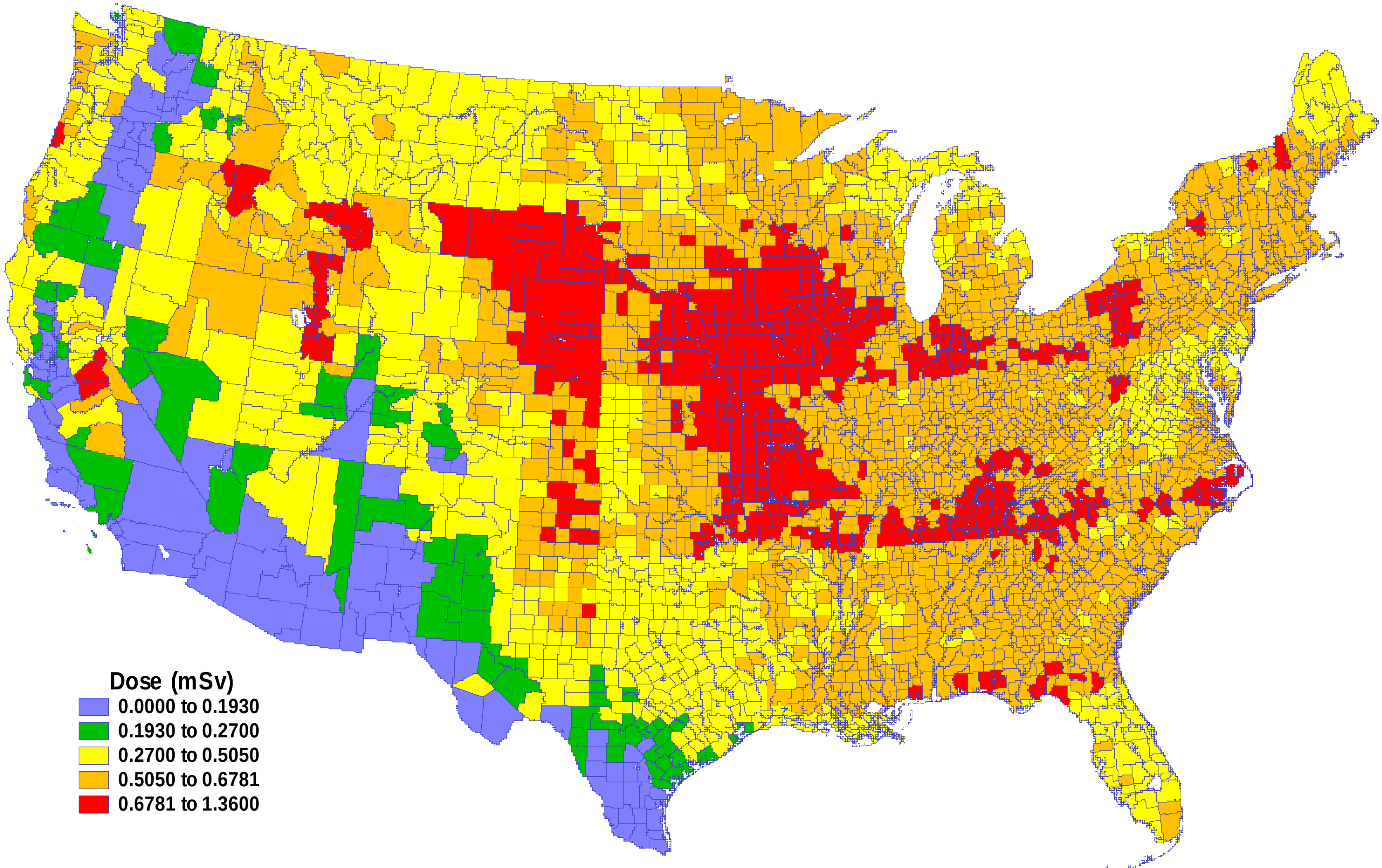

Fig. 21. Map of the committed dose (mSv) for a person born in 1951 to the red bone marrow from ^{90}*Sr deposited during 1953-1972.*

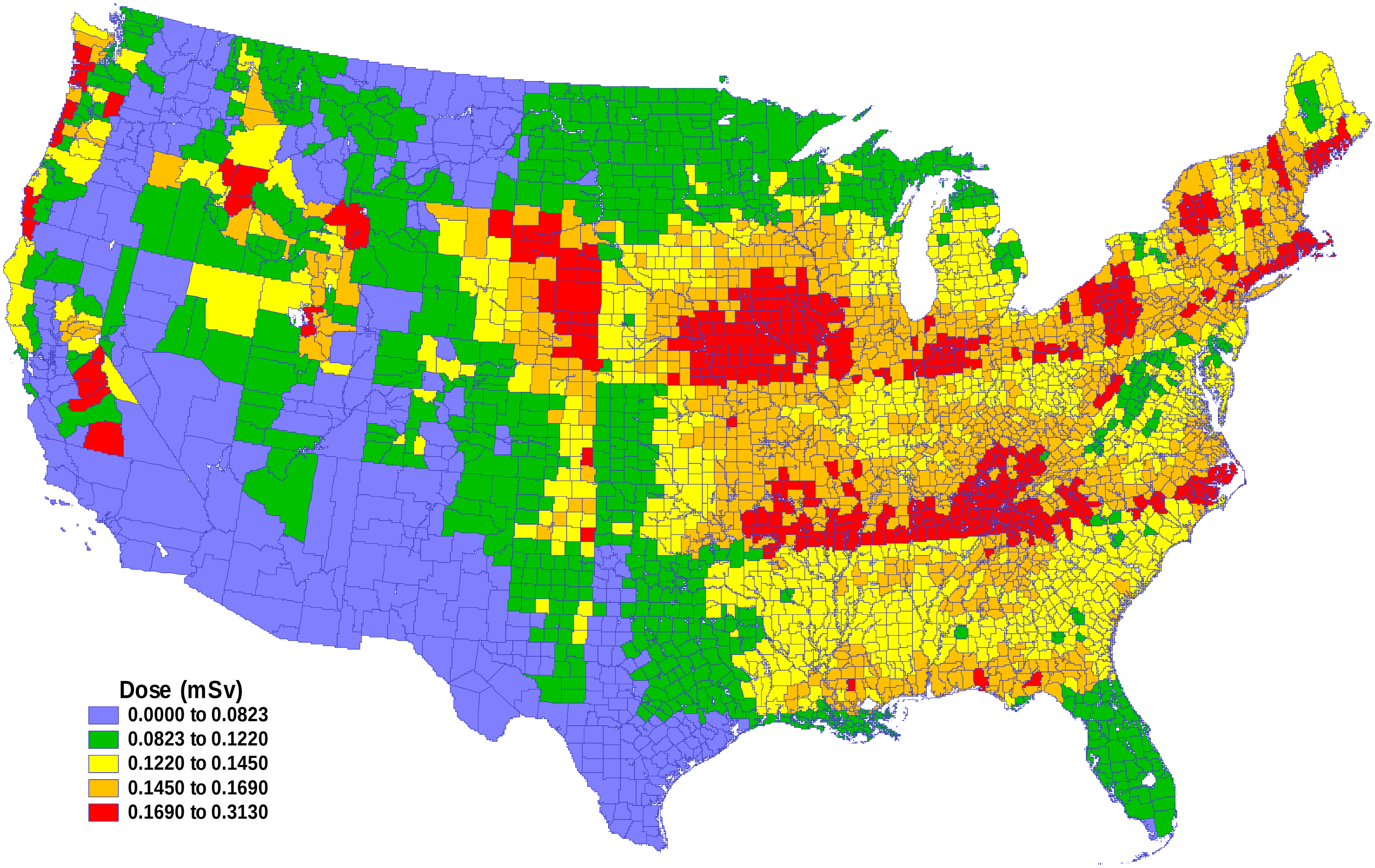

Fig. 22. Map of the committed effective dose (mSv) for an adult from ^{137}*Cs deposited during 1953-1972.*

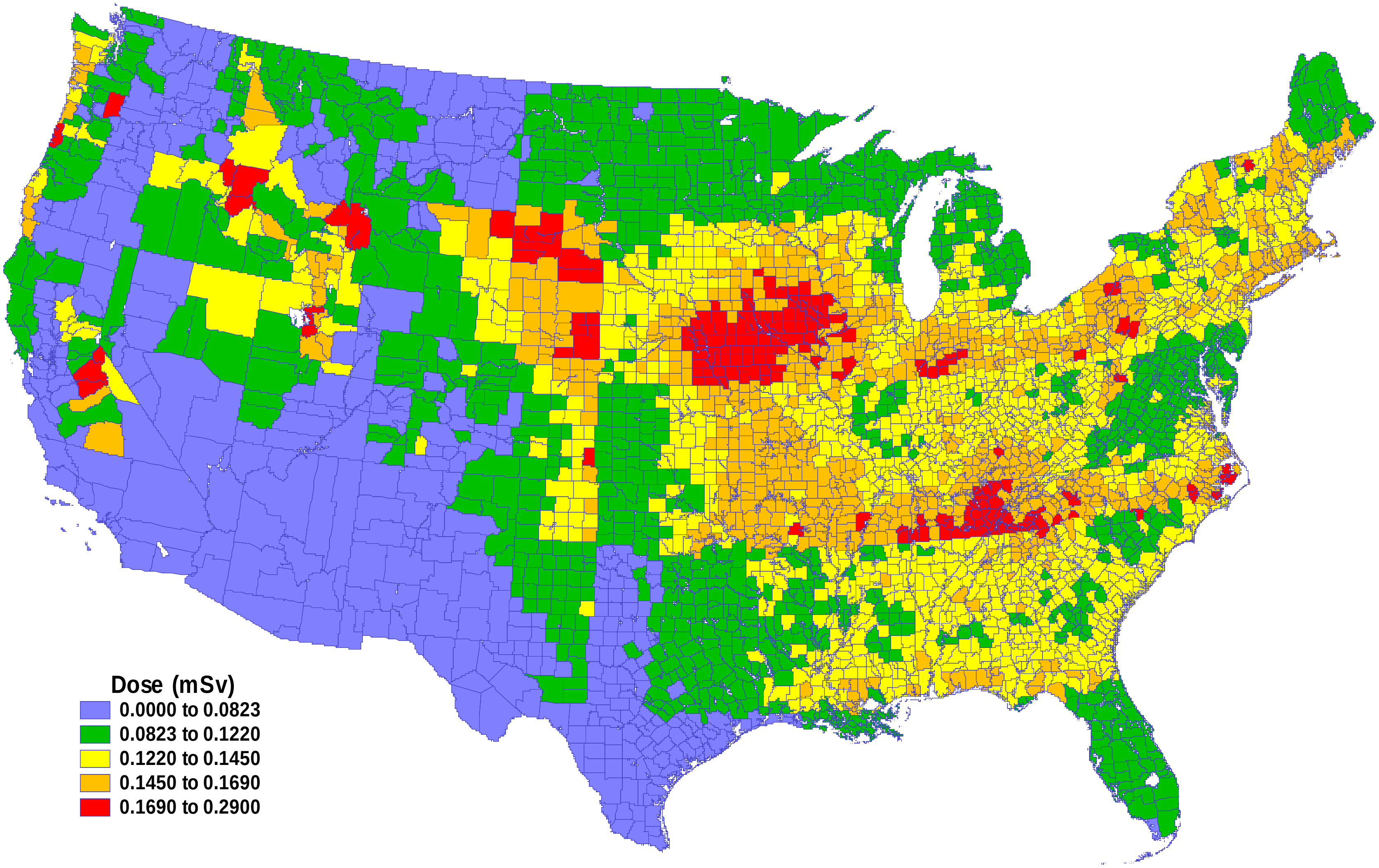

Fig. 23. Map of the committed effective dose (mSv) for a person born in 1951 from ^{137}*Cs deposited during 1953-1972.*

doses for the two age groups to the red bone marrow from ^{90}Sr and effective dose from ^{137}Cs that are summed over the entire period of calculation (1953–1972).

The appearance of the maps in Figs. 8–23 is influenced by the choice of the dose ranges used for the display. There are five dose ranges used for each map, and these dose ranges were selected in the following way with Figs. 8 and 9 used as illustrations. First, all of the data for the committed dose to the selected organ (or effective dose) for the selected radionuclide for the 3071 counties for both the adult and the person born on 1 January 1951 were combined into a single file and sorted. For Figs. 8 and 9 this combined file represented the committed doses to the red bone marrow from ^{90}Sr for the adult and for the person born on 1 January 1951 for all 3071 counties. Then, 10% of the 6142 combined sorted doses were assigned the color blue (lower doses) for each map, 25% green, 30% yellow, 25% orange, and 10% red (higher doses). Examination of Figs 8 and 9 indicates several features. First, it is clear that the higher committed doses from ^{90}Sr occurred to persons living in the eastern third of the country, although there are also “hot spots” in the Midwest, and in parts of California, Idaho, Oregon, and Washington. These areas of higher committed dose are related primarily to the amounts of rainfall that occurred in these locations. Second, comparison of the two figures indicates that a person born on 1 January 1951 received higher committed doses than a person who was an adult, although these doses are not greatly different. For Figs. 10 and 11 the same technique was used, except that committed effective doses due to ^{137}Cs are plotted. The same geographical pattern is evident, but in this case the dose to the person born on 1 January 1951 is lower than to the adult. Whether doses are higher or lower for a particular age group depends upon 1) the time of year when the fallout occurred, which in turn affects 2) the relative values of the age-dependent integrated intakes [see Figs. 1 and 2], and 3) the values of the age-dependent dose coefficients [Table 4].

The per caput doses over the entire period of analysis are summarized in Table 6 for adults and for a person born on 1 January 1951. In general, the doses calculated for a person born in 1951 from ^{90}Sr are two-three times higher than for the adult, but the doses from ^{137}Cs are essentially the same for the two age groups. The sum of effective doses from ^{90}Sr and ^{137}Cs is 170 μSv for the adult and 210 μSv for the person born in 1951.

Table 6. Total per caput doses calculated for the 1953–1972 period from the deposition of ^{90}Sr and ^{137}Cs in global fallout. Upper values are for adults; lower values are for a person born on 1 January 1951. Values are averaged over the entire U.S.

Radionuclide	Individual organ or effective committed dose, μSv				
	Bone surface	Colon	Red marrow	Thyroid	Effective
			Adult		
^{90}Sr	540	17	240	0.86	37
^{137}Cs		160			130
			Person born on 1 January 1951		
^{90}Sr	1600	34	530	2.3	87
^{137}Cs		160			120

Another way of examining the committed doses for individuals is to look at the sum of effective doses from ^{90}Sr and ^{137}Cs on a county-by-county basis. Such values can be summed for each county over the entire period of 1953–1972. When this is done, the resulting highest dose of 380 μSv is found in Alpine County, California, and the lowest dose of 6.8 μSv occurred in Imperial County, California, a range of a factor of nearly 60. It is rather surprising that both the lowest and the highest doses occurred in the same state; however, the two counties differ markedly. Alpine County is in the Sierra Nevada Mountains and experiences a high amount of precipitation. Imperial County borders on Mexico and is shadowed by the mountains east of San Diego. Thus, it receives very little precipitation. A list of the 80 counties with the higher estimates of summed committed effective doses is given in Table 7.

One of the interesting features of Table 7 is that there are many counties with essentially the same estimated dose—this is to be expected given that global fallout is rather evenly dispersed and that the amount of annual precipitation is the most important factor in determining the amount of global fallout deposited in any one county. Another interesting feature is that the state with the highest number of counties in Table 7 is Iowa (22) followed by Tennessee (14) and North Carolina (11).

Counties with the lower estimates of dose are listed in Table 8. Again, it is noted that there is a large number of counties with essentially equal doses, which are lower than those in Table 7 due primarily to the low amounts of annual precipitation in these counties. The state with the highest number of occurrences in Table 8 is Texas (29) followed by California (12) and Washington (9). Three states; California, Oregon, and Utah; contain counties that occur on both lists. This is due to the highly diverse climatic conditions found in these three states.

Fig. 24 is a plot of the country-average sum of committed effective dose from ^{90}Sr and ^{137}Cs as a function of time for two age cohorts: adults in 1951 and those born on 1 January 1951. The influence of changing intake rates and dose coefficients with age is seen. The relative position of the two curves changes as the person born in 1951 ages and is assigned different intake rates and dose coefficients.

^{131}I. As mentioned above, it was not possible for Beck (2000) to provide estimates of ^{131}I deposition on a county-by-county basis for this feasibility study. Rather, estimates of deposition through time were provided as country-average values. Because the dose from ingestion of ^{131}I is strongly age dependent, dose estimates were calculated for adults and for persons born on 1 January of each of the years 1951 through 1963. The calculations of dose from ^{131}I were not extended through 1972, as was done for ^{90}Sr and ^{137}Cs; this is because testing ended in 1963, and ^{131}I is too short-lived to contribute to doses in the later years. All doses from the ingestion of ^{131}I were estimated on the basis of age- and season-dependent intake factors and age-dependent dose coefficients.

The complete set of calculations of dose from the ingestion of ^{131}I is available on the CD-ROM in the workbook entitled "GBLI131." The year-by-year estimates of per caput bone surface, colon, red marrow, thyroid, and effective dose are summarized in Table 9. As expected,

Table 7. Counties with higher estimates of total individual effective dose from ^{90}Sr and ^{137}Cs.

State	County	Dose, μSv
CA	Alpine	380
SD	Lawrence	350
CA	Tuolumne	350
NC	Transylvania	320
ID	Valley	310
CA	Mariposa	310
NC	Richmond	290
NC	Polk	280
ID	Adams	280
NC	Macon	280
NC	Clay	280
SD	Pennington	270
ID	Fremont	270
NE	Logan	270
NE	Thomas	270
ID	Boise	270
TN	Sequatchie	270
IA	Taylor	270
IA	Iowa	270
NC	Cherokee	270
NC	Graham	260
TN	Marion	260
TN	Grundy	260
VT	Lamoille	260
MO	Worth	260
MO	Nodaway	260
NE	Hooker	260
NE	Nemaha	260
NE	Richardson	260
IA	Montgomery	260
UT	Salt Lake	260
IA	Page	260
NC	Swain	260
TN	Bledsoe	260
OR	Lincoln	260
TN	Meigs	260
TN	Rhea	260
TN	Van Buren	260
IA	Jones	260
IA	Adair	260
TN	Bradley	260
IA	Black Hawk	260
IA	Linn	250
SD	Custer	250
NE	McPherson	250
IA	Dallas	250
UT	Weber	250
NC	Yancey	250
IA	Marshall	250
IA	Delaware	250
IA	Lucas	250
IA	Story	250
IA	Audubon	250
IN	Montgomery	250
MO	Harrison	250
IN	Fountain	250
IN	Warren	250
IA	Dubuque	250
IA	Louisa	250
IA	Tama	250
WY	Teton	250
IA	Mahaska	250
TN	Hamilton	250
MO	Atchison	250
TN	Mcminn	250
MO	Gentry	250
NE	Pawnee	250
NC	Greene	250
NC	Lenoir	250
IA	Franklin	250
IA	Shelby	250
MO	Holt	250
MO	Putnam	250
IA	Benton	250
TN	Scott	250
IA	Monroe	250
WY	Crook	250
TN	Chester	250
TN	McNairy	250
TN	Hardin	240

Table 8. Counties with lower estimates of total individual effective dose from ^{90}*Sr and* ^{137}*Cs.*

State	County	Dose, μSv	State	County	Dose, μSv
CA	Imperial	6.8	WA	Franklin	52
AZ	Yuma	14	TX	Hudspeth	52
OR	Sherman	31	NM	Hidalgo	52
AZ	Maricopa	31	WA	Adams	52
OR	Gilliam	31	TX	Hidalgo	52
OR	Wasco	33	UT	Grand	52
TX	Presidio	35	NM	San Juan	53
NV	Clark	36	TX	Culberson	53
WA	Yakima	37	NM	Sierra	53
TX	El Paso	38	TX	Zavala	54
OR	Jefferson	38	CA	Orange	54
OR	Deschutes	38	TX	Live Oak	54
CA	Riverside	40	TX	Kleberg	54
NM	Dona Ana	40	NV	Esmeralda	55
CA	Merced	40	WA	Island	55
TX	Zapata	41	CO	Costilla	55
WA	Benton	42	CA	Santa Barbara	56
NM	Valencia	43	TX	Brooks	56
WA	Grant	44	TX	Kenedy	56
NM	Luna	44	AZ	Graham	56
AZ	Pinal	44	WA	Douglas	57
CA	Lassen	44	TX	Val Verde	57
TX	Brewster	45	TX	Jim Wells	57
TX	Jim Hogg	47	TX	Cameron	57
OR	Crook	47	TX	Nueces	57
WA	Klickitat	48	CO	Rio Grande	57
AZ	Pima	48	TX	Atascosa	58
CA	San Joaquin	48	TX	Willacy	58
TX	Webb	48	TX	Uvalde	59
TX	Starr	48	NM	Catron	59
TX	Duval	49	TX	Loving	59
OR	Wheeler	50	CA	San Diego	60
OR	Lake	50	UT	Wayne	60
CA	San Benito	50	CO	Conejos	60
NM	Socorro	50	TX	Frio	60
CA	Stanislaus	50	CA	Modoc	61
TX	Dimmit	51	UT	San Juan	61
WA	Chelan	51	CA	Inyo	61
TX	Mcmullen	51	AZ	Santa Cruz	62
TX	La Salle	51	TX	San Patricio	63

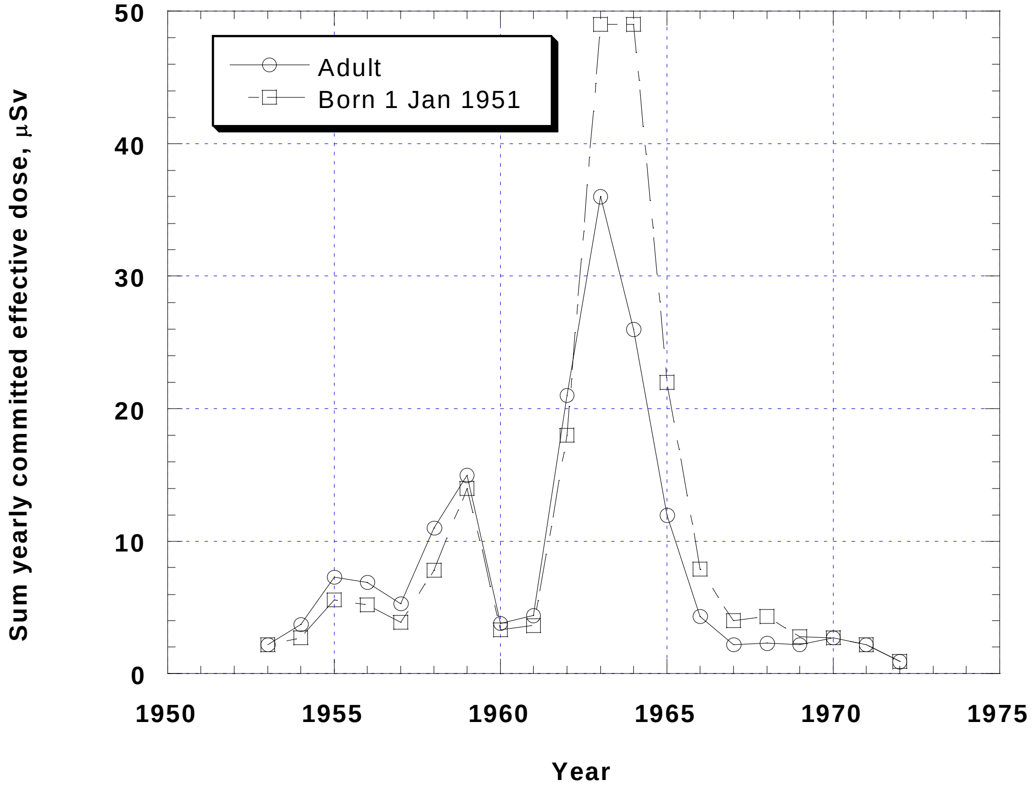

Fig. 24. Plot of the sum of committed effective doses from ^{90}Sr and ^{137}Cs as a function of time for two cohorts: those who were adults in 1951 and those born on 1 January 1951. Most of the variation in the doses between the two cohorts is due to changes in intake rates and in strontium metabolism as the young person ages.

due to the accumulation of iodine in the thyroid, the dose to this organ is the highest at 960 μSv and the effective dose is less by a factor of 20.

The estimates of yearly per caput thyroid dose, along with thyroid doses to the adult and a person born on 1 January 1951, are plotted in Fig. 25. As the person born on 1 January 1951 ages, s/he was assigned the appropriate age-dependent intakes and dose coefficients with time. As indicated, the dose to the young person is substantially higher than the per caput dose and the dose to the adult is substantially lower than the per caput dose. The combined effects on cumulative dose of birth year and of the amount of fallout experienced during a particular year are illustrated in Fig. 26 for persons born on 1 January in the years 1951 through 1963. The highest dose was received by a person born on 1 January 1956. Such a person would have received a substantial dose at a young age from the relative peak of fallout in 1957 and would have still been young enough to have both a high intake and a high dose coefficient for the highest yearly amount of ^{131}I in fallout in 1962. The person born on 1 January 1951 received less dose, because by the time of the fallout peak in 1962 s/he was older and would have experienced less intake and had a lower dose coefficient.

Table 9. Year-by-year estimates of per caput dose from the ingestion of ^{131}I in fallout from high yield weapons tests in the atmosphere. The estimates below are country averages, as reliable estimates of deposition on a county-by-county basis are not yet available.

Year	Per caput organ or effective dose, μSv				
	Bone surface	Colon	Red marrow	Thyroid	Effective
1953	0.0023	0.0045	0.0019	12	0.62
1954	0.011	0.020	0.0088	56	2.8
1955	0.00026	0.00046	0.00021	1.3	0.066
1956	0.031	0.059	0.025	170	8.2
1957	0.021	0.040	0.017	110	5.6
1958	0.044	0.083	0.036	230	12
1959	0.000021	0.000035	0.000017	0.10	0.0051
1960	0	0	0	0	0
1961	0.011	0.020	0.0088	58	2.9
1962	0.062	0.11	0.050	320	16
1963	0.00024	0.00040	0.00019	1.2	0.059
Sum	0.18	0.34	0.15	960	48

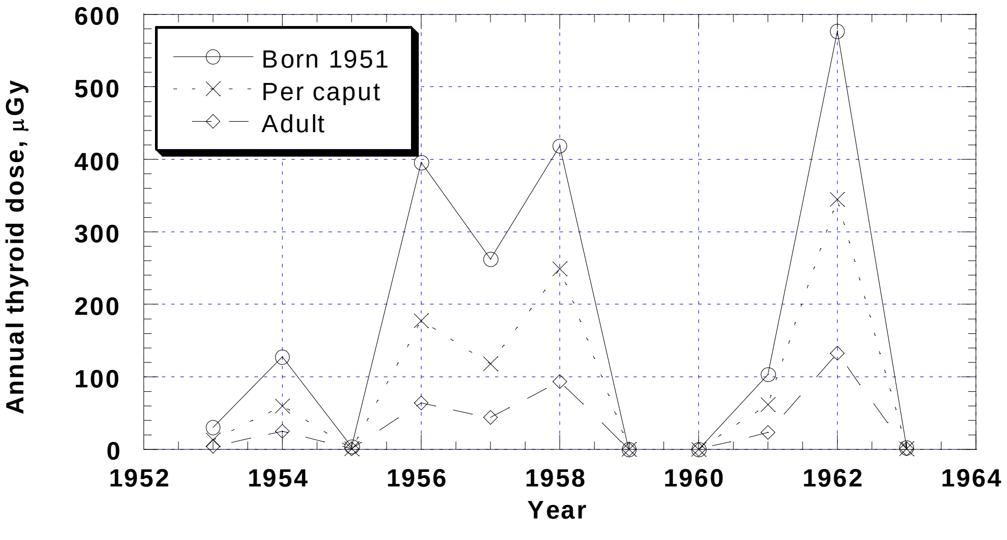

Fig. 25. Annual thyroid dose due to the ingestion of ^{131}I from global fallout as a function of year. Data are for three cohorts: those who were adults (≥18 y in 1953), the per caput value (population-weighted by age), and those born on 1 January 1951.

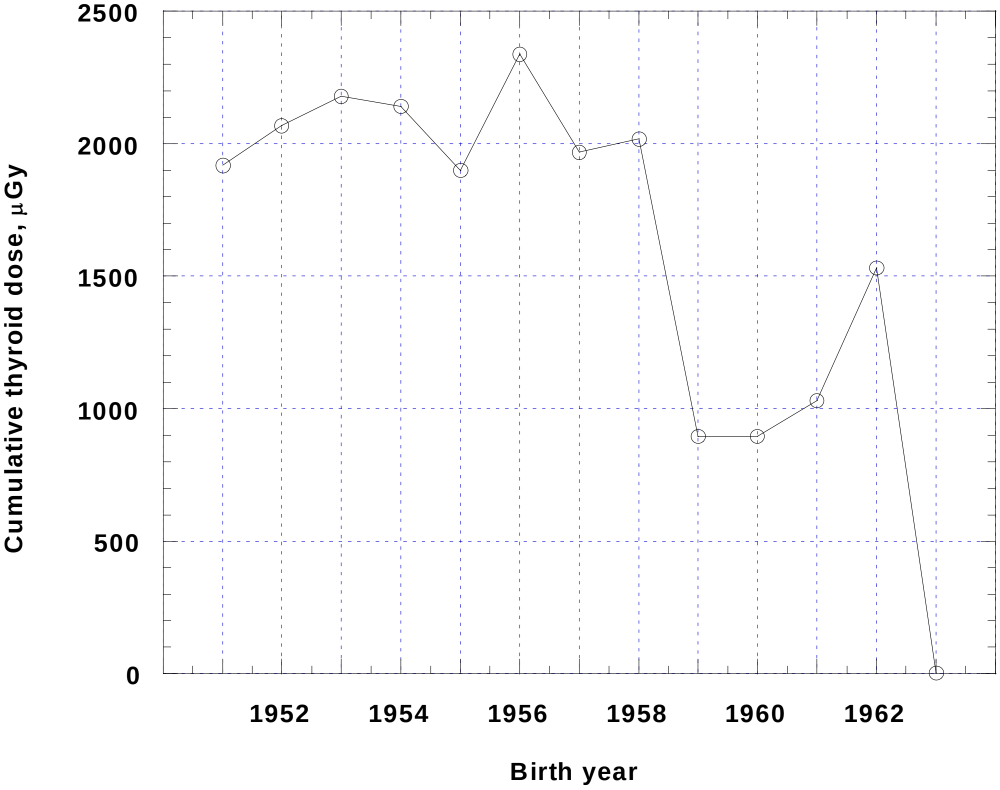

Fig. 26. Cumulative (1953 through 1963) thyroid dose as a function of birth year.

Tritium and ^{14}C. The calculated results for the individual effective doses from ^{3}H (tritium) and ^{14}C are given in Table 10. In contrast to the results for ^{90}Sr and ^{137}Cs the values in Table 10 are doses calculated to be actually received in the indicated year, whereas for ^{90}Sr and ^{137}Cs the computed values are for committed doses. The disparate treatments arise from the markedly different behavior of the two groups of radionuclides. Most of the intake of ^{90}Sr and ^{137}Cs will occur in the same year that the radionuclides are deposited in fallout and/or during the next year. However, ^{3}H and ^{14}C are in vapor or gaseous form and do not deposit with particulate matter. Rather, they take substantial time to be distributed throughout the world and their compartments of distribution are very large. Carbon-14 is also very long lived and will contribute to yearly dose for tens of thousands of years. In that regard it does not make sense within the framework of the present project goals to calculate a dose “commitment” that would be intergenerational. Therefore, the yearly doses for ^{3}H and ^{14}C have been calculated and summed only through the year 2000.

As indicated in Table 10, the calculated sums of effective doses through the year 2000 are 66 µSv for ^{3}H and 120 µSv for ^{14}C. The time dependencies of the doses from ^{3}H and ^{14}C are also plotted in Fig. 27, which is on a semi-logarithmic scale. Here, the effects of global distribution, size of compartments, and exchange rates are clearly evident; ^{3}H also has a much, much shorter

Table 10. Dose to an individual in the Northern Hemisphere from the creation or release of ^{3}H and ^{14}C from the testing of large fusion weapons in the atmosphere.

Year	Effective dose, μSv		Year	Effective dose, μSv	
	^{3}H	^{14}C		^{3}H	^{14}C
1952	0.95	0.032	1977	0.18	2.6
1953	0.20	0.10	1978	0.16	2.4
1954	3.4	0.24	1979	0.14	2.3
1955	0.69	0.51	1980	0.12	2.1
1956	2.8	0.68	1981	0.11	2.0
1957	1.3	0.95	1982	0.097	2.0
1958	6.3	1.3	1983	0.087	1.9
1959	1.1	1.7	1984	0.078	1.9
1960	0.58	1.9	1985	0.069	1.9
1961	14	2.4	1986	0.061	1.8
1962	21	4.0	1987	0.056	1.8
1963	3.8	5.4	1988	0.051	1.7
1964	2.0	5.6	1989	0.046	1.7
1965	1.4	6.2	1990	0.040	1.7
1966	1.1	6.3	1991	0.036	1.6
1967	0.86	5.8	1992	0.033	1.6
1968	0.71	5.3	1993	0.031	1.5
1969	0.59	4.8	1994	0.028	1.5
1970	0.50	4.4	1995	0.025	1.5
1971	0.43	4.1	1996	0.023	1.4
1972	0.38	3.8	1997	0.021	1.4
1973	0.33	3.5	1998	0.019	1.4
1974	0.28	3.2	1999	0.017	1.4
1975	0.24	3.0	2000	0.015	1.3
1976	0.20	2.8	Sum	66	120

half life. It is evident that the yearly dose from ^{3}H tracks more closely the amounts injected into the atmosphere, and the yearly dose from ^{3}H subsequently decreases fairly rapidly due to its half life. In contrast, ^{14}C takes a long time to be distributed throughout its compartments, the yearly doses track the injection rates only slowly, and the yearly doses decrease with time much more slowly.

Collective dose

The collective doses that can be calculated from the data contained in the CD-ROM accompanying this document are summarized in Table 11. The total collective effective dose is estimated to be 66,000 person Sv, and the total collective thyroid dose is estimated to be 210,000 “thyroid Sv.” In calculating the sum of the dose to the thyroid, it was assumed that the

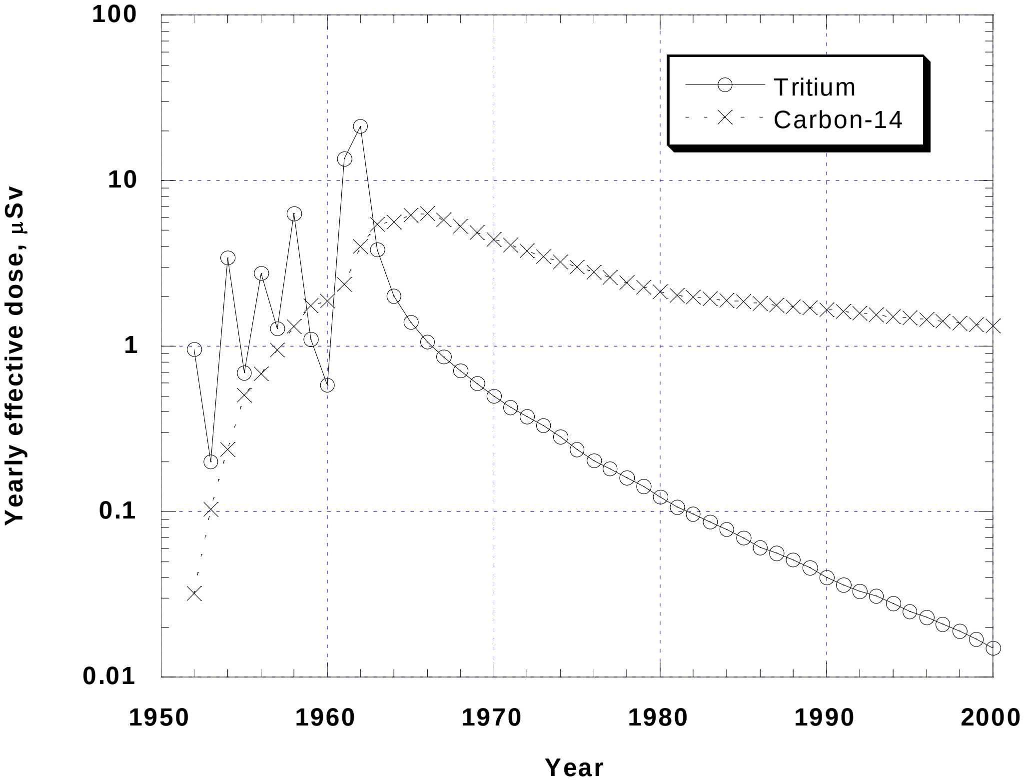

Fig. 27. Plot of the yearly doses from ^{3}H and ^{14}C calculated on the basis of specific activity models. Due to its large compartments that exchange carbon slowly and its long half life, the dose from ^{14}C tracks the injections more slowly than does the dose from ^{3}H.

Table 11. Total collective doses calculated for the 1953–1972 period from the deposition of ^{90}Sr, ^{131}I, and ^{137}Cs in global fallout and for the 1952–2000 period from ^{3}H and ^{14}C distributed throughout the Northern Hemisphere. Values are calculated for the 48 contiguous states in the U.S. The sum collective thyroid dose is estimated by summing the specifically calculated thyroid doses and adding the effective doses for ^{3}H, ^{14}C, and ^{137}Cs.

Radionuclide	Collective organ or effective committed dose, person Sv				
	Bone surface	Colon	Red marrow	Thyroid	Effective
^{3}H					11,000
^{14}C					20,000
^{90}Sr	87,000	2,800	38,000	140	5,900
^{131}I	30	56	24	160,000	7,800
^{137}Cs		25,000			22,000
Sum				210,000	66,000

dose to the thyroid from ^{3}H, ^{14}C, and ^{137}Cs was equal to the effective dose. This is a reasonable assumption, as these three radionuclides are distributed uniformly throughout the body.

Comparison of per caput effective doses

In Table 12 the doses calculated in this report are compared to similar estimates of dose from global fallout reported in UNSCEAR (1993) as doses averaged over the north temperate zone (40°–50°) of the globe and to values reported previously in Anspaugh (2000) for doses averaged over the contiguous U.S. from atmospheric tests conducted at the Nevada Test Site. Examination of Table 12 indicates that the global fallout doses reported in UNSCEAR (1993) are higher than those reported here for ^{90}Sr, ^{131}I, and ^{137}Cs, whereas the UNSCEAR reported doses are lower for ^{3}H and ^{14}C. There are several primary reasons for this: 1) the models used in this study are somewhat different from those used by the UNSCEAR and 2) the assessment domains are different, as the U.S. covers approximately 30°–50°. In general, the agreement between the two studies is reasonable given the relatively large amount of uncertainty in both studies. The UNSCEAR will report on a revised assessment this year that has been made possible by revised information on fission and fusion yields reported for the large yield tests; the UNSCEAR assessment models have also been revised.

Comparison of the doses reported here for the high yield tests versus those estimated previously for tests conducted at the NTS indicates that the sums of the per caput doses are roughly similar, although the importance of ^{131}I is much greater for the doses from the NTS tests. Also, other short-lived radionuclides are relatively more important for the NTS tests, notably ^{89}Sr and ^{140}Ba.

Uncertainty

It was not possible for this feasibility study for Beck (2000) to estimate uncertainty in the amounts of monthly depositions of ^{90}Sr and ^{137}Cs on a county-by-county basis or for the country-average values for the monthly deposition of ^{131}I. Thus, no attempt was made to estimate analytically the uncertainty in the estimates of internal dose reported here. Also, the models used to calculate doses from ^{3}H and ^{14}C do not at present allow for the analytical estimation of uncertainty. Based upon the author's subjective judgment, the uncertainty in doses for any individual county is a factor of three or more. The estimates of country-average per caput dose and the estimates of collective dose are likely uncertain by a factor of two or more. It is believed that a substantial amount of uncertainty is associated with estimating the amount of fallout retained by vegetation.

CONCLUSIONS

The results reported here are part of a feasibility study to determine if the external and internal doses from fallout from atmospheric tests conducted at the Nevada Test Site and from high-yield tests conducted at other locations can be estimated. Previously reported studies have determined that the internal dose from ^{131}I (NCI 1997) and other radionuclides (Anspaugh 2000)

Table 12. Summary of the estimates reported in this paper for per caput doses resulting from the ingestion of contaminated foods in the 48 contiguous states in the United States from fallout from high-yield tests in the atmosphere ("global fallout"). The current estimates are compared with those reported in UNSCEAR (1993) and with those previously reported for per caput doses from atmospheric tests in Nevada (Anspaugh 2000). Values in the table do not include external doses, which are reported separately by Beck (1999, 2000).

Radionuclide	Per caput effective dose commitment, µSv		
	This project		UNSCEAR (1993)
	Nevada Test Site	Global fallout[a]	Global fallout[b]
^{3}H	-	66[c]	48
^{14}C	-	120[c]	78[d]
^{55}Fe			14
^{89}Sr	17		2.3
^{90}Sr	3.7	37	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[e]	48	79
^{133}I	1.9		
^{136}Cs	3.6		
^{137}Cs	10	130	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[e]	400[f]	670[d]

[a] Averaged over the U.S.

[b] North temperate zone (40°–50°).

[c] To the year 2000.

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

[e] Age corrected.

[f] Incomplete sum for the radionuclides considered.

can be determined for tests at the NTS. Similarly, it has been demonstrated that it is feasible to estimate external doses from the tests at the Nevada Test Site (Beck 1999) and from the high-yield tests (Beck 2000). This report completes the individual components of this feasibility study with the demonstration that internal doses from the high-yield weapons tests can be calculated.

Except for the dose from ^{131}I and in very general terms, the dose from global fallout (or the dose from high-yield weapons) is more important than the dose from weapons tests at the Nevada Test Site. Also, the external dose tends to be higher than the dose from the ingestion of food contaminated with radionuclides. However, for ^{131}I and in particular the dose to the thyroid, the tests conducted at the Nevada Test Site were more important contributors to dose. In fact, for the Nevada tests, ^{131}I contributed about 90% of the total effective dose. Because the variations in dose on a county-by-county basis are very large for the Nevada tests, however, there can be major local variations in this general conclusion.

ACKNOWLEDGEMENTS

This work was performed under the terms of Purchase Order No. 263-MQ-008090-1 from the U.S. Department of Health and Human Services. The author thanks Dr. Nick Luckyanov of the National Cancer Institute for preparing the color-coded maps in Figs. 8–23.

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Radiation Dose to the Population of the Continental United States from the Ingestion of Food Contaminated with Radionuclides from High Yield Weapons Tests Conducted by the U.S., U.K., and U.S.S.R. between 1952 and 1963

Part II. Reference and Subsidiary Information

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

Report to the National Cancer Institute
Purchase Order No. 263-MQ-008090

COMPARISON OF CALCULATED DOSES WITH THOSE DERIVED FROM MEASUREMENTS IN FOODSTUFFS

One of the specified tasks was to compare the internal dose estimates calculated for ^{90}Sr, ^{131}I, and ^{137}Cs with those derived from the measurements of fallout radionuclides in foods. Extensive measurements of fallout radionuclides in foods started in 1960 with the establishment of the Pasteurized Milk Network (PMN) of the Public Health Service. Additional data were also taken on a limited and/or sporadic basis by many organizations [see PHS (1960)[**] for a summary of early measurement efforts], but many of the more sophisticated measurements were not well organized until after the end of the period of testing of high-yield weapons in the atmosphere.

A full-scale comparison of the measurements with the dose estimates provided in Part I of this report would be a major undertaking well beyond the limited funds made available for the present study.

One of the key issues, of course, is whether the model used in Part I of this study is a reasonable qualitative and quantitative description of the movement of fallout radionuclides to man. The model used for Part I of this study is the PATHWAY model of Whicker and Kirchner (1987).[††] During the development of this model it was extensively tested against several data sets, including the measured amounts of global fallout radionuclides in foodstuffs; in addition other data sets were used such as concentrations measured following tests at the Nevada Test Site and following the reactor accident at Windscale, UK. A major report on this subject was published (Kirchner and Whicker 1984).[‡‡] This article gives several graphs of long-term comparisons of ^{90}Sr and ^{137}Cs from global fallout in beef and milk. Many additional data sets are provided. The following is an excerpt from the abstract in Kirchner and Whicker (1984):

> "The statistical tests used to compare the predictions of PATHWAY to the observations include a correlation analysis, a paired t-test, and a binomial test. We use the correlation coefficient between observations and predictions through time to compare the dynamics of the simulated and real world system. Plots of the residuals from regression are then examined for bias between the predictions and observations. The significance of any trends in the residuals is evaluated using a runs test. The paired t-test and the binomial test are used to evaluate the accuracy of PATHWAY's predictions. The hypothesis for the paired t-test is that the ratio of predictions to observations is 1. The paired t-test can be used to test hypotheses about ratios because the distributions of observations and predictions appear to be lognormal. However, the paired t-test does not consider uncertainty in the predictions of the model. We use a binomial test to compare the observed data to an interval estimate from PATHWAY. The interval corresponds to a 95%

[**] Public Health Service. Radiological Health Data Vol. 1, No. 1; April 1960.

[††] See Part I References for citation.

[‡‡] Kirchner, T. B.; Whicker, F. W. Validation of PATHWAY, a simulation model of the transport of radionuclides through agroecosystems. Ecological Modeling 22:21–44; 1984.

> confidence interval on the prediction, and is derived from uncertainty analyses that have been conducted on PATHWAY.
>
> "PATHWAY's predictions are significantly correlated with observed levels of ^{137}Cs and ^{90}Sr in pasture and alfalfa. PATHWAY also simulates the dynamics of ^{131}I, ^{140}Ba, and ^{137}Cs in milk well, but fails to predict what appears to be a long term accumulation of ^{90}Sr in the agro-ecosystem. PATHWAY predicts the absolute concentrations of ^{131}I in milk quite well, but tends to predict levels of ^{140}Ba, ^{90}Sr, ^{137}Cs in milk that are different from those observed by factors of 2 to 7. PATHWAY predicts levels of ^{137}Cs and ^{90}Sr in pasture and beef within a factor of 2 of those observed."

Thus, while the PATHWAY model has been tested extensively and performs quite well, it is not perfect and has been noted to both underpredict and overpredict real world situations. In order to examine some important data sets that pertain directly to global fallout, the data presented to the U.S. Congress by Terrill (1963)[§§] are used here. The data pertain to the PMN mentioned above. Although data from 62 different locations are available, it is not easy to associate these milkshed data with counties. In addition deposition values for ^{131}I and dose estimates are not available on a county-by-county basis. Therefore, a comparison has been made only for the population-weighted average dose calculated for the 48 states with network-average concentrations, C_m, measured in milk. The relevant milk data are shown in Table 1.

The reported concentrations for ^{90}Sr, ^{131}I, and ^{137}Cs have been used as the starting point to calculate effective doses for adults according to the following equation:

$$E = C_m \times L \times T \times F_g \times \mathrm{K}$$

where E = Effective dose, Sv;
L = Consumption rate of milk, L day^{-1};
T = Number of days in time period, days period^{-1};
F_g = Ingestion-dose coefficient for the radionuclide, Sv Bq^{-1}; and
K = Units conversion constant, 0.037 Bq pCi^{-1}.

Values of F_g are the same as those used in Part I of this report. A value for L was taken to be 0.42 L day^{-1}, which is consistent with the PATHWAY model values (Whicker and Kirchner 1987). T is either 365 days per year or one fourth of that per quarter. The results of these calculations and the comparisons to the values estimated and reported in Part I of this report are shown in Table 2. A comparison of the values indicates that the dose values for ^{90}Sr and ^{131}I agree quite well, certainly within the expected uncertainties of the values. Dose values for ^{137}Cs do not agree as well, with the model results from Part I being substantially higher. However, a significant amount of the calculated dose from ^{137}Cs would be expected to have occurred from the consumption of contaminated meat; thus, the difference is reasonable.

[§§] See following list of documents for citation.

Table 1. Daily average concentration of radionuclides in milk from the 62 stations in the U.S. Public Health Service's Pasteurized Milk Network, 1960 through the first quarter of 1963. From Terrill (1963).

Time period or parameter	Concentration in milk, pCi L^{-1}				
	^{89}Sr	^{90}Sr	^{131}I	^{137}Cs	^{140}Ba
1960					
12-month average level	<5	8	0	10	0
12-month low station	<5	4	0	<5	0
12-month high station	<5	13	0	75	0
1961					
12-month average level	10	8	20	10	<10
12-month low station	<5	4	<10	<5	<10
12-month high station	30	16	70	65	10
1962					
12-month average level	50	13	32	45	12
12-month low station	17	3	<10	12	<10
12-month high station	170	30	104	108	29
1st Quarter 1963					
3-month average level	35	16	<10	70	<10
3-month low station	<5	4	<10	20	<10
3-month high station	265	37	20	135	30

Table 2. Calculated doses according to the measured concentrations of global fallout radionuclides in milk from Table 1 compared to the estimates of dose reported in Part I of this report. Estimates in the last three columns include doses calculated to arise from additional pathways.

Time period	Effective dose to adults, µSv					
	From milk concentration			From results in Part I		
	^{90}Sr	^{131}I	^{137}Cs	^{90}Sr	^{131}I	^{137}Cs
1960	1.3	0	0.74	0.81	0	3.0
1961	1.3	2.5	0.74	0.84	1.2	3.6
1962	2.1	4.0	3.3	4.4	6.8	17
1963, first quarter	0.64	<0.31	1.3	0.69	0.034	0.48

In general the results of this comparison are considered to be satisfactory and indicate that there are no gross errors in the assumptions used in the modeling process. Comparisons such as this can never be perfect and agreement within a factor or two or so is considered excellent.

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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.

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LIMITATIONS OF PRESENT CALCULATIONS OF DOSE FROM ^{131}I IN GLOBAL FALLOUT

Problems in calculating doses from ^{131}I contained in global fallout were mentioned in Part I. It is instructive to remember that by definition global fallout consists of debris that is injected into the upper regions of the atmosphere, from which it devolves slowly with time. A normal expectation would be that this material comes down so slowly that all of the ^{131}I contained in the debris would have decayed before it reached the earth. However, it was noted on many occasions that ^{131}I from global fallout did occur in milk, but mainly through the occurrence of uncommon atmospheric events such as the large-scale subsidence of air masses and from the penetration of large thunder storms into the upper troposphere and even into the stratosphere (Machta 1963).

In general these unusual occurrences were not predictable. Also, the networks that were established to monitor global fallout were not generally designed and equipped to monitor the presence of radionuclides as short-lived as ^{131}I. Thus, although some data exist and have been used by Beck (2000) to calculate country-average values of deposition of ^{131}I, it has not yet been possible to use such data to provide county-by-county estimates of the deposition of ^{131}I.

An alternate method of improving the estimates of dose from ^{131}I and in achieving much better resolution is to use the actual data on the measurements of the concentration of ^{131}I in milk. A summary of such measurements for the 1960–1963 (first quarter only) were presented earlier. Briefly, the history of such measurements is that the Public Health Service established the Raw Milk Network in 1957 to develop sampling and radiochemical analytical proficiencies (Terrill 1963). The Pasteurized Milk Network was established later and was used to monitor and report levels of radionuclides in milk from 1960 through 1974. The milksheds sampled through the PMN covered essentially all of the contiguous U.S. plus Alaska and Hawaii.

A proposed method to reconstruct radiation dose from ^{131}I in global fallout is to use the actual data reported from the PMN. This could cover at least the major periods of fallout from 1960 through 1963. Monthly summaries of such data are available in *Radiological Health Data,* a publication of the U.S. Public Health Service. It is hoped that the unsummarized data can be located and used for dose-reconstruction purposes.

An improved dose reconstruction for the important 1956–1958 years is more problematic, as very few measurements of radionuclides in milk were made. Perhaps additional work with the gummed-film data (Beck 2000) could be useful, and additional work could be done with the cattle-thyroid data collected by Van Middlesworth (1954, 1956, 1958,1960, 1963). There are also many measurements of concentrations of radionuclides in air that might be processed to derive useful information on the occurrence of ^{131}I in air; the deposition to ground and vegetation could then be estimated.

Appendix H

Communications Materials

Contents: Any additional fallout-related work will require an extensive communications approach. This appendix provides the outlined communications plan for the ^{131}I/NCI Communications Project (H.1), information pertaining to the January 2000 NCI/CDC workshop entitled "I-131 Fallout from NTS: Informing the Public" (H.2 – H.5), and description of tools typically utilized for communications planning materials (H.6).

H.1 Outline for I-131 Communications Plan

H.1.1 Situation Analysis

- In the 1950s and early 1960s, the United States Government conducted almost 100 atmospheric nuclear bomb tests in the Nevada Test Site (NTS), releasing iodine-131 (I-131) and other radionuclides into the atmosphere. In the same period, there were about a dozen underground tests where some atmospheric release of radioactive material was possible. Most of the current scientific information on the subject relates to I-131, which concentrates in the thyroid gland and may be linked to thyroid cancer and other thyroid disorders. Although I-131 released from the NTS has decayed and is no longer present in the environment, at the time of testing, radioactivity was deposited on soil and vegetation throughout the country. Doses of radiation varied widely according to geographic area based on wind and rainfall patterns. Some areas received minimal exposure, while others, sometimes far from the test sites, received higher radiation exposures. After cows and goats consumed the contaminated vegetation, I-131 appeared in the milk produced by those animals.
- Exposure to I-131 may increase the risk of thyroid cancer and other thyroid disorders. People who drank milk, particularly children, are estimated to have received higher than average doses of I-131 from the contaminated milk which have been associated with a higher risk for thyroid cancer and other thyroid diseases. Those who were or

may have been exposed to I-131 should be informed of their exposure and the potential health effects so that they can consult with a healthcare provider for monitoring of their thyroid and possible screening. Those who do not have a health care provider should be informed about existing resources that may be able to assist them. Although a diagnosis of thyroid cancer and other non-cancerous conditions must be treated seriously, thyroid cancer is relatively uncommon and is not normally fatal, particularly with early detection and proper treatment.

- Congress mandated that the National Cancer Institute (NCI) assess the public health impact of the NTS on the American people. Since the publication of NCI's report on estimated exposures and thyroid doses in 1997, an Institute of Medicine committee reviewed and assessed the validity of the report and made recommendations to the government on how to communicate with the public aboutI-131 exposure from the NTS.
- NCI has taken the lead role for the Federal Government in the development of a communications plan related to I-131 fallout exposure from NTS. In January 2000, a communications workshop – sponsored by NCI and the Centers for Disease Control (CDC) – was held to gather input from citizens, consumer advocates, physicians, scientists, health department representatives, and other government officials on the best ways to inform the public and health professionals about I-131 exposure. One outcome of the workshop was the formation of a Communications Development Group (CDG), made up of representatives from community groups, health professionals, and concerned citizens, to offer guidance to NCI staff with the development of an NTS I-131 communications plan.
- Although the current communications plan focuses on I-131 exposure from NTS, there are other sources of I-131 exposures in specific areas around the country. There are four additional nuclear reactor sites in the United States that released I-131 into the atmosphere that may have resulted in multiple I-131 exposures to nearby communities. These sites include the following: Hanford Nuclear Reservation in Richmond, Washington; Idaho National Engineering and Environmental Laboratory in Idaho Falls, Idaho; Oak Ridge National Laboratory in Oak Ridge, Tennessee; and

Savannah River Site in Aiken, South Carolina. There is a level of uncertainty associated with the health effects from multiple exposures to I-131, although it is likely that the health impact of multiple exposures may be more significant than a single dose exposure. In order to address this issue, the current plan will include messages that individuals who lived in and around the aforementioned areas may have received exposure to I-131 from NTS as well as from other sources, and that these multiple I-131 exposures may pose resultant health risks.

- The feasibility of collecting scientific information about the health effects from global fallout and the levels of exposure from other radionuclides is currently being assessed. If there is agreement on public health outreach concerning multiple I-131 exposures and the levels of exposure from other radionuclides, this communications planning process may be used as a blueprint for future communications efforts.

H.1.2 Challenges and Opportunities

Challenges:

- The credibility of the Federal Government, as a whole, has been compromised on the radiation issue. Therefore, the Federal Government should work with third parties in providing informational messages. In addition, credibility issues vary across government agencies and according to individuals' experiences with particular agencies on issues related to radiation. The general public is largely unaware of radiation exposure that occurred nearly 50 years ago and may experience a variety of emotions when they learn about potential exposure risks. Some people may be justifiably concerned about their exposure and the risks that result from it; others may be unnecessarily frightened; some may question why the government conducted the tests, exposing the public to I-131, while others may not have any interest in the issue. For those who have suffered from thyroid illness or have loved ones who have suffered, the new information may also create a sense of closure and provide some answers. Balancing the need to inform people while creating an appropriate level of concern with the possibility of creating a significant level of unwarranted anxiety will be an ethical and communications challenge.

- The I-131 issue is competing with many other health issues that may be perceived to be more current and pressing among health care providers and members of the general public.
- I-131 exposure and the potential health implications are complex issues marked by scientific and medical uncertainties, and are difficult to communicate to the public in non-scientific terms. Communications about this issue must include honest descriptions of the uncertainties about exposure and potential doses, and honest descriptions of uncertainties related to assessing past exposure and potential doses received. Such communication can help build trust or may exacerbate a lack of trust if it appears to "waffle" on the uncertainties. In addition, because these exposures were *involuntary* and not fully disclosed for many years, reactions to related information will likely be more negative. Therefore, risk communication principles should be employed throughout the program.
- Communications efforts involving American Indian audiences will have to be sensitive to a heightened distrust of governmental messages and must be coordinated with other government agencies based on the unique government-to-government relationship with American Indian Tribes.

Opportunities:

- There are strong citizen networks and health professional organizations in the communities that may support implementation of specific strategies in a comprehensive communications plan. These networks include advocacy groups, public health networks, and Internet communications networks.
- CDG involvement will ensure that the communications plan is thorough and directed at the most appropriate audiences. The CDG can also help brainstorm possible organizational structures through which the messages can be disseminated.
- NCI has received a positive response to its efforts to involve the advocacy and the health professional communities at the earliest possible stages in the development of communications surrounding I-131.

- Other agencies and organizations are involved in addressing I-131 exposure issues. For example, ACERER (Advisory Committee for Energy-Related Epidemiological Research) held a meeting to hear public input on the need for thyroid screening for those exposed to I-131 from the NTS on June 8th in Columbia, MD. They are currently considering that input as they develop their recommendations for Secretary Shalala.
- The research group led by Annette O'Connor has expressed an interest in developing a screening decision aid that may be one tool in the implementation of this communications plan. One activity of the plan, therefore, could be to work with this group to create and review such a tool. The feasibility will be explored for developing a decision tree that could help those without health insurance find existing programs that might assist them.

H.1.3 Communication Goals

- Individuals who may have been exposed to I-131 radiation from the NTS will seek the appropriate guidance of health care providers about the potential health effects of exposure and what can be done to address these effects.
- Healthcare providers will understand the risk of I-131 exposure and the potential health effects and will be able to advise patients regarding their individual health status, potential risks, and options.

H.1.4 Communication Objectives

- To communicate to the intended audiences understandable information about the release of I-131 from the NTS, the potential health effects of exposure, and what exposed individuals can do about those effects.
- To engage intended audiences in the issue and encourage individuals who are concerned about I-131 exposure to consult with a health care provider or other sources of health services.

- To inform health care professionals about the possible health effects of I-131 exposure and to provide information to assist them in working with patients who are concerned about exposure.

H.1.5 Intended Audiences

The Public:

- Individuals aged 40 and older, particularly those who lived in areas of highest exposure and consumed milk, with special emphasis on underserved populations, including minority groups and those with limited access to the health care delivery system.

Healthcare Providers:

- Primary care providers
- Thyroidologists
- Obstetricians and gynecologists
- Managed care organizations
- Nurses and nurse practitioners
- Providers in community health centers, migrant health clinics, and the Indian Health Service
- Psychologists and psychiatrists

Others:

- Social workers
- Advocacy and support groups
- Community-based networks
- Schools of Public Health

H.1.6 Channels

Members of the public, including those who may be at higher risk, may be reached through a variety of channels, including:

- Intermediary organizations such as environmental advocacy groups and downwinders
- Community groups (especially in high-risk locations)
- Healthcare providers (especially in high-risk locations)
- State and local health departments, sliding scale clinics, community health centers, and migrant health clinics
- Bureau of Primary Care, Health Resources and Services Administration (HRSA)
- Internet (NCI Web site and primary Internet health portals)
- NCI's Cancer Information Service (CIS)
- Health-related federal agencies, e.g., Public Health Service, Indian Health Service, CDC, Veterans Administration
- American Indian Tribal Governments through collaboration and support of the Indian Health Service and other federal agencies
- Churches and other religious organizations

(Note: Many of the channels listed above are being fleshed out with the names of specific organizations that can help channel information to the intended audiences.)

Healthcare providers may be reached through:

- Intermediary groups such as professional associations and their media (newsletters, journals, etc.)
- Professional meetings and continuing education
- Internet
- Health-related federal agencies, e.g., Public Health Service, Indian Health Service, CDC, Veterans Administration, Health Care Financing Administration

H.1.7 Core Messages

The Public:

- Brief explanation that everyone in the United States during the time of the tests was exposed to some level of I-131 and depending on individual risk factors, is at varying health risk; description of potential health effects and their symptoms; and how to determine exposure. Messages should also acknowledge that multiple I-131 exposures and exposure from other radionuclides were possible, although less is understood about these other exposures.
- Recommendation to consult with a health care provider to determine if any steps should be taken to monitor and protect their health. (Information will be available to guide people without health insurance to existing programs that may assist them.)

Healthcare Providers and Others:

- Brief explanation that everyone in the United States during the time of the tests was exposed to some level of I-131 and depending on individual risk factors, is at varying health risk; description of health effects and their symptoms; and how to determine exposure.
- Suggestions for counseling patients with concerns about the health effects associated with I-131 exposure.
- Suggestions for assessing appropriate health precautions/monitoring.
- Resources and references.

H.1.8 Message Tone

- Compelling, motivating; not frightening
- Empowering audiences to address their concerns
- Credible, truthful, engaging
- Not paternalistic

- Compassionate

H.1.9 Message Development Process

Message concepts will be developed and tested with members of the intended audiences to determine *how* to deliver the messages in the most useful way (after it is determined *what* to say). Concept testing is the type of research recommended in communications planning after exploratory focus groups and before material pretesting. Message concepts, also called creative concepts, are simple graphics paired with headlines and taglines designed to elicit responses from audience groups and get them talking about the issue in very concrete terms. A creative team then analyzes the responses to determine how messages will be positioned and crafted so that audiences can understand and act upon them.

Once materials are created, they will be pretested with appropriate audiences, including underserved individuals without access to health providers. They will also be provided in Spanish.

H.1.10 Strategies and Tactics

Create and activate existing community and grassroots networks, along with state and local health departments, to deliver program messages to identified audiences.

- Identify and create a contact list of potential organizations to include as a network for program implementation.
- Develop informational materials to be used at the local level by organizations already involved with radiation exposure issues and those committed to public health, including local health departments. By creating turnkey materials and kits, messages

can be controlled and consistent. Community groups can refer individuals to the Cancer Information Service (CIS) for additional information, answers to questions, and referrals to health provider services and other community services for assistance. Potential materials include:

  - Screening decision aid based on the "Annette O'Connor model"
  - Speaker kit
  - Fact sheets and decision trees for consumers dependent on Medicaid, Medicare, or state sponsored programs
  - Brochure
  - Idea kit for how to track potentially exposed people who have moved from the area to inform them of their risk factors

- Provide technical assistance in communicating information about I-131 and the potential health effects to public health departments in areas of highest exposure. Materials for health departments may include products such as a health fair package to be used with the community.

Work with health professional organizations and their members to provide information to patients who may be concerned about their exposure or who may be unaware, yet subject to health complications from their exposure.

- Develop materials to enable health professionals to respond to patient concerns about potential I-131 exposure and to address the issue with patients who may have received higher exposure. Potential materials include:
  - Screening decision aid based on Annette O'Connor model
  - Fact sheet for professionals
  - Q&A
  - Video for office use
- Appeal to health care providers through their professional organizations (such as medical societies) to raise their awareness of the issue and inform them about

materials available for their use. 1-800 numbers and web addresses can be highlighted to help health care providers ask for or obtain materials. Activities might include:

- Drop-in articles for professional journals or organizational newsletters
- Speakers at state or regional meetings
- Development of Continuing Education programs (this might include training on counseling patients who are concerned about this issue or who discover a radiation-related health problem)

Enable audiences to access materials through multiple channels so that information is both presented to them proactively but is also accessible upon demand.

- ♦ Refine material on I-131 exposure from the NTS on the NCI website. The page will offer sections for consumers and health professionals. If possible, the O'Connor self-assessment tool can be made available on-line as well. Making the NCI dose-calculator more user-friendly will also be explored.
- ♦ Partner with key health information portals targeting health professionals and consumers so that they can either provide a link to the NCI website or post the I-131 materials on their own site.
- ♦ Provide information and training on the topic to the CIS regional offices, which respond to telephone inquiries from consumers and professionals and conduct community outreach on specific cancer-related issues. Individuals who do not have easy access to the Internet will be directed to the CIS which can provide them with information about the tests at the NTS and the potential exposures and possible subsequent health effects. The CIS is also a resource for referrals to other services, such as counseling, for people who learn that they have cancer or other specified health conditions, such as problems caused by exposure to I-131.

Collaborate with other federal agencies, components of the government and other organizations to achieve consistent communication about I-131 and the potential health effects and demonstrate the effectiveness of the planning process model.

- Potential partners in this effort may include the Centers for Disease Control and Prevention, the Agency for Toxic Substances and Disease Registry, the Department of Defense, the Veteran's Administration, the Department of Energy, the Environmental Protection Agency, the Indian Health Service, Bureau of Primary Health Care, and others. The purpose of this activity is more to ensure consistent, inter-agency communication and actions on related radiation issues and facilitate more information sharing across agencies. (It is not foreseen that these agencies will help facilitate the specific activities described in this plan.)
- Coordinate and collaborate, as appropriate, with Canadian organizations.

Use a phased approach to build momentum around the message and an opportunity for on-going evaluation.

- Information about I-131 exposure will be delivered first through networks already interested in radiation exposure that can then provide feedback on messages and materials to NCI. First phase messages can then be assessed and revised, if necessary, to ensure the best possible impact on audiences not currently engaged in radiation issues.

Addendum A

Cancer Information Service's Role in I-131 Communication Plan

Materials Distribution

- The I-131 materials would be available from the Publication Ordering Service and on the Publications Locator on the Web.
- Callers to the CIS would be offered appropriate materials.

Information Calls to 1-800-4-CANCER

- CIS would use information prepared by NCI to answer inquiries form the public.
- CIS would make referrals to health care professionals according to its current referral policy. (Note: CIS does not make referrals to individual physicians, only to NCI sponsored programs.)
- CIS would not use any of the modeling techniques to perform risk assessments for callers.

Referrals to Other Services

- CIS has referral information for cancer screening, treatment, pain, and indigent care. CIS refers to other community/national organizations for support services; CIS does not maintain referrals for support groups or other local counseling services. If other specific referrals are necessary for this project, they would need to be provided to CIS.

Outreach

- The CIS Partnership Program would distribute I-131 materials to the state, regional, and community/local organizations it routinely works with.

Addendum B

Other Suggestions from the CDG

This document includes issues that cannot be addressed within the scope of the NTS I-131 Communications Plan, but will be shared with other governmental agencies.

- Develop a pilot project for addressing multiple exposures to I-131 as well as exposure to other radionuclides. This communications plan focuses on exposure to I-131 from NTS, but may be used as a model for future efforts, if deemed scientifically feasible and appropriate.
- Provide cost reimbursement for screening and/or medical costs associated with exposure to I-131 from the NTS, exposure to other radionuclides from NTS, and exposures to I-131 and other radionuclides from multiple sources, including “global” nuclear testing and radiation releases from United States nuclear facilities.
- Develop an Information Resource Center similar to the Hanford Health Information Center with a 1-800 number, Health Information Network, and On-line Exposure Health Database. This would enable people to get information, get connected, and get help accessing ancillary services, such as support and counseling.
- Develop an NTS Fallout Health Effects Subcommittee and an NTS Fallout Health Information Network originally proposed in Utah House Concurrent Resolution 10.
- Provide training or “train the trainer” sessions on exposure and screening to enhance community-based efforts.
- Provide counseling/support services (or cost reimbursement) for people who learn that their health has been affected by I-131 from NTS.
- Incorporate new ACERER recommendations into the plan once they are formally recommended and approved by the Department of Health and Human Services.

H.2 Workshop Agenda

(next page)

Workshop Agenda

January 19-21, 2000

Wednesday, January 19 – Briefing Day

9:00 a.m. – 9:30 a.m.	Arrival and Check-In	

Session A

9:30 a.m. – 10:00 a.m.	Opening Session	
	Welcome and Charge to Group	Alan Rabson, M.D. Mike Sage, M.P.H.
	Ground Rules and Introductions	Denise Cavanaugh, Facilitator

Session B

10:00 a.m. – 10:45 a.m.	Broad Overview and History	Mark Epstein, Moderator
	Brief NTS History	Mark Epstein
	A Citizen's Perspective	Trisha Pritikin, Esq., M.D., O.T.R.
	IOM Report	Robert Lawrence, M.D.
10:45 a.m. – 11:00 a.m.	Break	

Session C

11:00 a.m. – 12:30 p.m.	The Science of I-131 Exposure and Health	
	1. What Can Science Tell Us About the Health Risks of I131?	Charles Land, Ph.D.
	2. What I-131 Doses Did People Receive From NTS Fallout?	Steve Simon, Ph.D.
	3. Reflections From and Independent Scientist on the Science of I-131.	Owen Hoffman, Ph.D.
12:30 p.m. – 1:45 p.m.	Lunch	

Session D

1:45 p.m. – 2:15 p.m.	Public Health Communications Challenge	Elaine Arkin

Session E

2:15 p.m. – 3:00 p.m.	Table Discussions	Denise Cavanaugh
3:00 p.m. – 3:15 p.m.	Break	

Wednesday, January 19 – Briefing Day (Continued)

Session F

3:15 p.m. – 5:15 p.m. Communications Challenge: Group Discussions

1. Interest Group Perspectives

Moderator	Seth Tuler
State/Local Advocacy Organization	J. Truman
National Advocacy Organization	Maureen Eldredge
Physician Advocate	Tim Takaro, M.D.
Native American	Robert Holden
Ground Zero	Lincoln Grahlfs, Ph.D.
Consumer Organization	Jean Halloran

2. Health Provider: Channels and Gatekeepers

Moderator	Kevin Teale, M.A.
Practitioner	R. Michael Tuttle, M.D.
Sliding Scale Clinic	Delvin Little, M.D.
Medical Specialty Group	Henry Royal, M.D.
Risk Communicator	Jim Flynn, Ph.D.
Medical Ethicist	Kristin Shrader-Frechette, Ph.D.

Session G

5:15 p.m. – 5:45 p.m.	Wrap-Up	Denise Cavanaugh
5:45 p.m. – 6:30 p.m.	Break	

Session H

6:30 p.m. – 9:00 p.m. Networking Reception and Dinner

Thursday, January 20 – Discussion Day

7:30 a.m. – 8:30 a.m.	Continental Breakfast	
Session I		
8:30 a.m. – 8:45 a.m.	Summary of Day 1 and Charge for Day 2	Denise Cavanaugh
Session J		
8:45 a.m. – 10:15 a.m.	Screening/Medical Monitoring	Denise Cavanaugh Mark Epstein Moderators
	1. What Recommendations and Current Programs Exist for Screening and Monitoring?	Robert Spengler, Sc.D. R. Michael Tuttle, M.D.
	2. Assessing Individual Risk	Keith Baverstock, Ph.D. Owen Hoffman, Ph.D.
	3. A Model for Individual Decisionmaking	Valerie Fiset, R.N., M.Sc.N.
10:15 a.m. – 10:30 a.m.	Break	
Session K		
10:30 a.m. – 12:00 noon	Table Discussions:	
	What do we know that we can use to begin developing messages and defining populations?	
	What do we need to know to develop and effective campaign?	
	What questions should be forward for April screening forum?	
12:00 noon – 1:15 p.m.	Lunch	
Session L		
1:15 p.m. – 3:30 p.m.	Developing Model Outreach	
	1. Strategies for Message Development An approach to identifying Target audiences	Peter Sandman, Ph.D.
	Considerations for developing Science-based messages	Neil Weinstein, Ph.D.
	2. Audiences Research Results Presentation of preworkshop research	Ed Maibach, Ph.D.
3:30 p.m. – 3:45 p.m.	Break	

Thursday, January 20 – Discussion Day (Continued)

Session M		
3:45 p.m. – 5:15 p.m.	Developing Model Outreach (Continued) 3. Table Discussions What additional audience research Is needed?	Ed Maibach, Ph.D., Facilitator
Session N		
5:15 p.m. –5:45 p.m.	Wrap-Up Identify agreements and outstanding issues. Move forward on a communications plan.	Denise Cavanaugh

Friday, January 21 – Input Day

7:30 a.m. – 8:30 a.m.	Continental Breakfast	
Session O		
8:30 a.m. – 9:00 a.m.	Summary of Day 2 and Charge for Day 3 Review Operating Principles	Denise Cavanaugh
Session P		
9:00 a.m. – 11:00	Breakout Session Topic Decided on Thursday Afternoon	
10:00 a.m. – 10:15 a.m.	Break	
Session Q		
11:00 a.m. – 12:00 noon	Reports From Breakout Session Group Reporters	
12:00 noon – 1:00 p.m.	Lunch	
Session R		
1:00 p.m. – 2:00 p.m.	Summary	James Mathews/Kellie Marciel Joan Morrissey
	Next Steps	Nelvis Castro Owen Devine
Session T		
2:00 p.m. – 2:15 p.m.	Closings Comments and Thank You to Participants	Alan Rabson, M.D.

H.3 Workshop Summary

I-131 Fallout from NTS: Informing the Public
January 19-21, 2000

Workshop Summary

On January 19-21, 2000, a workshop titled "I-131 Fallout from NTS: Informing the Public" was held in Rockville, Maryland. It was sponsored by the National Cancer Institute (NCI) and the Centers for Disease Control and Prevention (CDC) and planned in consultation with a working group of citizen representatives and state health department staff. This report summarizes the workshop proceedings, for the benefit of participants and other interested individuals and organizations.

You may find the following Sections helpful as you read this Summary.

- Section H.3.1 - Workshop Proceedings
- Section H.3.2 - List of Working Group members and government staff
- Section H.3.3 - Workshop Participants
- Section H.3.4 - Proposed Campaign Operating Principles
- Section H.3.5 - List of Other Resources

The working group designed the workshop with five outcomes in mind:

1. Obtain input for the ongoing process of campaign development and implementation, including the structure for continued public participation in the process.
2. Get input on target audiences and a process for developing messages.

3. Get suggestions for additional audience research.
4. List the scientific questions that still need to be addressed, including suggestions for an April workshop on screening to be hosted by the Advisory Committee for Energy-Related Epidemiologic Research (ACERER), which advises the Department of Health and Human Services (DHHS) on radiation research[2].
5. Identify ways to leverage this model process to benefit subsequent efforts on the full range of health effects from radionuclides released from the Nevada Test Site (NTS).

The workshop brought together affected citizens, consumer advocates, physicians, scientists, health department representatives, risk communicators, and government officials. Some had a long history with radiation fallout issues; others were new to the field but experienced in communications or reaching specific at-risk populations.

By the end of the three-day workshop, participants agreed on a set of campaign goals, provided organized feedback on four areas of campaign development, and developed a "wish list" of outcomes they would like to see in the near and distant future.

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[2] At the time of the workshop, it was anticipated that the ACERER meeting to address screening issues would be held in April 2000. The meeting has since been scheduled for June, 2000.

H.3.1 Workshop Proceedings

H.3.1.1 Day One

Opening and Introductions

The workshop was opened by Alan Rabson, M.D., Deputy Director of the NCI, and Mike Sage, M.P.H., Acting Deputy Director of the National Center for Environmental Health at the CDC. They charged the group with providing input to NCI and CDC in the development of a communications program that will 1) inform the public, and more particularly, the members of the public who are at high risk for health problems because of their exposure to radioactive iodine-131, and 2) educate health providers so they can provide appropriate care. The challenge will be to figure out how best to communicate the history, the science, and the possible health risks from exposure to radioactive iodine-131 from the Nevada Test Site. Dr. Rabson noted the active interest of the Department of Health and Human Services (DHHS), acknowledging the presence of Dr. William Raub, representing DHHS Secretary Donna Shalala.

Denise Cavanaugh, the workshop facilitator, reviewed the ground rules and desired outcomes for the workshop. She reiterated the desire to identify some common ground, to provide scientific background, history on the issue, and to discuss the communications challenges and strategies that might be employed in the campaign. Ms. Cavanaugh encouraged participants to use the listserv set up by NCI to interact and give additional feedback after the workshop. A handout was provided with directions on how to subscribe to the listserv. Ms. Cavanaugh also pointed out the Operating Principles drafted by the working group.

Overview and History

Mark Epstein of Porter Novelli, Washington, D.C., gave a brief overview of the history of the Nevada Test Site, referring participants to the Institute of Medicine (IOM) Report[3] and working group member Trisha Pritikin's document[4] for further details.

Robert Lawrence, MD, of Johns Hopkins University, and chair of the IOM Committee that reviewed NCI's report[5] on I-131 dose estimates, offered a brief presentation of the IOM Report. He focused on the factors that contribute to individual dose estimates and the problems in making estimates due to geographic variation, dietary patterns, and individual susceptibility. He agreed that excess cases of thyroid disease were caused by radioactive fallout, but he asked whether trying to identify individuals who are at greatest risk and screening them would lead to greater harm than good. And so, the IOM committee took the approach "first, do no harm," in recommending against mass screening for thyroid cancer. He encouraged the group to work toward a communications program that focuses on shared decision-making between individuals and their health care providers.

Trisha Pritikin, a member of the working group, brought the perspective of a citizen exposed to NTS fallout and environmental ionizing radiation emissions, including I-131, from the Hanford nuclear weapons facility. She noted that radioiodine is only one of a host of biologically significant radionuclides released during the NTS nuclear bomb tests. She asked that this I-131-focused campaign be followed by similar campaigns on other NTS

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[3] *Exposure of the American People to Iodine-131 from Nevada Nuclear Bomb Tests: Review of the National Cancer Institute Report and Public Health Implications.* 1999. National Academy Press: Washington, DC

[4] Ms. Pritikin was a Working Group member who prepared a document, "NTS History," which was included in the packet of materials for workshop participants.

[5] *Estimated Exposures and Thyroid Doses Received by the American People from Iodine-131 in Fallout Following Nevada Atmospheric Nuclear Bomb Tests.* 1997. U.S. Department of Health and Human Services, National Institutes of Health, National Cancer Institute.

radionuclides. She called for an appropriate government response to these involuntary environmental exposures. She also encouraged a discussion of government-sponsored screening for those at highest risk from their childhood exposures, as is anticipated to occur at an upcoming ACERER meeting.

Ms. Pritikin detailed the impact of radioactive fallout on her family, describing her illness and the death of both of her parents. She grew up in Richland, Washington, adjacent to the Hanford nuclear weapons facility. She called for estimates of cumulative exposures and risk, based on multiple radioactive exposures such as NTS, Hanford, and global fallout. She also called for discussion of all potential health outcomes, including thyroid cancer, autoimmune thyroiditis, hypothyroidism, hyperthyroidism, hyperparathyroidism, and other related diseases. She noted that screening for non-cancer outcomes involves a simple blood test, which has a different benefit/risk ratio than thyroid cancer screening.

At the completion of her presentation, Ms. Pritikin read from the written and oral transcripts of the Hearing before the Senate Permanent Subcommittee on Investigations of the Committee on Governmental affairs, citing Senator Tom Harkin’s support for medical screening for those at highest risk from NTS I-131 exposures, and citing his disagreement with the recommendations against screening made by the IOM committee that reviewed the NCI I-131 report. Dr. Lawrence, chair of the IOM committee, responded by stating that he had spoken with senior members of Senator Harkin’s staff regarding these IOM recommendations, and that those staff members then indicated that they understood why the IOM made the recommendations it did.

The Science of I-131 Exposure and Health

Charles Land, Ph.D., of NCI's Division of Cancer Epidemiology and Genetics, explained how NCI developed its estimates of exposure and explained why children were at higher risk than adults: children are more sensitive to radiation, their thyroid glands receive higher doses from ingested or inhaled I-131. They have a higher intake of milk (the main pathway of ingestion), and higher metabolism.

Steve Simon, Ph.D., of the National Research Council's Radiation Effects Research Board, described dose estimates. He explained how dose is calculated and described how uncertainty is factored in. He also showed a number of maps that showed the high exposure areas, or "hot spots," by birth year.

Both speakers described the complexity of estimating exposure and doses and the limitations of the sources of I-131 exposure information from the 1950s and 1960s, based on the time of year, weather patterns, cow grazing patterns, dairy management practices, etc. Dr. Simon explained the difficulties in coming to individual dose estimates, which rely on the accuracy of the person's memory of where they were and what they were doing during the testing. County-specific estimates already carry a high degree of uncertainty. Individual estimates are more uncertain, still.

F. Owen Hoffman, Ph.D., from SENES Oak Ridge, Inc., shared his perspective. He stated that, although the risk from exposure to iodine-131 is uncertain, it does not prevent us from estimating risk. The uncertainty can be quantified, allowing an estimated range of 8,000 to 208,000 excess cases of thyroid cancer due to NTS fallout. He suggested that most of the excess cases would occur in females who were children at the time of the testing and who resided in the eastern United States because that was where the population was most dense and where the most milk was produced.

Age, gender, and diet are more important determinants of risk than is location, said Dr. Hoffman. He also noted the need to bring together dose reconstructions from various sources of fallout to estimate cumulative doses. He also called for work to extend discussion beyond iodine-131 to other radionuclides in both NTS and global fallout.

Dr. Hoffman argued that health risk evaluations with regard to fallout should include more health effects than thyroid cancer, such as benign nodules and autoimmune thyroiditis. He also urged that other I-131 exposure sources and time periods beyond 1962 be investigated, including the underground testing era.

Dr. Hoffman also reported that there is now a more sophisticated method of calculating the uncertainty associated with dose estimates than what was used in the NCI on-line dose calculator. Calculations using the “Monte Carlo” method take into account the adding of uncertainties from disparate time periods, and result in smaller uncertainty ranges.

Public Health Communications Challenge

Elaine Bratic Arkin, a health communications consultant, defined health communications and social marketing, using a CDC definition: “the crafting and delivery of messages and strategies based on consumer research to promote the health of individuals and communities.” Communications can prompt people to take simple actions, like call a toll-free number or make an appointment with a doctor. It can correct misconceptions, and it can coalesce relationships. She said that the campaign’s challenges include the public’s complacency (since these exposures happened decades ago), a media environment cluttered with health messages, and a very complex topic to convey to the public.

To be successful, the communications campaign needs to be planned, budgeted and supported over time, Ms. Arkin stated. It needs to be tracked and evaluated in case adjustments are needed. It may need to be part of a multifaceted program, coupled with provision of services and physician education, for example. She also described the components of a communications plan.

Table Discussions

Small group discussions following Ms. Arkin's presentation focused on two questions: what is the issue, and what one change might advance the effort? Some of the issues and actions discussed:

- Lack of trust in the government
- The government must accept accountability for past events and future actions.
- The program should be comprehensive instead of separating nuclear fallout from mining, milling, production, waste, and weapons use. In other words, the public wants to know about isotopes beyond I-131 and exposures beyond Nevada Test Site.
- There are two public health issues here: the actual physical impact of exposure and the psychological stress induced in people by the exposure.
- How will we help people who are mobile and speak a language other than English understand the risk?
- We've got to make clear there was an impact, even if we are uncertain about the magnitude.

- There is a need to educate physicians so they will take patients' complaints and concerns seriously. If a doctor is honest and up-front, the patient will have less fear and uncertainty.
- Physicians must be contacted before a public campaign is launched. We need to get the attention of primary care physicians and get health care providers, such as HMOs, on board.
- It may be difficult to identify a credible source for the information, due to issues of mistrust.
- There are two components: a notification piece, to educate and reduce fear, and a call-to-action so that high-risk individuals will seek medical advice, which would include educating physicians to be prepared to respond. There also may need to be some kind of direct help for the affected citizens from the government.
- Give people a full view of their risk from a combination of sources.
- Give people the information they need about risk factors so they can determine their own risk level and then give them information on obtaining follow-up consultation or care, if needed.

Panel 1: Interest Group Perspectives

Working group member Seth Tuler, Ph.D., of the Childhood Cancer Research Institute and Clark University, moderated the workshop's first panel discussion. Dennis Nelson, Ph.D., of Support and Education for Radiation Victims (SERV), described the lifestyle of the downwinder population near the Nevada Test Site to give a sense of the downwinder's exposure. He argued against focusing exclusively on I-131 and cancer and called for a national plan to notify people throughout the country so that they could look into their own exposures and seek early detection.

Maureen Eldredge of the Alliance for Nuclear Accountability described her organization's relationship with the government on nuclear weapons issues as a pattern of deceptions and cover-ups. She stated that the government has an obligation to tell the public that they were involuntarily and unknowingly exposed, regardless of how low the exposure or how minimal the health risk. She suggested also looking at all thyroid disease, not just cancer, and helping people figure out their cumulative doses so they have the full picture of their exposures. It is not up to the government to decide what information people should or shouldn’t have because they might make a bad decision with all the information. People should make their own decisions about their health care. Lastly, she said that we should be aware of the impact of money. She said the government might be fearful of providing information out, as people who were exposed may sue the government, whether or not they suffered any ill consequences of exposure. She said the government should pay for the communications, the training and education of health providers, and perhaps even for treatment.

Tim Takaro, MD, of the University of Washington, represented Physicians for Social Responsibility. In his experience with Hanford, the people in the Northwest want to know about their families’ illnesses. They want to know if they are at risk, whether they should be tested and whether their children may be affected. He noted the importance of cumulative doses and called for looking at exposure from mining through weapons disposal. At the same time, physicians don’t need to get an accurate dose on a patient to address concerns about risk for certain diseases based on their exposure from Hanford, NTS, and others. He noted that screening large populations with no restrictions is not cost effective, but that screening should not be denied a person who is concerned about his health and the impact of radiation exposure. Physicians will need to address patient anxiety, which in itself is a psychological and physiologic burden.

Robert Holden, of the National Congress of American Indians, discussed the history of the relationship between the Federal government and native peoples, stating that the government has a responsibility, based on treaties, to provide for Indian health and welfare. Many Native Americans had multiple exposures. For example, uranium was mined on Navajo land and a national laboratory sits on Pueblo land. He noted that there are certain protocols to communicate with tribal officials. He stated that he hopes that the Native American community can continue a relationship with those planning this campaign to help them better understand Native Americans. He suggested a Native American caucus to work on these issues.

F. Lincoln Grahlfs, Ph.D., is an atomic veteran representing the National Association of Radiation Survivors. He described his experience educating Congress that nuclear radiation is hazardous and getting the word out about the NCI report. His group’s media work got tremendous response in areas like St. Louis, Missouri, and Idaho Falls, two “hot spot” areas identified in the report. He warned that special interest groups might try to sabotage efforts to educate the public on issues of radiation exposure and health risks.

Mike Hansen, Ph.D. represented Jean Halloran from Consumer’s Union. From his background working on advocacy issues on pesticides and genetically engineered foods, he stated that the government will have to do a few things to gain credibility: 1) take a comprehensive view, broader than I-131 and all potential health effects, 2) provide as much information as possible, and 3) admit the government was wrong. Even if the risk is small, the public will get upset at risks that were involuntary, that they had no control over, and that were done to them without their knowledge. The government will need to be up-front about what happened and how much they don’t know. They’ll need to work with grassroots organizations and those advocacy organizations that are critical of the government in order to make the campaign successful. The process will be difficult, but important. He suggested working with *Consumer Reports* magazine to write an article on this topic. Dissemination would be widespread, with a readership of 4.8 million subscribers in their 50s and 60s.

Seth Tuler ended the panel by discussing the findings of the ACERER's subcommittee for community affairs. 1) Federal efforts to address the public health consequences of NTS fallout are still inadequate. 2) Difficulty identifying specific fallout injuries does not absolve the Federal government of its responsibility to shape a meaningful public health response. 3) Research is not a public health response and is not a substitute for the assistance that many exposed people believe that the government has a responsibility to provide. 4) Delays in sharing important public health information about fallout exposures have reinforced public cynicism toward federal officials.

He then reviewed the ACERER's recommendations. 1) Fulfill the legislative intent of Public Law 97-414, which mandated NCI's study of I-131 NTS fallout. 2) Complete a comprehensive dose reconstruction project for NTS fallout, with an oversight committee created to keep things on track. 3) Notify Americans of the factors that might help them determine if they received significant radiation doses from NTS fallout, targeting high-risk groups. 4) Create a public and health care provider information service. 5) Support an archival project to document the experiences of exposed people. 6) Further evaluate screening opportunities for thyroid disease.

He finished by summarizing the common themes heard during the panel discussion.

- The legacy of mistrust
- Identifying who is at high risk and providing more to them than mere notification
- Empowering people to make informed decisions about their health care
- Addressing fears versus creating fears
- Covering multiple exposures and contaminants
- Overcoming political resistance to implementing programs.

Panel 2: Health Provider Channels and Gatekeepers

The final panel on the first day of the workshop included health professionals and gatekeepers. Kevin Teale, of the Iowa State Health Department, moderated. He began by pointing out the challenge the group faces in trying to get a message about this complex topic out to the broadcast media, which relies on four-second sound bites. He also raised the issue of getting the public to pay attention to the risk, when they already don't pay attention to some of the big health risks like smoking or weight control.

R. Michael Tuttle, M.D., from Memorial Sloan-Kettering Cancer Center, is a practicing thyroid specialist. He treats patients with thyroid disease, many of whom already ask him about radiation exposure and their disease. He sees a big challenge in translating excess relative risk, radiation dosage, and other relevant technical jargon into something meaningful to tell a patient. The program will have to help physicians define who is high risk and help them discuss risk in a way that makes sense to their patients, which may vary by geographic location and cultural background. Give physicians a strong scientific rationale for determining whether a patient is at risk or not.

Henry Royal, M.D., of the Washington University School of Medicine, was a member of the committee that wrote the IOM Report. He contrasted the public health perspective, which shows that thyroid cancer accounts for just 3% of all cancer deaths, with the personal, devastating perspective of a family member dying of thyroid cancer. He advocated allocating limited health care resources where they can have the greatest impact to reduce premature deaths. He acknowledged the difficulty in taking this view when individuals are dying of thyroid cancer, but shifting public health resources to a program that would have a small public health impact would cause others to needlessly suffer the tragedy of premature death.

Delvin Littell, M.D., of the Morgan County Medical Center, adjacent to Oak Ridge, Tennessee, encouraged the group to work with the organizations of community health centers, clinics that reach low-income individuals. In particular, he noted that the migrant labor movement might offer a resource of particular use with people who don't trust "the system." He also advised that communicators keep in mind how they would like to be treated when developing messages and strategies to reach the public.

James Flynn, Ph.D. Decision Research, talked about risk communications, explaining that the messages developed for this campaign will be going to people who will receive them within the context of suspicion of nuclear technology as well as their personal experiences and preformed judgments. These factors will affect the way they receive and respond to the messages.

Kristin Shrader-Frechette, Ph.D., of the University of Notre Dame, provided a medical ethicist's perspective. Two things she says have gone wrong with risk communication about radiological hazards are: the tendency to present scientific opinion as if it were fact and the tendency to make covert ethical judgments as if they were scientific judgments. She used the example of the IOM report recommending against mass screening because of the benefit to harm ratio. That's a value judgment that takes away individual rights. In a democracy, people have the right to know, the right to compensation, to due process, and to self-determination. People have the right to make mistakes for themselves. Lastly, she stated that, to communicate in a credible way, the government will have to state that this will not be repeated. People are willing to forget the past if we can assure them that what they went through in the past is not going to happen again. Deciding about screening is not just a scientific issue, it is an ethical issue and several members of the public should be involved in the decision-making. She recommended using the 1996 National Research Council report, *Understanding Risk: Informing Decisions in a Democratic Society,* as a way to improve risk communication and involve the public in a meaningful way. She also argued that the government is obligated to take responsibility and spend health care dollars on this issue, even if it involves diseases with small public impact because the government is accountable for the radiation fallout and its impact.

H.3.1.2 Day Two

Screening/Medical Monitoring

Day Two began with a session on Screening and Medical Monitoring. Robert Spengler, Sc.D., of the Agency for Toxic Substances and Disease Registry, and R. Michael Tuttle, M.D., reviewed existing recommendations and programs for screening and monitoring. They provided a handout that described the recommendations of various interested organizations and studies. Dr. Spengler also presented the proposed Hanford Medical Monitoring Program, which is not yet funded. He discussed recent revisions to the proposed program that address and reduce the potential harms of thyroid cancer screening expressed in the IOM report. In addition, he submitted documents on the proposal and revisions to NCI as handouts for the participants.

Keith Baverstock, Ph.D., of the World Health Organization, Helsinki, Finland, and Owen Hoffman, Ph.D., talked about assessing individual risk. Dr. Baverstock discussed the value of estimating individual risk, and the limitations of such estimates. He presented the NAS/IOM scheme for describing individuals' risk as falling into three non-numerical categories. Individuals born after the cessation of testing are not at risk; individuals over 18 at the time of testing are at very low risk. For other age categories, the NAS/IOM recommends that DHHS develop a method for calculating an individual "score"—for purposes of categorizing only, not as a numerical expression of risk—that takes into account location, milk consumption, milk source, and gender differences. The resulting scores would then be linked to recommendations for appropriate actions for individuals in each category.

Dr. Hoffman discussed the identification of high-risk sub-groups. He suggested the following criteria be used to determine high-risk status: those in childhood at the time of atmospheric testing, goat's milk drinkers, those with a family history of thyroid cancer or other thyroid abnormalities, and those with estimated doses above a given decision level. Dr. Hoffman emphasized that for the case of goat's milk drinkers who were children during the testing period, enough is known already to classify them as high-risk, without further dose refinement. He highlighted the inherent uncertainty of individual dose estimates and proposed that decisions be based on either the upper or lower bound of confidence on the dose estimates, and suggested a detailed framework for doing this.

Valerie Fiset, R.N., M.Sc.N., of the Sisters of Charity Ottawa Health Service, Ontario, Canada, presented a model for helping people make difficult health-related decisions. Decision aids walk patients with their health care provider through steps that help them look at options available, the potential outcomes of those options, and help the patient consider their values in relation to those options. Decision aids are used when the outcomes of the options are not very well known and the patient needs to judge the value of the benefits and risks. They are also useful when there is practice variation around a screening or treatment option. Her group has developed decision aids around chemotherapy for advanced lung cancer, hormone replacement therapy, and lumpectomy versus mastectomy for breast cancer treatment.

At this point, participant discussion began. Audience members were looking for clarification of the scope and goals of the campaign. Some expressed frustration with the government's past record on radiation issues and skepticism that things would change.

Denise Cavanaugh, the workshop facilitator, asked the group for recommendations and to develop a "wish list" of outcomes for the campaign. They are listed below.

General Recommendations

- Move forward with a campaign. Do not wait until all of the science is in. Talk about what you know and offer that more information on dose and associated risks will be provided when feasible.
- Educate the "publics" about the basics of radiation fallout, exposure (from individual facilities, and globally), and health impacts, while giving a sense of the complexity of the information.
- Keep public representatives involved as partners.
- The participants agreed on a framework to discuss I-131 first and then additional radionuclides, as information becomes available. That framework was called: "Public Health Legacy of Nuclear Production, Research, and Testing."

"Wish List" of Activities

Near Future (3 months)

- A communications plan with financial support.
- A decision about access to federally sponsored screening for uninsured and underinsured populations.
- Inclusion of state health departments in campaign development and implementation.
- Partnership with Native American tribal governments in developing the campaign.
- Use of the listserv as an interactive communications tool for discussion and review of draft planning documents.
- Consideration of a resource center with a toll-free number, i.e., an entity responsible for delivery of information.

- Development of an archive (or expansion of existing archives around the country) of documents and resources pertaining to the Nevada test Site and resulting exposures, in keeping with the ACERER recommendation.
- Continuation of relationships built at the January 2000 Workshop.
- Government acknowledgment of the legacy of nuclear production, research, and testing and commitment to prevention in the future.
- A clear set of recommended actions for the public to take with regard to exposure.
- Study of the ongoing health effects of existing nuclear action.

Distant Future (36 months)

- Outreach to communities.
- Outreach to Federal agencies.
- Physician education implementation.
- Evaluation of campaign implementation.
- Benchmarks for physician education, etc.
- Development of cultural- and language-appropriate messages/materials for special populations.
- Addressing additional radionuclides.
- American public understanding fallout and health legacy.

Developing Model Outreach

Peter Sandman, Ph.D., a risk communications consultant, explained the difference between hazard (how dangerous something is) and outrage (how much it upsets people) and the fact that they are often poorly correlated. He suggested a two-pronged campaign. One audience is people who are significantly endangered by NTS fallout and deserve a warning. The second audience is the larger public whose hazard is low. He offered five options for messages to them, ranging from doing what you can to keep them from becoming outraged to getting them outraged to organize them politically. He suggested that the diverse interests in the room could work together on a campaign to reach those who are high risk, but would probably need to work separately to communicate to the larger public, since their goals would likely vary.

Regardless of how hazardous the fallout is to the public's health, Dr. Sandman noted that public outrage over nuclear fallout should be expected and is justified based on a list of twelve factors, including the involuntary nature of the exposure and the government's unresponsiveness to public concern. He said that in order to be credible, the government must acknowledge the outrage and admit that it is justified. He ended by saying that the government should apologize a lot; overestimate, rather than underestimate the risk; show concern, feeling and humanity; and acknowledge the moral relevance of the situation.

Neil Weinstein, Ph.D., of Rutgers University, discussed the challenges involved in communicating about risk, based on his experience with radon and other programs. He talked about the public's difficulty in understanding numbers and probabilities and the likelihood that people will be apathetic to the message that a health risk has occurred. He also warned against providing too much information in an effort to enable people to make their own informed decisions. He advocated giving recommendations for action with sufficient background information, without flooding people with all the details on dosing, probabilities, and the science of I-131 exposure.

Ed Maibach, Ph.D., of Porter Novelli, presented the results of six focus groups held with consumers and physicians to begin getting a sense of their knowledge and attitudes about radiation fallout and health risks, to understand their perceived risk, their degree of concern, and to understand their needs for information on these issues. The participants were drawn from two cities with a high exposure to I-131 and one with a lower exposure. The preliminary report was provided at the meeting.

- The consumers in both areas showed little concern about radiation fallout, had little interest in something that occurred in the past, and were more concerned by health issues they face today. But there was great passion for securing assurances that the tests never happen again. People wanted to know the big picture about the consequences of NTS testing rather than just about I-131.
- The physicians knew very little about nuclear testing and its health impacts. They called for a permanent ban on nuclear testing. They asked that a public education campaign not be mounted because it would create a mess without helping the public. They said a physician campaign might be a good idea, though they weren't convinced it would change their clinical practice at all.

Dr. Maibach ended by reminding the workshop participants that this was just the beginning of the audience research needed to develop a campaign. During the question and answer period following the presentation, workshop participants noted the likelihood that focus group responses were tied to the source and format of the information stimulus they received. It was pointed out that this should be taken into account in locating appropriate "messengers" for delivering exposure information to the public. Later in the workshop, the participants spent time discussing additional audience research needs.

Campaign Goals

Following the audience research presentation, workshop participants developed four goals for the communication campaign, which received wide support:

1. Acknowledge/explain what happened as a result of nuclear weapons production, research, and testing and what is happening now. Engage or encourage the public in a policy discussion on this issue.
2. Educate the public on the potential health consequences of I-131 and other radiation exposures so they can make good decisions. Provide mechanisms for follow-up (e.g. toll-free number) for people without a health care provider.
3. Educate health care providers about the health consequences of I-131 fallout and other radiation exposures as well as the pros and cons of thyroid evaluation so they can help their patients make good decisions.
4. Facilitate diagnosis, screening, and if necessary, treatment, for those with cancer and non-cancer radiation-related illnesses.

A number of organization representatives committed to working on specific campaign goals:

- Physicians for Social Responsibility, Alliance for Nuclear Accountability, and the National Indian Council on Aging expressed interest in working on goal #1 and bringing the topic to their organizations' meetings in May (PSR and ANA), and August (National Indian Council on Aging).
- Physicians for Social Responsibility, Alliance for Nuclear Accountability, National Association for the Advancement of Colored People (NAACP), and the National Association of Radiation Survivors offered to work with the federal government on goal #2.

H.3.1.3 Day Three

Organized Feedback

In small working groups, participants gave feedback regarding:

- Design of an ongoing campaign development workgroup.[6]
- Recommendations for issues to be addressed at the April 2000 ACERER workshop on screening.
- Additional audience research needs.
- Preparation for audience messaging: What key information needs to be communicated?

Each small group’s recommendations and comments are presented below.

1. Campaign Development Workgroup

The workgroup that worked with NCI and CDC to plan the January workshop included individuals familiar with the following perspectives, groups, or organizations:

- Hanford downwinders
- Alliance for Nuclear Accountability
- ACERER Subcommittee for Community Affairs
- Hanford Health Information Network
- NAACP
- Physicians for Social Responsibility
- A Physician

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[6] During the Workshop, this group was frequently referred to as the “Campaign Development Group” or “CDG.” Since then, NCI staff have elected instead to call the group a “Communications Development Group” to be more encompassing of all the efforts involved in communications planning.

- State Public Health Department (Radiological Health Section)
- NCI/CDC/ATSDR staff

Workshop participants in the small group that discussed this topic proposed that the new “Campaign Development Group” include the following types of representation (this is a list of perspectives to be represented—not specific organizations):

- Activists (2)
- Downwinders (2)
- African American
- Health educator
- Health professional organization
- Hispanic from community and migrant health center
- Native American
- Physician
- State Public Health Department: health education and radiation control (2)
- Local health department
- Thyroid Foundation

Criteria for inclusion in workgroup:

- long-term view
- a view broader than I-131 and thyroid cancer
- ability and willingness to make necessary time commitment
- ability to do outreach to their communities
- work toward geographic diversity

It was also agreed that workgroup members need to be reimbursed equitably for the work they do on this project, and that the federal agencies involved must commit adequate staffing to this effort.

2. Recommendations for topics to be addressed at the ACERER meeting to address screening issues

- Feasibility of identifying higher- and lower-risk groups
- Basis for decisions regarding policies on screening—scientific analyses alone, versus incorporation of social justice considerations
- Risks and benefits of screening for cancer and non-cancer thyroid illness
- Incidence of false positives from most recent Hanford Thyroid Disease Study thyroid cancer medical evaluation
- Review of science regarding noncancer thyroid outcomes of I-131 exposure
- Cumulative effects: how do multiple exposures change a person’s risk classification?
- Progress report on research into other radionuclides
- Examination of other screening programs around the world
- Potential funding mechanisms for screening programs; comparison of other screening programs
- Case study of affected citizens
- Operating principles

A workgroup will help plan the ACERER workshop. Individuals working on this list offered to participate. They were: John Bagby, Trisha Pritikin, Henry Royal, Robert Spengler, Oscar Tarrago, J.B. Hill, David Becker, and Steve Simon. Tim Takaro, Keith Baverstock, Owen Hoffman, and Kristin Shrader-Frechette also expressed interest in participating in the planning process.

3. Recommendations for Additional Audience Research

- Who are we trying to reach? This must be determined before audience research begins.
- Once this is determined, the research would address:
- Demographic research on language, culture, education, and literacy levels.
- Preferred sources of information.
- Psychographic data -- beliefs/attitudes, epidemiologic data, role of the media.
- Message and strategy testing -- look at research and campaigns that have already been done. Do a meta-analysis to transform and digest that data to determine audience needs.
- Process evaluation: Was the campaign done on time, within budget?
- Outcome evaluation: What were the campaign's effects? What was the reach, frequency, and duration of communications? How many were exposed over a period of time? What were the effects on knowledge, attitudes, and behaviors? What were the long-term effects on behaviors?

4. Preparation for Audience Messaging: What key information needs to be communicated?

- The general United States population should receive information to improve their awareness.
    - Give historical context, discuss research, production, and testing. Discuss I-131 and other radionuclides. Discuss local testing, global fallout, associated social and ethical issues, and general risk factors (e.g., milk, and gender) so that people can self-identify. Give history of government action and where there is still work to be done. Describe the work that continues on outstanding issues to ensure that exposures from testing won't happen again.
- "Hot spot" audiences should receive:

  - All the information that the general United States population is receiving (see above).
  - Information on general risk factors plus multiple exposures so they can self-identify.
  - Assurance that health care providers and other agencies (e.g., managers at DOE/contractor facilities) are being told about this.
- Self-identified as at-risk or other concerned people should receive:
  - Information that the above audiences receive.
  - Information on what to do if you don't have a health care provider.
  - Details on the ongoing work regarding outstanding issues (screening, compensation, etc.)
  - A fact sheet from an official organization to bring to a clinic or physician's office.
- Health care providers should receive:
  - Everything the above two audiences receive and additionally, resources on screening for all thyroid disease.
- Payers of Healthcare (HMOs, government programs) and insurance commissioners should receive:
  - Clinical practice guidelines or Standards of Care.
- Workers (research, production, mining, etc.) should receive:
  - All information that "hot spot" and self-identified at-risk people receive.
- State Health Departments should receive:
  - All information that health care providers receive so they know they will also be disseminators, and must be kept informed as campaign progresses.
- State Regulators should receive:

  - All the same information that health care providers and state health departments receive.
  - Still need to determine the right organizations to communicate messages to various target audiences.

Summary Comments

Anne Lubenow, Acting Co-chief of the Health Promotion Branch in the Office of Cancer Communications, NCI, thanked all of the participants and expressed NCI's appreciation for everyone sharing their views. She encouraged participants to contact the NCI staff as needed. She also strssed that although we don't yet have all of the answers, we are on the road to developing a campaign, and have identified some common ground, as well as areas that need further discussion.

Joan Morrissey, Health Communicator with the Radiation Studies Branch, CDC, followed by thanking the workgroup for the tremendous amount of work they put in to planning this successful workshop. She specifically noted her desire to put together a Native American caucus, as suggested by Robert Holden. She reiterated the agencies' commitment to developing and implementing this program and doing it right.

A sampling of participants' closing remarks

"It's been really heartening for me as a person from a significantly impacted community to feel that all these people actually care about people like me, finally, because there are a whole lot of times when I don't feel that way. And I want to thank the agencies involved for never telling us that we couldn't discuss something. We were able to put all the issues on the table and discuss everything that I think people wanted to talk about. I feel very good about this process."

"I see an incredible variety of talent, knowledge, and goodwill in this room, and I see a huge opportunity to make a truly positive impact on all of society."

"A grave concern in all of this is that these issues have the ability to divide people in this country rather than unite them. If the same spirit of bringing different people together here could be the spirit of whatever moves out of it, I think we can go very far."

Next Steps

Nelvis Castro, Acting Associate Director for Cancer Communications at the NCI, thanked the participants for their candor and their dedication to this effort. She stated that the summary of the meeting would be posted on the listserv for a 2-week comment period, then finalized and distributed to interested parties. Dr. William Raub has committed to bringing the report to Secretary Shalala's attention. A Campaign Development Group will be formed and will review the draft communications plan and help with future activities. She estimated that the plan will take about six months to draft. The plan will be refined and modified as necessary based on feedback received from this group. She also hopes to learn about the communications channels that participants use to reach their constituents to expand the reach of the messages that are developed for this campaign.

Owen Devine, Ph.D., chief of the Risk Assessment and Communication Section, Radiation Studies Branch, CDC, talked about future plans to study other radionuclides and global fallout. A feasibility assessment will be presented to ACERER in June 2000 and to Congress in July 2000. It will be an assessment of the scientific feasibility of estimating dose and risk to the United States population from global fallout, including NTS. There will be a large discussion of communications in the report as well. He thanked all of the participants.

Dr. Alan Rabson closed the meeting by repeating the apology for NCI's delay in finishing the Nevada Test Site Fallout report. Processes have been put in place at the Institute so that such an "unconscionable delay" will never happen again. He called the workshop an "historic meeting" that has given NCI a new understanding and commitment to working with community representatives. He assured participants that NCI intends to follow through.

H.3.2 List of Working Group Members and Government Staff

H.3.2.1 Community Representatives

H. Jack Geiger, M.D. - (Departed group 11/99)

James B. Hill, Jr. - President, NAACP, Oak Ridge Branch

Yvette Joseph-Fox - National Indian Health Board (Departed group 10/99)

Bea Kelleigh - Executive Director, Hanford Health Information Network Resource Center

Stan Marshall - Radiological Health Section, Nevada State Health Division

Robert Musil - Executive Director, Physicians for Social Responsibility

Trisha Pritikin, Esq., M.Ed., O.T.R. - Downwinder

Robert Tiller - Physicians for Social Responsibility (Departed group12/99)

Seth Tuler, Ph.D. - Childhood Cancer Research Institute and Clark University

H.3.2.2 Government Staff

National Cancer Institute

Nelvis Castro - Acting Associate Director for Cancer Communications

Betsy Duane - Communications Coordinator, Division of Cancer Epidemiology and Genetics

Mark Epstein - Porter Novelli (Consultant)

Anne Lubenow - Acting Chief, Health Promotion Branch

Kelli Marciel - Presidential Management Intern, Health Promotion Branch

Jim Mathews - Senior Science Writer, Health Promotion Branch

Alan Rabson, M.D. - Deputy Director, National Cancer Institute

Paul Van Nevel - Van Nevel Communications, (Consultant - then Associate Director for Cancer Communications - retired as of 12/31/99)

Cori Vanchieri - Vanchieri Communications (Consultant)

Centers for Disease Control, National Center for Envronmental Health

Owen Devine, Ph.D. - Chief, Risk Assessment and Communication Section, Radiation Studies Branch (moved to another division 2/1/00)

Christie Eheman - Epidemiologist

Joan Morrissey - Health Communicator, Radiation Studies Branch

Judy Qualters, Ph.D. - Acting Chief Risk Analysis and Communication Section, Radiation Studies Branch

Agency for Toxic Substances and Disease Registry

Oscar Tarrago, M.D., M.P.H. - Fellow, Office of the Director, Division of Health Education and Promotion

H.3.3 Workshop Participants

In alphabetical order by last name

Elaine Bratic Arkin, Health Communication Consultant

John Bagby, Ph.D., Chairman, Advisory Committee for Energy Related Epidemiologic Research

Wayne Ball, Ph.D., Toxicologist, Utah Department of Health, Bureau of Epidemiology

Keith Frederick Baverstock, Ph.D., Regional Advisor, Public Health and Environmental Radiation, World Health Organization

David V. Becker, M.A., M.D., Professor of Radiology, Professor of Medicine, New York Presbyterian Hospital, Weill Medical College of Cornell University

Marco Beltran, M.P.H., Program Specialist, Migrant Head Start Quality Improvement Center

Joni Berardino, M.S., National Center for Farmworker Health

Luis Buen Abad, M.Ed., Environmental Specialist, Hanford Health Information Network

John Burklow, Deputy Director for Communications, Office of Communications and Public Liaison, NIH

Leticia Camacho, J.D., M.A., Director of Policy and Advocacy, Migrant Clinicians Network

Nelvis Castro, Acting Associate Director, Office of Cancer Communications, National Cancer Institute

David Cooper, M.D., Director, Division of Endocrinology, Sinai Hospital of Baltimore

Sharon Cowdrey, R.N., President, Miamisburg Environmental Safety and Health

Owen Devine, Ph.D., Chief, Risk Assessment and Communication Section, Radiation Studies Branch, CDC

Betsy Duane, Communications Coordinator, Division of Cancer Epidemiology and Genetics, National Cancer Institute

Christie Eheman, Ph.D., Epidemiologist, Centers for Disease Control and Prevention

Maureen Eldredge, Program Director, Alliance for Nuclear Accountability

Mark Epstein, Communications Consultant, Porter Novelli

Valerie Fiset, R.N., M.Sc.N., Clinical Nurse Specialist, Palliative Care, Sisters of Charity of Ottawa Health Service

James Flynn, Ph.D., Senior Research Associate, Decision Research

Patricia George, Community Research Coordinator, Nuclear Risk Management for Native Communities Project

Thomas M. Gerusky, Certified Public Health Physicist, Retired Director, Pennsylvania Bureau of Radiation Protection, Conference of Radiation Control Program Directors

Hossein Gharib, M.D., Professor of Medicine, Mayo Medical School, Mayo Clinic

F. Lincoln Grahlfs, Ph.D., M.A., President, National Association of Radiation Survivors

Michael Hansen, representing Jean Halloran, Director, Consumer Policy Institute, Consumers Union

James B. Hill, Jr., President, NAACP Oak Ridge Branch

Felicia Hodge, Dr.P.H., Director, Center for American Indian Research and Education

F. Owen Hoffman, Ph.D., President, SENES Oak Ridge, Inc.

Robert Holden, Director, Nuclear Waste Program, National Congress of American Indians

Bea Kelleigh, M.P.A., Executive Director, Hanford Health Information Network Resource Center

Gary Kodaseet, Vice Chairman, National Indian Council on Aging

Susan Koppi, Director, Public Affairs, The Endocrine Society

Gary L. Kreps, Ph.D., Chief, Health Communication and Informatics Research Branch, National Cancer Institute

Charles Land, Ph.D., Division of Cancer Epidemiology and Genetics, National Cancer Institute

Robert Lawrence, M.D., Associate Dean for Professional Education and Programs, School of Hygiene and Public Health, Johns Hopkins University

Lisa Ledwidge, M.P.A., M.S.E.S., Outreach Coordinator and Editor, SDA, Institute for Energy and Environmental Research

Delvin Littell, M.D., Medical Director, Morgan County Medical Center

Paul A. Locke, M.P.H., Dr.P.H., Deputy Director, Pew Environmental Health Commission

Anne Lubenow, M.P.H., Acting Chief, Health Promotion Branch, National Cancer Institute

Roger Macklin, M.S., Health Physicist, Tennessee Department of Environment and Conservation, Director of Radiological Health

Kelli Marciel, M.P.A., Presidential Management Intern, Health Promotion Branch, National Cancer Institute

Stan Marshall, Radiological Health Section, Nevada State Health Division

James Mathews, Senior Science Writer, Office of Cancer Communications, National Cancer Institute

Normie C. Morin, Ph.D., M.P.H., Project Director, Rocky Flats Health Studies, Disease Control and Environmental Epidemiology Division

Joan Morrissey, Health Communicator, Radiation Studies Branch, Centers for Disease Control and Prevention

Robert Musil, Executive Director, Physicians for Social Responsibility

Dennis Nelson, Ph.D., Director of Research, Support and Education for Radiation Victims

Nancy Nelson, Mass Media Branch, Office of Cancer Communications, National Cancer Institute

Claudia Parvanta, Ph.D., Director, Division of Health Communication, Office of Cancer Communications, Centers for Disease Control and Prevention

Judy Patt, Cancer Information Service, National Cancer Institute

Devon Payne-Sturges, M.P.H., Assistant Commissioner for Environmental Health, Baltimore City Health Department

Stacye Poer, Program Analyst, Office of Legislation and Congressional Activities, National Cancer Institute

Trisha T. Pritikin, Esq., M.Ed., O.T.R., Downwinder/Community Representative

Idaho J. Purce, Project Director, HIV/AIDS Education, NAACP; INEEL Health Effects

Judith R. Qualters, Ph.D., Acting Chief, Risk Analysis and Communication Section, NCEH, Centers for Disease Control and Prevention

Alan S. Rabson, M.D., Deputy Director, National Cancer Institute

William Raub, Deputy Assistant Secretary for Science Policy, Department of Health and Human Services

Karim Rimawi, Ph.D., Director, Bureau of Environmental Radiation Protection, New York State Department of Health

Jacob Robbins, M.D., Scientist Emeritus, National Institute of Diabetes and Digestive and Kidney Diseases

Henry D. Royal, M.D., Professor of Radiology, Division of Nuclear Medicine, Mallinckrodt Institute of Radiology, Washington University School of Medicine

Michael Sage, Acting Deputy Director, National Center for Environmental Health, Centers for Disease Control and Prevention

Peter Sandman, Ph.D., Risk Communication Consultant

Elke Shaw-Tulloch, Manager, Environmental Health Education Program, Idaho Division of Health

Kristin Shrader-Frechette, Ph.D., Medical Ethicist, Department of Philosophy and Department of Biological Sciences

Steven L. Simon, Ph.D., Senior Staff Officer, National Academy of Sciences, Board on Radiation Effects Research

Robert F. Spengler, Sc.D., Associate Administrator for Science, Agency for Toxic Substances and Disease Registry

Patrice Sutton, M.P.H., Western States Legal Foundation

Diana Swindel, Associate Director, Communications Office, National Center for Environmental Health

Tim K. Takaro, M.D., M.P.H., M.S., Acting Assistant Professor, University of Washington School of Medicine

Oscar Tarragó, M.D., M.P.H., Fellow, Office of the Director, Agency for Toxic Substances and Disease Registry, Division of Health Education and Promotion

Kevin Teale, M.A., Communications Director, Iowa Department of Public Health

Stephen Thomas, Ph.D., Associate Professor, Director, Institute of Minority Health Research, Rollins School of Public Health, Emory University

Tim L. Tinker, Dr.P.H., M.P.H., Chief, Communications and Research, Agency for Toxic Substances and Disease Registry

Seth Tuler, Ph.D., Childhood Cancer Research Institute and Clark University

R. Michael Tuttle, M.D., Assistant Attending, Memorial Sloan-Kettering Cancer Center

J. Paul Van Nevel, Van Nevel Communications, Consultant to the National Cancer Institute

Cori Vanchieri, Vanchieri Communications, Consultant to the National Cancer Institute

Neil Weinstein, Ph.D., Professor, Department of Human Ecology, Rutgers University

H.3.4 Proposed Campaign Operating Principles

- Honesty, openness to differing points of view, and a willingness to answer questions will characterize the ongoing planning, operation, and evaluation of the campaign.
- Trust and credibility will be earned and maintained by providing accurate and comprehensive information.
- The campaign will be respectful of human rights and the dignity of affected people.
- Persons who may have been exposed to radiation released from the Nevada Test Site will be involved in the development, implementation, and guidance of the campaign.
- Campaign information will be accurate, scientifically sound, and will explain the uncertainties of current knowledge.
- Information will be supportive, reflecting compassion and an understanding of scientific, medical, psychological, and ethical issues involved.
- The campaign will consider the needs of underserved populations and will strive for social equity.
- Efforts will be outcome oriented.

H.3.5 List of Other Resources

- The NCI Fallout Report and several related documents, including an individual dose calculator can be found on-line by visiting www.cancer.gov/cancerinfo/ , and selecting "Information for the Public and the Media," then selecting "About Radiation Fallout" from the menu at the left of your screen.
- The IOM's review of the NCI report can be viewed on-line as well. Visit www.nap.edu and enter 'Exposure of the American*' in the "search all titles" field.
- The National Research Council report referenced by Kristin Shrader-Frechette in her remarks, *Understanding Risk: Informing Decisions in a Democratic Society*, is also available at www.nap.edu using the title search feature.

Other valuable websites:

- NIH ListServ Homepage (to subscribe/unsubscribe to I-131NTSFALLOUT-L): http://list.nih.gov
- CDC's National Center for Environmental Health, Radiation Studies Branch homepage (includes links to Hanford Thyroid Disease Study): www.cdc.gov/nceh/programs/radiation
- Hanford Health Information Network: www.doh.wa.gov/hanford
- The NCI publication *Making Health Communication Programs Work* is an excellent guide to planning health communications. It is available on-line by visiting http://publications.nci.nih.gov/ , and executing a search for "Communication." An updated version of *Making Health Communications Work* will be released in late spring 2000.

H.4 Report of Key Findings: In-depth interviews with Experts about ^{131}I Exposure from NTS Fallout

(Next page)

In-depth Interviews with Experts About I-131 Exposure From the Nevada Test Site

Report of Key Findings

Prepared by:

Office of Cancer Communications
National Cancer Institute
31 Center Drive MSC-2580
Building 31, Room 10A03
Bethesda, MD 20892-2580

January 2000

I. INTRODUCTION AND METHOD

The National Cancer Institute (NCI) and Centers for Disease Control and Prevention (CDC) are designing a national campaign to implement Institute of Medicine (IOM) recommendations to communicate to Americans the potential health effects of Iodine-131 (I-131) radiation released during atmospheric testing in Nevada during the 1950s and 1960s. To inform this effort, NCI conducted 19 in-depth interviews with individuals who have expertise in areas related to the issue of nuclear fallout. The main objectives of this research were to measure awareness level, concern, familiarity with, and evaluation of the NCI Report & IOM recommendations about I-131 from the Nevada Test Site, and to obtain recommendations about how to conduct a communication campaign.

A working group consisting of NCI staff, CDC staff, and a panel of community representatives generated a list of potential interviewees. Individuals were suggested in a number of categories, including state and local public health officials, community advocates (including environmental, health, and pro-nuclear groups), scientific experts (e.g., radiation scientists), health oriented professional organizations, veterans, health care providers (e.g., thyroid specialists), and health educators.

The selection of interviewees was based on the following criteria: 1) level of expertise; 2) an effort to obtain representation from all the categories listed above; and 3) geographic diversity. The original interviewee list was comprised of 29 contact names collectively agreed upon by working group members. Interviews were completed with 19 interviewees. When an effort to contact a particular interviewee was not successful, an alternate name was generally provided by working group members. Alternates were selected from the same type of background as the originally proposed interviewee.

In order to report the interview results in a way that incorporates the contextual background of individuals, interviewees were separated into three major reporting categories. These categories are as follows:

> **Public Health Officials:** Six government officials were interviewed in this category. Participants included those employed in public health departments in states with varying degrees of I-131 exposure from the Nevada Test Site and other representatives involved in radiation issues at the state level.
>
> **Advocacy Groups:** Seven individuals were interviewed in this category. Participants held a variety of positions in organizations dedicated to different issues associated with nuclear or radiation issues. Organizations were selected to represent a broad range of opinion. Included in this category were representatives of groups dedicated to radiation-exposed populations, the environment, and the advancement of nuclear science.
>
> **Scientific Experts:** Six individuals were interviewed in this category. Participants included both radiation and thyroid experts associated with a variety of institutions.

Interview questions were designed to measure awareness, concern and opinions about what constitutes an appropriate outreach response (See Appendix A for copy of the interview instrument). It should be noted that the interview guide was not followed verbatim, and language was altered in some cases to be sensitive to the background and expertise level of each respondent. Each interview lasted approximately 30 minutes.

It should also be noted that in-depth interviewing is a qualitative research technique. Although the findings from this research can provide useful, detailed insights into the perceptions and views of different organizations and experts involved with the I-131 fallout issue, they cannot represent the views of all such groups or persons.

II. KEY FINDINGS

This section outlines the key/preliminary findings from the interviews. Differences in responses between reporting groups are outlined separately.

A. Awareness and Concern

- **For public health officials, the NCI report frames the boundaries of awareness.**

When asked what they knew about the potential health effects of the Nevada Test Site, the majority of public health officials cited the NCI study as their primary reference point. All agreed that thyroid cancer or “the thyroid problem” was the main potential health outcome to be concerned about. Although two officials mentioned other possible conditions, like autoimmune illnesses and damage to other organs, they qualified these statements indicating that the data and science were only available on the thyroid cancer link. Only one official could name other radioactive substances released from the site in addition to I-131.

On a scale of one to ten, with one indicating “not at all severe” and ten indicating “very severe,” most officials gave the potential health effects from the Nevada Test Site a fairly low severity rating of two or three. Only one official gave it a relatively high rating of six.

None of the officials said their organization had a formal position on I-131 exposure from the Nevada test site. One official, in a state with some highly exposed counties, said they were “struggling” to determine whether or not the potential risks justify a public outreach effort.

- **Advocacy groups have a far broader scope of concern.**

Fewer advocacy group participants mentioned the NCI report when asked about their knowledge of the potential health effects of the Nevada Test Site. Although most mentioned thyroid cancer and other non-cancerous thyroid abnormalities as possible outcomes, a few participants also mentioned leukemia. One representative said genetic mutations and birth defects were also a possibility.

In addition to being concerned about more health effects, advocacy group representatives were also more aware of other radioactive materials emitted from the tests. The most frequently cited substances after I-131 were cesium, strontium, and plutonium. When asked which substances they worried about the most, advocates said that all the substances posed significant reasons for concern, but for different reasons. Some pointed out the varying half-lives of the substances; several, for example, talked about plutonium's ability to persist in the environment for long periods of time. One representative took the opportunity to say that the NCI report was "too narrowly and conveniently" focused on thyroid cancer instead of on other more lethal cancers like leukemia, breast and bone cancer that may be caused by other materials like strontium and cesium.

Advocates rated the severity of the health effects from the Nevada Test Site much higher than did the public health officials. Most gave a rating somewhere in the range of eight to ten. Only one respondent thought differently. This participant, who refused to use the rating scale, characterized the potential health effects from Nevada Test Site exposure as 100 times more severe than an accident like Three Mile Island or waste disposal sites, but much less severe than radiation received from medical diagnostic tests.

All but two representatives said their organization had a position on exposure from the Nevada Test Site. One representative said there needed to be more education and research on the association between exposure and non-thyroid disorders, particularly parathyroid disorders. Another said the government needed to be more "forthright" and "conscientious" in its efforts to inform the public. Others called for health care provider education efforts and clinical screening and monitoring. Although two representatives said their organization did not have a formal or official position, they did say their organization generally supports the cause of research and educational efforts conducted for the benefit of exposed populations.

- **<u>Concerns of scientific experts are defined by their evaluation of "the evidence."</u>**

Scientific experts chose to focus primarily on the thyroid-cancer link when asked what they knew about the health consequences of the Nevada Test Site. Most made evaluative comments about the findings. The level of detail provided about the relationship between I-131 and thyroid cancer varied by the type of expert. Radiation experts provided much more detailed information and critiques of the NCI data. One such expert said, "I am aware that 10,000 to 75,000 new thyroid cancers will result from these tests." Another radiation expert characterized the findings as "statistically suggestive rather than significant." Strontium, cesium, and plutonium were most frequently mentioned by radiation experts as some of the other key radionuclides that were emitted from the tests. One expert said I-131 should be paid the most attention because it was the "main fallout product."

Thyroid experts had less detailed knowledge and seemed to retain only the facts they felt were relevant to their concerns and practice areas. These specialists were primarily concerned about the relationship between I-131 and thyroid disorders and less interested in other health effects. They were aware of the Nevada Test Site solely because of its relationship to I-131 (an issue thyroid specialists are quite knowledgeable about), since the site presents another potential avenue of iodine exposure. These specialists expressed limited concern, stating that exposure was found to be minimal for the most part and that thyroid cancer is highly treatable.

Expert ratings of the severity of potential health effects were more mixed than the other two interviewee groups. One radiation expert rated the severity of the health effects as a one or a two, while another rated it as an eight or nine. Many had difficulty providing unqualified responses, probably due to their high knowledge levels. For example, one radiation expert said the severity rating is dependent on geography, giving a one for a person living in New York City and a four for a person living in Utah. Thyroid specialists shared more commonality in their ratings with most giving it a low rating of a one or two. One specialist said the rating is dependent on age of exposure, giving it a rating of five for a child and only a rating of one for an adult.

B. Familiarity and Evaluation of NCI Report and IOM Action Recommendations

- **Public health officials are in agreement with findings and recommendations.**

All public health officials were quite familiar with the reports, and most had a good working knowledge of risk factors and other specifics. Officials in states with heavily exposed populations were more informed than officials from states with less exposure. One official of a state with areas of high exposure reported using the NCI data to conduct their own state-level investigation. Two officials in less exposed states had a more general level of knowledge about the NCI findings.

Overall, public health officials found the reports useful. Two officials said the most useful information was the county-level exposure information. Two others said the reports serve as good background pieces about the relationship between I-131 and thyroid cancer and will be a useful framework for thinking about other exposure sites throughout the country. There were few suggestions for additional information. One official said more definitive information on the risk associated with I-131 exposure was needed to determine what the exposures really mean from a health perspective. Another official thought information on the relationship between I-131 exposure and non-cancerous thyroid disorders would be important to have since there was a lot of “talk” about this issue.

All officials agreed with the IOM position that screening would cause more harm than good, due to the number of false positives. One individual said screening was also not advisable because the exposure findings were uncertain, and individuals would be better served if their own doctor decided whether or not screening was appropriate for them.

Most public health officials thought the proposed strategy of educating the general public and providing physicians with information to respond to inquiries would be very effective. Some said this was important because health care providers lack knowledge about the association between iodine and thyroid disease. One individual said it would be effective because people listen to and trust their doctors. Another official thought that the strategy made sense but that the nature of the information would be difficult for the public to understand.

- **Advocacy groups disagree more with findings and recommendations.**

Approximately two-thirds of the advocates said they were very familiar with the NCI and IOM reports. The remaining one-third recalled major pieces of information but without specifics. Advocacy group opinion about the information in the reports was considerably more divided than among public health officials. One representative said that some of the exposure information was inaccurate and that there were more areas listed as low exposure areas than should be. Another representative held the opposite view, saying that there were more high exposure areas than should be. A couple of representatives said the reports were useful in the sense that there was an "admittance" of responsibility, and some information was at least "out there." And another representative took credit for pushing Congress to get the report "done in the first place."

Advocacy representatives were far less supportive of the IOM screening recommendations than public health officials. Half thought screening for thyroid cancer was necessary, and half agreed that it was not a beneficial course of action. One individual supported the notion that screening for thyroid cancer would result in too many false positives, but felt screening for other disorders like hypothyroidism and hyperparathyroidism should be conducted.

When asked how effective the IOM strategy of educating physicians and the public would be, most advocates characterized the strategy as one that would be "helpful." Two participants focused on the need to educate physicians so patients will be "taken seriously" and will not have to "educate their physicians." Only one participant felt the action would be unnecessary and expressed doubt about the ability to educate physicians who are "essentially lay people when it comes to nuclear and radiation issues and lack technical knowledge and background."

- **Thyroid experts are in agreement, while radiation experts are more divided.**

While the radiation experts were very familiar with the NCI and IOM reports and had examined them in detail, the thyroid specialists were only vaguely familiar with the actual reports. Despite their uncertainty about having read the reports, however, the thyroid specialists felt certain that they understood the overall findings from other sources like professional journals, newspapers, and presentations. In general, they recalled that the exposure did not pose a very significant health threat.

Those radiation experts who had read the reports found some information useful and some not. While one expert said the reports were "most inclusive and helpful," another said they were "inconclusive" because the findings were "extrapolated from only 100 sites." Another expert felt the information was useful, but needed to be translated in a way that would make it possible for the lay public to understand. The lack of "risk information" was "curiously avoided" according to another expert.

The radiation experts were also divided on the issue of screening. One agreed with the argument that "screening will do more harm than good." Another agreed that it made no sense to screen the general population, but did think the issue of screening high-risk populations needed to be addressed. Another expressed agreement with not screening for thyroid cancer, but thought looking into screening for other non-cancerous thyroid disease was essential. The thyroid specialists were less divided, all indicating that wide-scale screening for thyroid cancer would result in too many false positives and could result in harm to the patient in terms of unnecessary surgical procedures.

Most experts thought the action recommended by the IOM would be very effective. Their reasons for thinking this strategy would be effective were similar to the other groups. Explanations provided were that physicians lack knowledge and have direct patient contact, while patients for the most part feel comfortable with their doctors. One expert said the strategy would be only "moderately effective" because physicians may not take the time to review the information provided and because not everyone has health insurance and/or is under the care of a physician.

C. Educational Efforts: What's Needed?

- **<u>Public health officials think risk factors should determine the focus and scope of the campaign.</u>**

When asked if the entire U.S. needs to be the target of an educational effort or if the effort should be confined only to those most heavily exposed, officials answered in accordance with their understanding of the risk factors and exposure patterns. One official thought the campaign could be focused on those who were children at the time and drank milk from a backyard goat or cow since these individuals were most at risk. Another official thought everyone should be given information, but the campaign should be more aggressively focused on those at higher risk. Those who thought a campaign would need to target the whole population grounded their opinions on the premise that it would be difficult to "find" everyone at high risk due to factors like mobility and storm and wind patterns.

By far, the most important information that officials thought needed to be provided to people is a profile of the risk factors. One official thought such a profile, along with an 800 number for those who need more information, would be a good idea since it is so difficult to separate out those who need to be concerned from those who don't.

- **<u>Advocacy groups say a "right to know"argument prevails.</u>**

A majority of advocates said a national campaign was needed because citizens have "a right to know" about the actions of their government. For example, one advocate said, "Everyone should know that this was done without our knowledge" because "the government has no right to contaminate us." Another said information should not be "denied to people," but qualified the response by saying it would be difficult to really get the information to everyone because a “large portion of the public is apathetic,” especially when something seems so “far away.” Some thought a general public information campaign was needed along with a more targeted and aggressive effort to ensure that high-risk groups are reached. Only one advocacy group representative thought that little needed to be done; this individual expressed the view that something “had to be done” because the issue had become “so political,” but thought that the campaign should be very targeted to those at highest risk.

In addition to providing information on risk factors, advocates often mentioned a need to translate the information into a format that people can understand. One said people need to be provided with a listing of symptoms that may signal a thyroid problem so they can ask their doctor for a blood test or ultrasound. Another said people needed all the information required to calculate their own dose.

- **Scientific experts propose solutions mixed with some worry about invoking “unnecessary” fear.**

Although solutions proposed by scientific experts varied, more participants in this group than others expressed concern about the need to present information in a way that does not provoke anxiety or panic on the part of the public. The thyroid specialists frequently made this argument and expressed a preference for a targeted “talk to your doctor” type approach, especially aimed at those who were children at the time of exposure. One specialist thought it would be important to assure people that the NCI study was a “very carefully run study so they should not be afraid.”

Radiation experts were more divided. One expert thought the “right to know” demanded a national campaign. This individual characterized the notion of a targeted campaign as a scientific impossibility because it would be too difficult to “find” the people most heavily affected. Another felt the information was already “out there” for people who needed to find it. He said that “the advocates do a good job of letting people know who need to know” and any further effort will start a public panic.”

D. Participant Recommendations for How to Conduct A Campaign

- **The majority of participants are in consensus about campaign “how-to’s.”**

Although there was much disagreement about the appropriate scope and focus of a potential educational information campaign, a high degree of consensus emerged on how a campaign would be best implemented.

  - Most participants said that such a campaign would need to be conducted at a national level with significant use of mass media. Even many of those who thought more targeted campaigns were appropriate “back-tracked” a little here realizing that a national effort may be needed in order to “find” everyone.

- Providing information about exposure and risk was seen as important; dose information, as less so. A substantial amount of concern was expressed about the use of risk comparisons because they may tend to trivialize the issue.

- By far, participants across all three groups thought a coalition of different types of organizations (government, advocacy groups, and non-profits) should implement the campaign.

- The belief that a coalition was needed to counteract a lack of public trust in government and lend credibility to the campaign was expressed far more often by advocates than by public health officials and scientific experts.

- State public health officials thought their departments could play valuable coordinating roles at the state and local levels.

- In terms of federal government participation, there was little preference for which agency(ies) should lead the effort. It became apparent throughout many of the interviews, particularly with advocates, that individuals do not make distinctions between various federal agencies -- for example, the CDC, the NCI, the Department of Energy (DOE), or the Environmental Protection Agency (EPA). Many think of the "government" as an all encompassing entity. When participants did make agency recommendations, the NCI and CDC were the most frequently mentioned.

- Participants thought a variety of materials and resources would be helpful to their organizations: fact sheets, information kits, videos, in-person meetings, conferences and web-based materials. Web-based information was very appealing; videos and in-person meetings, somewhat less so.

APPENDIX A

OMB #0925-0046
Exp. Date: 8/31/00

INTERVIEW GUIDE FOR IN-DEPTH INTERVIEWS ABOUT I-131 EXPOSURE FROM THE NEVADA TEST SITE

November 1999

I. INTRODUCTION (3 MINUTES)

Hello, my name is __________ from Porter Novelli, and I'm calling on behalf of the National Cancer Institute and the Centers for Disease Control and Prevention. These organizations are currently working to develop educational efforts to address health effects that may be related to nuclear fallout from an atomic weapons testing program conducted in Nevada in the 1950s and 1960s. Do you have approximately 30 minutes so that I can talk with you about health issues related to the Nevada nuclear tests?

[IF YES, CONTINUE. OTHERWISE, TRY TO RESCHEDULE FOR ANOTHER DAY AND TIME.]

If it is alright with you, I would like to audio-record this discussion because everything you say is important. All of your comments will be kept confidential, and your responses will never be connected to your name or organization.

IA. ORGANIZATIONAL DEMOGRAPHICS (4 MINUTES)

First of all, I'd like to understand more about your organization.

1. What is your organization's mission and goals?
2. Who or what does your organization represent?
3. Does your organization have membership? Approximately how many members do you have?
4. Does your organization have any other core audiences or stakeholders?
5. How do you typically communicate with your audiences?

II. AWARENESS AND CONCERN (5-10 MINUTES)

1. What nuclear or radiation issues are you involved with or concerned about?

   PROBE for both locations (e.g., Hanford, etc.) as well as different types of radiation.

2. I'd like to talk specifically about the Nevada nuclear bomb tests now. What knowledge do you have about the Nevada tests and their consequences? What about health effects specifically?

   PROBE: Potential cancer-related health effects?
   Non-cancer related effects?

3. Overall, on a scale of 1 to 10 (with 1 meaning not severe at all and 10 meaning very severe), how severe do you think the possible health effects of the Nevada nuclear bomb tests are? (INTERVIEWER NOTE: Collect professional/organizational perspective rather than personal.)

4. How would you rate the severity of these effects in relation to other nuclear or radiation issues that you are concerned about on a scale of 1 to 10? (INTERVIEWER NOTE: Collect professional/organizational perspective rather than personal.)

5. About 100 nuclear bomb tests were carried out in Nevada in the 1950s and 1960s. These tests released different types of radioactive material into the atmosphere. Which of these radioactive materials are you aware of?

   IF AWARE OF MORE THAN ONE MATERIAL: Are you concerned about some of these radioactive substances more than others? Why?

   Before proceeding, I'd like to provide you with some additional background. One of the radioactive materials released from the Nevada tests was Iodine 131, commonly referred to as I-131. As you are probably aware, some epidemiological studies have found an association between exposure to I-131 and the risk of thyroid cancer. In addition, I-131 may also be related to other types of thyroid disease, such as hypothyroidism or an underactive thyroid gland, hyperparathyroidism, a condition in which the parathyroid glands located next to the thyroid become overactive, and noncancerous thyroid growths. While everyone in the United States experienced some exposure to the I-131 fallout, those in areas adjacent to the Nevada Test Site, downwind, and in other areas of the country where wind patterns served to increase fallout were most heavily exposed. These risks may be highest for young children who drank milk and lived in high fallout areas during the time of the tests.

   [INTERVIEWER NOTE: Read high exposure state list only if interview asks about the heavily affected region: Some adjacent states with high county exposure rates are

Colorado, Idaho, Kansas, Minnesota, Missouri, Montana, Nebraska, Nevada, South Dakota, Utah]

In 1997 and 1999, two documents regarding the Nevada tests were released to the public. The National Cancer Institute or NCI released results of a study that assessed U.S. residents' possible exposure to radioactive Iodine-131 fallout during and shortly after the nuclear bomb tests.

In addition, the National Academy of Science's Institute of Medicine or IOM released a review of the NCI's methods and findings. This review also included recommendations on educating the general public about I-131 and advising physicians on how to approach patients who may have questions about I-131.

6. How familiar are you with the NCI and IOM reports, if at all?

7. If FAMILIAR: Do these reports provide your organization with the information you need to communicate with your key audiences about this issue?

   IF YES, PROBE: What information is useful?

   IF NO, PROBE: Why haven't the reports been useful?

8. Aside from what is provided by the NCI and IOM reports, what else does your organization know about this issue?

   PROBE: Where has your organization gotten that information?

      How has that information been useful?

9. What additional information do you need to understand the issues involved with I-131?

10. Does your organization have a position on the issues surrounding I-131 exposure from the Nevada Test Site?

    IF YES: What is that position?

       What specific concerns about I-131 exposure does your organization have?

III. EDUCATIONAL EFFORTS (10-15 minutes)

1. Residents of the U.S. were not uniformly exposed to I-131 fallout. In addition to factors such as geography and residential history, the dose of radiation individuals may have received varies by other factors, like age and dietary patterns.

In your opinion, who needs to be informed about the possible risks of associated with the I-131 emitted by the nuclear tests? Should everyone in the U.S. be the focus, or should information be more targeted to those who may have been more heavily exposed?

[INTERVIEWER NOTE: Read high exposure state list only if interview asks about the heavily affected region: Some adjacent states with high county exposure levels are Colorado, Idaho, Kansas, Minnesota, Missouri, Montana, Nebraska, Nevada, South Dakota, Utah]

2. What information do you think people who were heavily exposed need about I-131?

   IF THEY BELIEVE GENERAL PUBLIC SHOULD BE INFORMED: Which of these types of information do you think the general public should know?

3. Now I'm going to read you a list of different types of educational information that could be provided. Please rate how helpful each would be on a scale from 1 to 5 with 1 meaning not helpful at all and 5 meaning very helpful.

   a. Potential exposure levels based on factors like geography and age
   b. Dose information, an estimate of the amount of radiation actually absorbed by the thyroid)
   c. Risk information about potential health effects
   d. Risk comparisons, which quantify risk levels in various contextual ways to aid understanding
   e. Information about scientific uncertainties surrounding the estimates and associations between cause and effect

4. What do you think would be the most effective way to reach these populations?

   PROBE: Should education be conducted on a national, regional or local level? Why?

5. The IOM report concludes that the available science does NOT warrant routine clinical screening for thyroid cancer in the general population or within subgroups of the population as an intervention strategy. Do you think that the general population or any groups within the population need to be screened? Why or Why not?

   The IOM report suggests that the general public be targeted with educational information about their possible exposure to I-131 from the nuclear bomb test fallout. It also suggests that information be provided to health care providers so they can answer any questions that members of the public may ask them about the fallout and potential health consequences such as thyroid cancer.

6. How effective do you think this approach would be in educating the general public about I-131 fallout from the nuclear tests at the Nevada Test Site? Why?

7. What else, if anything, do you think would need to be done to better educate the general public about the issue of I-131 exposure?

8. Overall, who do you think should implement these efforts? Who should NOT conduct them?

   PROBE: Government agencies, non-profit organizations, or advocacy groups? National, regional, state, or local level?

   IF FEDERAL GOVERNMENT AGENCIES: Which government agencies do you think should implement the efforts? (PROBE: CDC, EPA, NCI, DOE)

   (INTERVIEWER NOTE: If regional, state, or local organizations are suggested, collect information that would be useful for future contact.)

9. Would your organization want to play a role in efforts to educate the public about possible I-131 exposure from nuclear tests conducted at the Nevada Test Site?

   IF YES: Which publics or groups would your organization want to play a role in educating?

   What would that role be?

   How would that role fit in with your organization’s mission, goals, values, and activities?

10. Now, I’m going to read you a list of materials. Please indicate on a scale from 1 to 5 how helpful each would be to your organization (with 1 meaning not helpful at all and 5 meaning very helpful).

    a. Stand-alone materials such as brochures and fact sheets
    b. Information kits
    c. Videos
    d. In-person meetings
    e. Conferences/group meetings
    f. Web-based materials
    g. Would any other types of materials be helpful?

IV. CLOSING (2 MINUTES)

Thank you very much for speaking with me today. NCI and CDC are working together on this project to provide information on this issue to the public and health care providers. If you have any questions or if you would like to receive materials about the Nevada tests and I-131 fallout, please call Kelli Marciel at the National Cancer Institute at 301-496-6667.

H.5 Preliminary findings from Public and Physician Groups

Key Focus Group Findings on I-131 Exposure from the Nevada Test Site

Preliminary Findings from Public & Physician Groups

Prepared by:

Office of Cancer Communications
National Cancer Institute
31 Center Drive MSC-2580
Building 31, Room 10A03
Bethesda, MD 20892-2580

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KEY FOCUS GROUP FINDINGS ON I-131 EXPOSURE FROM THE NEVADA TEST SITE

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I. INTRODUCTION

The National Cancer Institute (NCI) and Centers for Disease Control and Prevention (CDC) are designing a national campaign to implement Institute of Medicine (IOM) recommendations to communicate to Americans the potential health effects of Iodine-131 (I-131) radiation released during atmospheric testing in Nevada during the 1950s and 1960s. To inform this effort, Office of Cancer Communication (OCC) conducted six focus groups during December 1999 with members of the higher-exposure public, the lower-exposure public, and primary care physicians. Primary objectives of this research were:

- To gauge participants' awareness and knowledge of I-131 radiation fallout from the Nevada Test Site (NTS), as well as the potential risk for thyroid cancer and other non-cancerous thyroid conditions resulting from this exposure;

- To determine whether participants perceive themselves or anyone else as being at-risk for health problems resulting from I-131 exposure and, if so, how concerned participants are about such risk;

- To evaluate participants' reactions to IOM recommendations which discourage mass screening for thyroid cancer, but advocate for an educational campaign to communicate to Americans the potential health effects of I-131; and

- To gain a better understanding of the information needs and wants of the general public and health care professionals.

Preliminary findings from the focus groups are presented in this report. These findings will be used to help determine the direction and scope of further research for the campaign.

II. Methodology

Audience Segments

A total of six focus groups were conducted with three audience segments, referred to as the "higher-exposure public," the "lower-exposure public," and "physicians." The higher-exposure public was defined as adults ages 39-64 who had lived in at least one of 18 states exposed to high levels of I-131 for at least 5 years from birth to age 15.[7]

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[7] The higher-exposure and lower exposure public definitions were extracted from NCI's report, "Estimated Exposures and Thyroid Doses Received by the American People from Iodine-131 in Fallout Following Nevada Atmospheric Nuclear Bomb Tests: A Report from the National Cancer Institute" (NIH Pub #97-4264), which outlined the key risk factors due to I-131 exposure. Participants had to be ages 39 to 64 because that is the present age of the individuals who were ages 0 to 15 during the time of the Nevada testing. The 18 states designated as high exposure by the report were: Arkansas, Colorado, Idaho, Illinois, Iowa, Kansas, Minnesota,

The lower-exposure public was defined as adults 34-64 years of age who had NOT lived in one of the 18 higher-exposure states from birth to age 15. Conducting research with both the higher- and lower-exposure public was done to obtain a preliminary sense of how risk status might affect one's awareness, knowledge, and concerns about the Nevada Test Site and I-131 health implications.

Physicians were defined as general practitioners, family physicians, or general internists who had been practicing medicine for at least three years in a high-exposure state. The three-year criterion ensured that physician participants had been in practice long enough to have some chance of seeing patients with radiation issues or health effects, and that they had been practicing in the surrounding area long enough to be familiar with their communities. Research was conducted with primary care physicians, because past research has shown that they are the most trusted source of both health care and health information.

A total of 51 people participated in the focus groups: 33 were members of the higher-exposure or lower-exposure public, and 18 were physicians. The six focus groups were structured as follows:

Location	Date and Time	Audience Segment	Number of Participants
Philadelphia, PA	December 7, 1999 6:00-7:30 PM	Lower-exposure public	9
Philadelphia, PA	December 7, 1999 8:00-9:30 PM	Lower-exposure public	7
Omaha, NE	December 13, 1999 5:30-7:00 PM	Higher-exposure public	9
Omaha, NE	December 13, 1999 7:30-9:00 PM	Physicians	9
Burlington, VT	December 14, 1999 5:30-7:00 PM	Higher-exposure public	8
Burlington, VT	December 14, 1999 7:30-9:00 PM	Physicians	9

Focus Group Sites

The higher-exposure public and physicians groups were conducted in two states exposed to higher levels of I-131 radiation. Omaha, NE, was chosen because of its close proximity to the Nevada Test Site, and Burlington, VT, was included because it

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Missouri, Montana, Nebraska, Nevada, North Dakota, Oklahoma, South Dakota, Utah, Vermont, Wisconsin, and Wyoming.

is farther away from the site. These locations were selected to provide an initial reading of whether geographic proximity to the Nevada Test Site would affect focus group responses, particularly perceived risk to health problems due to I-131 exposure. The lower-exposure public groups were held in Philadelphia, PA, a lower-exposure state.

Participant Recruiting Criteria

Higher-exposure and lower-exposure individuals were recruited in advance of the focus groups. The screening questionnaire was designed to separate out people with a personal history of thyroid cancer or disease, individuals having an immediate family member with a history of thyroid disease, or individuals who self-reported that they were familiar with the issue of radioactive fallout from nuclear testing. The reason for excluding these individuals was the desire to talk with people for whom the I-131 issue is not already salient because of personal knowledge or experience. Clearly, any information campaign which is developed will have to address those who are already concerned about the issue, but it will also need to address the concerns and information needs of a potentially much larger number of people who will become aware (through the campaign) they may have a health risk due to I-131 exposure. It is this latter group – those not already knowledgeable or savvy about their potential risk – that the focus groups sought to speak with[8].

In addition to the above criteria, the screening criteria ensured that the groups would contain a mix of women and men, a mix of races, and participants whose educational levels ranged from a high school graduate through college graduate. Copies of the recruitment screeners for the public and physician groups can be found in Appendix A.

	Number of Participants (Higher-exposure)	**Number of Participants (Lower-exposure)**	**Number of Participants (TOTAL)**
Gender			
Female	8	9	17
Male	9	7	16
Race or Ethnicity			
White	11	11	22
Black	4	5	9
American Indian	2	0	2
Education			
High school degree	3	5	8
Some college or technical school	8	8	16

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[8] It should be noted that earlier research, in the form of in-depth interviews, was conducted in November 1999 with advocates, scientific experts, and public health experts to obtain the viewpoint of those more cognizant of the I-131 health issue.

College degree	5	3	8
Not specified	1	0	1

Topic Guide Development

The moderator's guides for the general public and physicians' groups were designed to: a) measure initial awareness, knowledge and concern about the Nevada nuclear testing in the 1950s and 1960s; b) assess reactions to information presented during the groups about the I-131 exposure and its possible relationship to thyroid cancer and other non-cancerous thyroid disease; and c) gather opinions about the IOM screening recommendations as well as suggestions about implementing a communication campaign.

After participants were asked about their general awareness, knowledge and concern, they were shown a newspaper article from the *Chicago Sun-Times* dated August 2, 1997, along with a fact sheet and map illustrating exposure patterns across the U.S. They were then asked questions to elicit their reaction to the information. The newspaper article was selected from a sample of press coverage appearing after the release of the NCI report, "Estimated Exposures and Thyroid Doses Received by the American Public from Iodine-131 in Fallout Following Nevada Atmospheric Nuclear Bomb Tests." Potential articles were judged on their objectivity in communicating basic facts about the I-131 exposure and its potential relationship to thyroid cancer.

Each focus group was two hours in length and was conducted by a male moderator in his forties. Participants were paid for their participation. A copy of the topic guide, as well as the stimulus materials, can be found in Appendices B and C.

Limitations

It should be noted that focus groups are a qualitative research technique which provide useful, detailed insights into the target audience's perceptions and motivations. Findings from qualitative research, however, cannot be projected to a larger audience. Rather, they are intended to provide guidance and direction in determining the best approach for communicating with key audiences about cancer risk research. In addition, findings from focus groups should be considered preliminary, laying the groundwork for further research with key target audiences.

III. KEY FINDINGS

The remainder of this report presents the main findings from the focus groups. Findings related to the lower-exposure public, the higher-exposure public, and the physicians' groups are presented separately in order to give the reader an overall profile of each audience. However, it should be noted that there were many similarities across the three audience segments, particularly between the lower- and higher-exposure groups.

A. Lower-Exposure Public

Awareness, Knowledge & Concern **Before** Reading Newspaper Article & Fact Sheet

- Participants were concerned about a broad range of environmental concerns, including noise and water pollution, trash disposal, power plants, power lines, exhaust from vehicles, and "radiation" from computers.

- Participants were generally aware or had some vague recollection of the tests conducted at the Nevada Test site. The tests in Nevada were brought up by a few participants and then seemed to "ring a bell" for others who indicated a vague awareness of them.

- Several participants in each group knew the tests were conducted around the time of the 1950s or 1960s, but one thought tests had continued throughout the 1980s.

- Although participants were aware of the Nevada Test Site, they had little specific information about where their knowledge came from. No one knew about the NCI or IOM reports, or any other government reports on the issue. A couple of participants recalled seeing a movie about the Nevada Test Site called "Black Rain." Other participants mentioned television, and one got more specific and mentioned documentaries on programs like *Nova* and *60 Minutes*.

- None of the participants had specific knowledge of different types of radiation or radiation-induced health effects. Most expressed health concerns about "deformities" or "genetic alterations." One participant said the tests left people "crippled." Another said it could cause skin problems similar to those that resulted from "Agent Orange." Participants were particularly concerned about radiation-related illnesses being "passed through the genes."

- Participants felt little or no concern that they would suffer any negative health effects from the Nevada tests. Most did not consider themselves to be at risk and felt it was more of a concern for other people. One participant said, "If I lived out there I'd be concerned." Another said it was a problem for "those military people who were there at the time."

Concerns & Perceptions of Risk **After** Reading Newspaper Article & Fact Sheet

- Participants were provided with a newspaper article and additional facts regarding the association between the Nevada tests and thyroid cancer, risk factors that increase the likelihood of exposure, examples of higher and lower exposure areas, and possible associations between I-131 and two other types of non-cancerous thyroid disease: hypothyroidism and hyperparathyroidism. Questions were then asked to gauge their level of concern, perceptions of risk, and opinions about actions that should be taken.

- The newspaper article and fact sheet raised levels of suspicion among many respondents. When asked about their initial reaction to the materials, many made comments like “there must be a big lawsuit coming” or referred to the newspaper article as a “scare tactic” no different from what they usually see in the news.

- Responses to the actual content of the material varied and included responses such as “frightening,” surprise about the fact that “everyone was exposed” or the problem was so “widespread” and feelings of “sadness because children were affected.” Others said the information was just “another thing to worry about.”

- Even after reading the newspaper article and fact sheet, participants still did not feel a high level of personal concern about their risk of thyroid cancer or other non-cancerous thyroid disease from the Nevada Test Site 1-131 exposure. A few said there were more important health risks to worry about like stroke and heart attack. One respondent who stated that she has hypothyroidism said the information made her wonder about the possible connection to the Nevada Site, but even she did not seem overly concerned. Another said that the radiation had a “short half life” and no longer posed a risk because it was “long gone.”

- When asked who is most at risk, participants thought the exposure posed a significant problem primarily to people living closer to the site. One said it was just not “plausible” that the radiation could cause problems in people thousands of miles away, and the rest of the group agreed. One person emphasized that she was still concerned about “other people being sacrificed.”

- Few participants seemed to make the connection that *they* are the people who were children at the time of the tests and therefore at some level of risk. The length of time that has passed since the tests occurred and the aging of those who may be at greater risk seemed to make this a difficult concept for people to comprehend.

Actions Needed

- While some participants said they would like more information about I-131 exposure from the Nevada Tests, few seemed to want it out of concern for their own health. Most wanted more information in order to clear up what they perceived as discrepancies in the newspaper article. More participants in the first group wanted additional information than those in the second group. A few participants said they didn’t want more information because the issue “does not affect me” or “it is someone else’s problem.” One participant said it was like “AIDS” in the sense that “sometimes you just don’t want to know if you have a problem or not.”

- Among the few who wanted more information, interest focused primarily on more conclusive information on the association between I-131 and development of thyroid cancer, why the study took 14 years, and why it was still going to take more time to know whether people are “going to get cancer from the tests or not.”

- In general, thyroid screening and the false positives associated with screening were difficult concepts for people to understand.

- Reactions to the IOM recommendation not to conduct screening were mixed. Reasons for not supporting the IOM recommendation included statements like “If there is anything the government can do, it should be done” or “It sounds like the government is copping out.” Participants who supported screening stressed the individual’s right to choose, rather than concern about whether they themselves should (or might elect to) be screened.

- Proponents of the IOM recommendation expressed other views. One participant said screening would just cause a “panic.” Another suggested screening in “limited areas.” And one, who inaccurately thought cancer could be detected by a blood test, kept asserting that blood tests should be conducted because they would not cause anyone any harm.

- Regardless of whether or not they agreed with the IOM screening recommendation, many thought each individual should have the final say in whether or not to be screened.

Educational Effort: Who Should Conduct It?

- Most participants thought government should be involved in an educational effort because the government was “responsible” for what happened. Many individuals thought the American Cancer Society would be appropriate. Other groups mentioned included the Red Cross, Greenpeace, local and city health centers and other medical groups. A few thought a combination of government and non-government groups would be best.

- When asked what organizations should not be involved, some said the federal government because it “caused the problem” and therefore would not be trusted. A few said that only the part of government which caused the problem (i.e., “the military”) should not be involved. One participant expressed distrust of the Environmental Protection Agency (EPA) and said that agency should not take part.

- When probed about the appropriateness of the National Cancer Institute's involvement in an educational effort, participants said they had never heard of the institute. One participant said he thought the National Cancer Institute might be part of the National Institutes of Health, which may be associated with Johns Hopkins. Another participant then said the National Institutes of Health was a "research organization" that might be affiliated with that "group out of Atlanta," prompting another respondent to mention the "CDC."

Ethical Considerations

- Participants were generally divided over whether there was good reason for conducting the Nevada bomb tests during the 1950s and 1960s. Some said the tests were necessary to ensure the safety of Americans during the Cold War. Others said that it is "never right to sacrifice anyone" and that the nuclear testing "should not have been done because of the problems it caused." One participant also mentioned that the public could have been better protected from the radiation fallout at the time of the nuclear testing.

- Several participants expressed the opinion that "the government" (no agency specified) will always keep secrets and will never disclose the "full story" about nuclear testing pertaining to the past, present, or future.

- A couple of participants said that, in addition to being informed about the Nevada bomb testing and its resultant health effects, they would want assurance that nuclear testing would never happen again. Most of the other participants, however, took the viewpoint that the nuclear testing was over and that nothing could be done about it. In the words of one participant, "You can't right a wrong."

B. Higher-Exposure Public

Awareness, Knowledge & Concern **Before** Reading Article & Fact Sheet

- Participants expressed a broad range of general concerns about environmental hazards, from air and water pollution to lead paint, but provided few specifics. One participant said she was worried about "carcinogens...that are just everywhere nowadays."

- Participants had little knowledge about nuclear testing in general or the Nevada Test Site in particular. A few participants could name locations in the U.S. where nuclear testing has been conducted, including "the Pacific," "the West," and the state of Nevada. A couple of these participants thought testing was still going on in these locations. Only a few recalled specific dates of the nuclear testing, expressing a vague recollection that "there was some nuclear testing that went on in the 1950s and 1960s." Participants had no specific knowledge of different types of radiation or radiation-induced health effects from the

Nevada Test Site. Several expressed the view that the government has kept secrets about nuclear testing.

- Most participants could not recall the source of their information about the Nevada nuclear tests. A few vaguely recalled hearing something in "the news" or through "a documentary." One participant, for example, recalled seeing a program on the History Channel that "had something to do with radiation exposure and military men." Another said she thought the Discovery Channel might have run a documentary about the issue in the not too distant past. Another participant remembered some media coverage happening "when people were invited to watch some above-ground testing with special glasses." Although she couldn't recall the specifics, she characterized the event as "a real big deal."

- Participants initially expressed little concern about suffering any negative health effects from the Nevada tests. One participant, describing the tests as "underground tests, " said he hoped the people conducting the tests now were protecting the environment to avoid any "contamination of the atmosphere or water supply." Another participant responded by saying it was more important to be concerned about the effects of such tests on people and animals than the environment. Another emphasized that people should worry more about the present than the past. One Vermont participant expressed little concern because of living far away from the Nevada Test Site (Note: this perception later changed when participants saw a map illustrating that radiation fallout had been carried from the West to the East).

Perceptions of Personal Risks & Concerns **After** Reading Article and Fact Sheet

- Prior to seeing the article and factsheet, participants were asked whether they remembered hearing anything in the news about two years ago. None remembered anything too specific. A couple of participants said they remembered hearing something, but they either could not recount the details or mentioned other events such as the nuclear testing in India and Pakistan.

- The newspaper article and fact sheet initially evoked an emotional reaction from some participants. Some Nebraska and Vermont participants said they were "shocked" and that the information made them feel "unsafe." However, these emotional reactions dissipated quickly after the first few minutes of conversation.

- When asked who in the population is most at risk, most participants in Nebraska and Vermont immediately noted that people living in their own geographical areas were exposed, often referring to the color map of exposure levels. Comments like, "We are in the red" or "It is right over us" were fairly frequent during the course of the groups. Few participants, however, fully comprehended that they might also be at risk because they were children at the time of testing and may have consumed contaminated milk.

- Despite some initial surprise over seeing the “red spots,” personal concern about developing cancer or non-cancerous thyroid disease was minimal. Most participants said they were not too concerned because:

  - They cannot change the past
  - They need to focus on the future
  - They question the credibility of some of the information in the article
  - They need more information to determine their true risk
  - It would be difficult to prove that any thyroid occurrence is actually caused by I- 131 exposure
  - They have other more immediate health concerns such as heart disease, high blood pressure, prostate cancer, and breast cancer
  - They have other (non-health) concerns such as neighborhood violence
  - Thyroid problems have not surfaced thus far after routine checkups
  - The chances of getting thyroid cancer are small

  As one participant explained, “I’m sure we probably read about these nuclear tests at one time but then forgot about them. It’s not the ‘here and now.’ The only reason we are thinking about it now is because you are making us think about it.”

- The issue of whether or not their children or spouses could be affected resonated more with participants than their own personal risk. A few asked questions about whether or not the effects of the exposure could be “passed down.” Another said, “If we were affected, that means someone in our family could be affected. How are offspring affected?” One person was worried that the exposure could have caused “a flaw in the[genetic] system that will keep getting passed down.” Another participant, still misunderstanding the time period of exposure, said she was glad her children don’t drink milk.

- A couple of participants said they would worry more about getting other types of cancers from the tests as opposed to developing thyroid problems. One participant asked, “Why does all this focus on the thyroid?” Another participant said he thought skin and bone cancer might be more likely problems based on what happened to the people who were bombed in Japan.

Actions Needed

- Throughout the discussions, participants raised more questions than personal concerns about the tests. Questions that have not already been mentioned include:

  - Were all the tests underground?
  - How long does the I-131 fallout last? What is the half-life?

  - -- Can radiation sink into the ground? If so, can it rise back above the surface of the ground?
  - -- Was the information on the factsheet compiled during the time of the testing or now?
  - -- Weren't the tests conducted in the desert so they wouldn't harm any people, plants or animals?
- The majority of participants agreed that a public information campaign would be appropriate. One participant said, "The more people know the better." However, a couple individuals in the groups noted that it would be important to conduct the campaign carefully so people don't panic needlessly.

- The majority of participants were not supportive of the IOM recommendation against screening. Most thought people should have the option to decide whether or not they needed to be screened. As one participant put it, "If they think it is relevant for them and they want to have it done, this should override the recommendation."

- Several participants requested more information about how to get tested for thyroid disease, including where to go and what the test involves. One respondent suggested providing information about how to check one's own thyroid gland for lumps or problems.

- A couple of participants were concerned that mandatory screening might cause a panic. This prompted one participant to suggest a campaign to inform doctors, so doctors could then decide whether or not a patient needed screening. A few others agreed with this recommendation.

- A few participants focused on compensation issues related to screening. One thought the government needed to pay for the screening, particularly for people with no insurance, since it was the government that caused the problem. Another participant questioned the motive behind the IOM recommendation, saying insurance companies and medical doctors were probably trying to get out of paying for the screening. One participant said those who were hurt should get " a big check" from the government and then laughed.

- A few participants thought that additional research was needed to develop a less-invasive screening test for thyroid cancer so more people can get screened without being harmed. Several also wanted more conclusive evidence showing that I-131 does cause health problems.

<u>Educational Effort: Who Should Conduct It?</u>

- Participants had few suggestions about who should conduct an educational effort. When probed, a few said the federal government should head the effort since it was responsible for the exposure; several specifically said the Public Health Service and Centers for Disease Control and Prevention. In addition, a few participants indicated that their local governments should be responsible. Another participant said that "public health organizations that do things like vaccines" would be appropriate. Other organizations mentioned were Blue Cross, EPA, and the American Cancer Society.

- A few participants thought that people would be best educated by their own personal doctor. One participant suggested using an article in a medical society journal to educate physicians.

- When asked if the federal government needed to stay out of the effort, only a few participants commented. One said yes because "they lied once and they'll do it again." Another participant thought it was okay for the government to conduct the effort "because the people in government today are not the same people as 40 years ago." Some participants felt that local government would be better, explaining that local government is more personal and less likely to withhold information.

<u>Ethical Considerations</u>:

- Ethical issues related to the Cold War were brought up at two different points during the focus groups -- at the very beginning when participants were asked for their concerns about consequences from the Nevada tests and then again after reading the article. A few participants said testing needed to be conducted for the U.S. to maintain the "balance of power."

- Only a couple of individuals commented when asked why it was or why it was not important to educate the public about what happened. One participant said it was important because people were "exposed without their knowledge." Another participant was unsure whether an educational effort was justified because "there was no real thyroid cancer outbreak."

C. Primary Care Physicians

<u>Awareness, Knowledge & Concern **Before** Reading Article & Fact Sheet</u>

- In general, physicians had vague memories but little actual knowledge about nuclear weapons tests conducted in the United States. A couple of participants said they had heard something about the issue in the last few years, but could not provide specifics. One participant said he remembered hearing that the government admitted to exposing people to radiation from some tests that were conducted in the 1950s and 1960s. Another said the government also admitted that workers at a test site in the 1950s were exposed to radiation. In addition, one participant recalled that soldiers were affected by tests conducted "when the atomic bombs were developed." Another physician recounted his father warning him as a child to refrain from eating snow, though he did not understand why. Only one participant in Vermont knew specific details about the Nevada testing, recalling that fallout resulted from tests conducted around 1946-1955, that one type of fallout was strontium 90, and that weather patterns carried fallout across the US.

- Participants mentioned the western United States, Nevada, Utah and New Mexico when asked about nuclear testing locations.

- Most participants could provide no details about specific types of radiation emitted from the tests or about specific health or non-health related consequences.

- Participants could not recall where they received information about the Nevada nuclear tests. One participant thought there might have been a program about the issue on the Discovery Channel at one time. Another recalled seeing a person on television who recounted watching atomic bomb tests and suffering health effects afterward.

- Participants expressed little concern about their patients having negative health consequences as a result of the Nevada Test Site exposures. One participant said, “I have no day-to-day concerns. It was many years ago.” Another participant thought that any serious consequences “would have shown up by now.”

- Only a few participants recalled having any patients ask them about negative health effects from exposure to nuclear fallout. One physician said that only a few of his patients have expressed concern, and he told them how to “watch for lumps on their thyroid and other symptoms.” Another participant said he had one patient with leukemia ask him if it might be related to the tests, but he couldn’t give the patient an answer. Another mentioned a patient with a brain tumor who once asked about the possible connection to radiation fallout. Other participants said their patients are concerned about and ask questions about cancer, but they don’t tend to relate it to the environment.

- Participants offered some explanations for why their patients are not concerned about radiation from the Nevada Test Site. One participant said patients are more concerned about negative health effects from nuclear power plants or disposal sites. A couple other participants said cellular telephones have recently become a big issue. Another physician noted that a majority of the population of Omaha, Nebraska, moved there from someplace else, thereby diluting the level of concern. Another said, “The testing was so long ago that people have forgotten about it; that’s what the government wants.”

Awareness, Knowledge & Concern **After** Reading Article & Fact Sheet

- When asked about their initial reaction to the news article and fact sheet, participants responded with questions such as:
    - How did they determine radiation exposure for various areas of the country?
    - How was the data on dosage collected?
    - How can there be areas in the Central US where there was no exposure in between areas in the West and East where there was high exposure?
    - Do thyroid cancer rates map out similar to the radiation dosages displayed on the factsheet?
    - What type of thyroid cancer might result from exposure to I-131?
    - Is there any scientific evidence that shows a direct link between I-131 exposure and thyroid diseases of any kind?
    - What's happening in Canada?

- Physicians repeatedly expressed a desire for sound scientific data about radiation dosage and links to negative health effects. Some even questioned the validity of the data that currently exists. One participant said he remembered a talk given by a lecturer at the National Cancer Institute who said the NCI exposure data was inaccurate and excluded some people who had higher-exposure because they drank milk from cattle. Another participant said she assumed any exposure information provided by the government would be wrong.

- The majority of participants said they would only be concerned for their patients if they received appropriate risk information indicating that there is a substantial increase in thyroid cancer. One participant said physicians would need to know if there was some type of evidence pointing to a "10% to 15% increase in thyroid cancer." Another asked, "Is this a hypothetical or a *true* risk?"

- The majority of participants agreed that they would not change the way they practice medicine based on the information they had just received and the ensuing discussion. Reasons for not changing their practice were as follows:
    - Thyroid cancer is rare (particularly in Nebraska and Vermont). One participant said she has only seen one case of thyroid cancer in twelve years.
    - Thyroid cancer is very survivable.
    - Most patients have other, more pressing health concerns such as breast cancer.
    - People are already "dying off from something else" by the time they get thyroid cancer.
    - The issue of I-131 has "fallen off the radar screen."

- -- There is not enough scientific evidence to warrant a high degree of concern.
- -- They do not want to unnecessarily alarm their patients with information that, to date is scientifically unfounded.
- -- They already routinely check for cancerous and non-cancerous thyroid problems during regular physical exams.

Actions Needed

- When asked what should be done to address I-131 exposure from the Nevada bomb testing, participants mentioned that the environment (air, water, and soil) should be tested and that nuclear testing should be permanently banned.

- Most participants thought an educational campaign targeting the public would be unnecessary and would only serve to cause undue public alarm. One participant said, “Too many things have been done in medicine before all the facts are in; we often put education before science.” Others agreed that nothing should be done until a meaningful increase in actual risk is demonstrated. A couple participants said a public education campaign would cause “a mess.” Another stated that physicians are sometimes pressured by media coverage to do things just to put their patients concerns to rest.

- Nearly all participants agreed that a medical education campaign targeted at physicians would not be beneficial because, again, the information would not change the way they practice medicine. One participant thought some very basic information provided to physicians in higher-exposure areas may be useful just to put them “on alert.”

- All participants agreed with the IOM recommendation that screening at this time is unwarranted. All agreed that thyroid cancer is rare, very survivable and that false positives would result in more harm than good being done to patients. A couple of participants said they were also uncertain about the real benefits associated with early detection of thyroid cancer. One participant stated that checking everyone’s thyroid would be a “logistical public health nightmare.”

Educational Effort: Who Should Conduct It?

- If any educational effort were to be conducted, some participants thought the National Cancer Institute or the National Institute of Health would be the most appropriate sponsor because they are science-oriented. Others mentioned medical societies like the American Medical Association or their professional membership organizations such as the American Association of Family Physicians (AAFP).

- A couple participants expressed concerns about sponsorship by advocacy organizations because they are not research-based and could be motivated by self-interests. Some participants said the American Cancer Society should not be involved for this reason. When the Vermont participants were asked about the Society of Physicians for Responsible Medicine, all of them laughed and immediately discredited the group as being too politically extreme.

Ethical Considerations

- Ethical issues regarding why the nuclear tests were conducted and about individuals' right to know triggered little interest among physician participants.
- Most physicians thought it would be unethical to launch any type of educational effort before there is scientific data to support the necessity of such an effort. One participant said, "It would not be a public service announcement, it would be a public disservice announcement."

APPENDICES

A. Participant Screening Questionnaires
B. Moderator's Topic Guides

Appendix A

OMB# 0925-0046
Exp. Date 8/31/00

Screener for Health Focus Groups with Public

Name: ____

Street Address: ____

City: ______________________ **Zip Code**: __________ ________

Home Phone: ______________ **Work Phone**: __________________

	City	Group	Facility	Date	Time
☐	Philadelphia, PA	Lower risk	Focus Pointe	Dec. 7	6:00 PM
☐	Philadelphia, PA	Lower risk	Focus Pointe	Dec. 7	8:00 PM
☐	Omaha, NE	Higher risk	Midwest Survey	Dec. 13	5:30 PM
☐	Burlington, VT	Higher risk	Action Research	Dec. 14	5:30 PM

INTRODUCTION

Hello, my name is ___________, and I’m calling on behalf of a national, non-profit organization concerned about the health and well-being of Americans. We’re talking to people to learn their opinions about some important environmental and health issues. I want to assure you that we’re not selling anything and that your responses will be kept confidential.

May I speak to an adult in the household? (ONCE SPEAKING TO ADULT, REPEAT INTRODUCTION IF NECESSARY AND ASK:) Would you be willing to answer a few questions?

☐	Yes	(CONTINUE)
☐	No	(THANK AND TERMINATE)

1. What is your exact age? (RECORD EXACT RESPONSE AND CODE IN APPROPRIATE AGE SUBGROUP.)

   Age: ______________

☐	Younger than 39	(THANK AND TERMINATE)
☐	39-47	(RECRUIT 4)
☐	48-56	(RECRUIT 4)
☐	57-64	(RECRUIT 4)
☐	65 or older	(THANK AND TERMINATE)

2. I'm going to read you a list of statements. For each one, please tell me whether you agree, neither agree nor disagree, or disagree with that statement. (READ.)

	Agree	**Neither Agree nor Disagree**	**Disagree**	**Don't Know/ Refused**
To protect the environment, people need to make big changes in the way they live.	1 (CONTINUE)	2 (CONTINUE)	3 (CONTINUE)	9 (CONTINUE)
I am concerned about the environment because of the potential harm to myself and my family.	1 (CONTINUE)	2 (CONTINUE)	3 (CONTINUE)	9 (CONTINUE)

3. Different areas of the country are more or less concerned about environmental issues. Thus, where we have lived can affect our opinions about the environment.

   a. I'm going to read you a list of states, and please tell me if you lived in any of these states between the time you were born and age 15. (READ STATES IN COLUMN "a" AND CHECK ANY STATES WHERE RESPONDENT LIVED BETWEEN THE AGES OF 0-15. MULTIPLE RESPONSES ACCEPTED.

   IF NO CHECKS ARE MADE IN COLUMN "a," CLASSIFY AS "LOWER RISK" AND SKIP TO Q3.

   IF ONE ORE MORE STATES ARE CHECKED, ASK Q2b FOR EACH STATE MENTIONED.)

   b. Did you live in [STATE] for at least 5 years? (USE COLUMN "b" TO CHECK ANY STATE(S) WHERE RESPONDENT LIVED AT LEAST 5 YEARS.

   CLASSIFY AS "HIGHER RISK" ANY RESPONDENT WHO HAS LIVED IN AT LEAST ONE OF THE LISTED STATES FOR AT LEAST 5 YEARS BETWEEN THE AGES OF 0-15.)

	a. Lived in state from age 0-15	**b. At least 5 years (ASK HIGHER RISK ONLY)**
(1) Arkansas	☐	☐
(2) Colorado	☐	☐
(3) Idaho	☐	☐
(4) Illinois	☐	☐
(5) Iowa	☐	☐
(6) Kansas	☐	☐

(7) Minnesota	☐	☐
(8) Missouri	☐	☐
(9) Montana	☐	☐
(10) Nebraska	☐	☐
(11) Nevada	☐	☐
(12) North Dakota	☐	☐
(13) Oklahoma	☐	☐
(14) South Dakota	☐	☐
(15) Utah	☐	☐
(16) Vermont	☐	☐
(17) Wisconsin	☐	☐
(18) Wyoming	☐	☐

4. Currently there are many issues about the environment under public debate, and different people are more or less familiar with them. I'm going to read you a list of specific environmental issues. For each one, please tell me whether you are "familiar," "neither familiar nor unfamiliar," or "not at all familiar" with that issue.

	Familiar	**Neither Familiar Nor Unfamiliar**	**Not at All Familiar**	**Don't Know/ Refused**
Liquid waste from chemical plants.	1 (CONTINUE)	2 (CONTINUE)	3 (CONTINUE)	9 (CONTINUE)
Residual pesticides in the water supply.	1 (CONTINUE)	2 (CONTINUE)	3 (CONTINUE)	9 (CONTINUE)
Radioactive fallout from nuclear testing.	1 (THANK AND TERMINATE)	2 (CONTINUE)	3 (CONTINUE)	9 (CONTINUE)
Toxic air emissions from coal plants used to generate electricity.	1 (CONTINUE)	2 (CONTINUE)	3 (CONTINUE)	9 (CONTINUE)

5. Since this study is also about health, I'm going to ask you some health related questions. Have you have ever been diagnosed with any of the following diseases … (READ. DO **NOT** RECRUIT PARTICIPANTS WHO HAVE HAD THYROID DISEASE OR CANCER.)

☐ Respiratory disease	(CONTINUE)
☐ Heart disease	(CONTINUE)
☐ Thyroid disease	(THANK AND TERMINATE)
☐ Cancer of any kind	(THANK AND TERMINATE)

6. Have any of your immediate family members, that is, your parents, brothers or sisters, partner, or children, ever been diagnosed with any of the following diseases … (READ. DO **NOT** RECRUIT PARTICIPANTS WHO HAVE HAD IMMEDIATE FAMILY MEMBER DIAGNOSED WITH THYROID DISEASE.)

   ☐ Respiratory disease (CONTINUE)
   ☐ Heart disease (CONTINUE)
   ☐ Thyroid disease of any kind, including thyroid cancer (THANK AND TERMINATE)
   ☐ Cancer of any other kind (CONTINUE)

7. I have a few more questions to ask for classification purposes. Which of the following best describes your race? (READ. RECRUIT 8 WHITE AND 4 NON-WHITE. NEBRASKA FACILITY MUST RECRUIT AT LEAST 2 AMERICAN INDIAN/ALASKA NATIVE.)

   ☐ White
   ☐ Black or African American
   ☐ Hispanic or Latino
   ☐ Asian
   ☐ Native Hawaiian/Other Pacific Islander
   ☐ American Indian /Alaska Native

8. Which of the following best describes your highest level of education? (READ.)

☐ Less than high school degree	(THANK AND TERMINATE)
☐ High school degree	(RECRUIT AT LEAST 3)
☐ Some college/technical school/associates degree	(RECRUIT AT LEAST 3)
☐ 4-year college degree	(RECRUIT NO MORE THAN 3)
☐ Some graduate school or more	(THANK AND TERMINATE)

9. (NOTE GENDER:)

☐ Male (RECRUIT 6)
☐ Female (RECRUIT 6)

10. Have you ever been employed in any of the following settings?

	Yes	No	Don't Know/Refused
Medical or health setting	(THANK AND TERMINATE)	(CONTINUE)	(THANK AND TERMINATE)
Advertising or market research setting	(THANK AND TERMINATE)	(CONTINUE)	(THANK AND TERMINATE)

11. Have you ever participated in a focus group discussion or been paid to be part of a discussion group?

☐ Yes (CONTINUE)
☐ No (SKIP TO INVITATION)

12. How recently did you participate in the focus group?

☐ 6 months ago or less (THANK AND TERMINATE)
☐ More than 6 months ago (CONTINUE)

13. What did you talk about during the groups? (RECORD VERBATIM. DO NOT RECRUIT IF TOPICS WERE ABOUT THE ENVIRONMENT, ATOMIC BOMBS, NUCLEAR RADIATION, THYROID DISEASE, OR CANCER.)

____

____

____

INVITATION

Thank you for answering our questions. We'd like to invite you to take part in a focus group discussion of 8-10 people. We're talking to adults across the U.S. so that we can better plan for a national program focusing on the environment and the health of Americans. Your participation is very important to us. The focus group will take place [FACILITY, DATE, TIME] and will last about 2 hours. Participants will be paid $_____ in cash for their time to take part. We'll also serve refreshments. Will you take part?

☐ Yes (CONTINUE)
☐ No (THANK AND TERMINATE)

Thanks for accepting our invitation. For contact purposes, may I get your name, address, and daytime and evening phone numbers? (RECORD INFORMATION ON FIRST PAGE)

We will send you a packet with a confirmation letter three to five days before the focus group is held. It will include directions to the location where the discussion will take place. It is very important that you arrive on time. If you need glasses for reading, please bring them to the discussion. If you have any questions or find out that you cannot attend the focus group, please call ___________ at __________ so that we can find someone to take your place. Thank you for agreeing to take part in our study. We look forward to meeting you. Goodbye.

(NOTE TO RECRUITER: If respondents have any questions or concerns about the focus group topic, please contact Memi Miscally at Porter Novelli at 202-973-5845. Do NOT give her name to respondents.)

Recruited by: ______________________________ **Date**: _______________________

Confirmed by: _____________________________ **Date**: _______________________

OMB# 0925-0046
Exp. Date 8/31/00

Screener for Health Focus Groups with Physicians

Name: ____

Street Address: ______________________________________

City: ______________________ **Zip Code:** __________________

Home Phone: _______________ **Work Phone:** __________________

	City	Group	Facility	Date	Time
☐	Omaha, NE	Physicians	Midwest Survey	Dec. 13	7:30 PM
☐	Burlington, VT	Physicians	Action Research	Dec. 14	7:30 PM

INTRODUCTION

Hello, my name is ___________, and I'm calling on behalf of a national, non-profit organization concerned about the health and well-being of Americans. We're talking to physicians to learn their opinions about some important health issues. I want to assure you that we're not selling anything and that your responses will be kept confidential. May I speak to a physician? (ONCE SPEAKING TO PHYSICIAN, REPEAT INTRODUCTION IF NECESSARY AND ASK:) Would you be willing to answer a few questions?

☐ Yes (CONTINUE)
☐ No (THANK AND TERMINATE)

1 Which of the following best describes the kind of medicine you practice? (READ.)

a. General practice (CONTINUE)
b. Family practice (CONTINUE)
c. General internist (CONTINUE)
d. Other (THANK AND TERMINATE)

2. Are you a practicing physician—that is, do you see patients on a regular basis?

a. Yes (CONTINUE)
b. No (THANK AND TERMINATE)

3. Which of the following best describes how old the majority of your patients are? Are they … (READ.)

    a. Younger than 18 (THANK AND TERMINATE)
    b. 18-64 (CONTINUE)
    c. 65 or older (THANK AND TERMINATE)

4. Do you see approximately equal numbers of males and females?

    a. Yes (CONTINUE)
    b. No (THANK AND TERMINATE)

5. How many years have you been practicing medicine?

    a. Less than 5 years (THANK AND TERMINATE)
    b. 5 years or more (CONTINUE)

6. How long have you been practicing in the state of Nebraska/Vermont?

    a. Less than 3 years (THANK AND TERMINATE)
    b. 3 years or more (CONTINUE)

7. Are you employed full-time by a managed care company such as Kaiser Permanente or Aetna?

    a. Yes (RECRUIT NO MORE THAN 2)
    b. No (CONTINUE)

8. Have you ever been employed in an advertising or market research setting?

    a. Yes (THANK AND TERMINATE)
    b. No (CONTINUE)

9. Have you ever participated in a focus group discussion or been paid to be part of a discussion group?

☐ Yes (CONTINUE)
☐ No (SKIP TO INVITATION)

10. How recently did you participate in the focus group?

☐ 6 months ago or less (THANK AND TERMINATE)
☐ More than 6 months ago (CONTINUE)

11. What did you talk about during the groups? (RECORD VERBATIM. DO NOT RECRUIT IF TOPICS WERE ABOUT THE ENVIRONMENT, ATOMIC BOMBS, NUCLEAR RADIATION, THYROID DISEASE, OR CANCER.)

    ____

    ____

    ____

INVITATION

Thank you for answering our questions. We'd like to invite you to take part in a focus group discussion of 8-10 people. We're talking to physicians across the U.S. so that we can better plan for a national program focusing on the health of Americans. Your participation is very important to us. The focus group will take place [FACILITY, DATE, TIME] and will last about 2 hours. Participants will be paid $_____ in cash for their time to take part. We'll also serve refreshments. Will you take part?

☐ Yes (CONTINUE)
☐ No (THANK AND TERMINATE)

Thanks for accepting our invitation. For contact purposes, may I get your name, address, and daytime and evening phone numbers? (RECORD INFORMATION ON FIRST PAGE)

We will send you a packet with a confirmation letter three to five days before the focus group is held. It will include directions to the location where the discussion will take place. It is very important that you arrive on time. If you need glasses for reading, please bring them to the discussion. If you have any questions or find out that you cannot attend the focus group, please call ___________ at __________ so that we can find someone to take your place. Thank you for agreeing to take part in our study. We look forward to meeting you. Goodbye.

(NOTE TO RECRUITER: If respondents have any questions or concerns about the focus group topic, please contact Memi Miscally at Porter Novelli at 202-973-5845. Do NOT give her name to respondents.)

Recruited by: _____________________________ **Date**: ______________________

Confirmed by: ____________________________ **Date**: ______________________

Appendix B

OMB# 0925-0046
Exp. Date 8/31/00

Moderator's Guide for I-131 Focus Groups with the General Public

I. EXPLANATION AND INTRODUCTIONS (10 minutes)

1. **Thanks** for coming today. Your participation is very important to us; your insights will help us develop a national public health program.

2. My name is ______ and I work for ______, an independent research company. I do not work with the sponsor of these groups, so please feel that you can give me your **honest** opinions—**positive and negative**.

3. What we're doing today is called a focus group. You may have guessed that all of you **live in the Philadelphia/Omaha/Burlington area**, and for the next 2 hours, we're going to talk about the **environment and your health**.

4. I'm interested in all of your ideas, comments, and suggestions. There are **no right or wrong answers**. It's important that I hear what everyone thinks, so please speak up, especially if your view is different from something someone else says.

5. We'll **audio-tape** and **video-tape** this discussion. In addition, program planners sitting behind this mirror will **observe**. We're taking these steps because everything you say is important to us, and we want to make sure we don't miss any comments.

6. Please **talk one at a time** and in a voice at least as **loud** as mine so that the recording equipment can pick up everything that is said.

7. Later, we'll go through all of your comments and use them to write a report. Remember that all of your comments are **confidential**. Your name will not be used in the report.

8. If you need to use the bathroom, please go **one at a time**.

9. Please turn off any **beepers, pagers, or cell phones** that you may have.

10. Before we begin the discussion, please **introduce** yourself. Please tell us your:

- First name
- Number of years you've been living in the Philadelphia/Omaha/Burlington area

II. GENERAL AWARENESS, KNOWLEDGE, AND CONCERN (25 minutes)

1. What are some of the environmental issues that you've heard about, if any at all? Where does nuclear radiation fit into the list of issues? (SPEND ONLY A MINUTE AND THEN MOVE ON)

2. What words, images, or feelings come to mind when I say the word nuclear radiation?

3. What, if anything, have you heard about nuclear weapons tests conducted in the United States? (TRY TO OBTAIN PLACES AND DATES OF ATOMIC BOMB TESTING AND TYPES OF NUCLEAR RADIATION RELEASED)

About 100 atomic bomb tests were conducted in the state of Nevada during the 1950s and 1960s. These tests released different types of radioactive material into the atmosphere. The rest of this discussion will pertain to these tests and the nuclear radiation fallout.

4. Have you heard anything about these tests? IF YES: What have you heard about these tests?

PROBE: Types of radiation released?
IF AWARE OF MORE THAN ONE MATERIAL: Are you concerned about some of the radioactive substances more than others? What makes you more concerned?

5. What, if any, questions do you have about these tests and the nuclear radiation released?

PROBE: How about health related consequences?
How about any non-health related consequences?

6. What, if any, concerns do you have about these tests and the nuclear radiation released?

PROBE: How about health related consequences?
How about any non-health related consequences?

7. From what sources have you gotten any information you might have? IF MEDIA: From what sources did the media get their information? For example, do you remember any specific individuals, experts or organizations that the media quoted or mentioned? (PROBE FOR AWARENESS OF NCI AND IOM REPORTS)

III. REACTIONS AFTER SEEING ARTICLE (30 minutes)

Now, I'm going to give you a newspaper article (or fact sheet) to read about the Nevada nuclear bomb tests. Some of this information you may already know. Please read all the information carefully as we will be discussing this material in detail next.

I'd like to mention one other thing. The newspaper article mentions that people were most likely to be exposed to I-131 radiation if they lived around Nevada, specifically in the states of Montana, Idaho, Utah, South Dakota, and Colorado. FOR NEBRASKA GROUPS: Please note that Nebraska is near this region and was also a highly exposed state. FOR VERMONT GROUPS: Please note that Vermont was another highly exposed state, because weather patterns carried the radiation north and east of Nevada.

1. What are your initial reactions to this article and the additional information I've given you? (LEAVE OPEN DISCUSSION AROUND EMOTIONS/FEELINGS OR THE INFORMATION ITSELF)

2. When might people living in the U.S. have been affected by I-131? During the 1950s and 1960s when the tests were conducted? Now, in the 1990s? In the future, when it's 2000 and beyond?

You may or may not have a thorough understanding of thyroid cancer. To ensure that all of us have the information we need to get through tonight's discussion, I'd like to give you some information about thyroid cancer. (SHOW BOARD)

Thyroid Cancer

This type accounts for 1% of all cancers.

Symptoms:
Lump in the neck (most common)____________
Tight or full feeling in the neck______________
Difficulty breathing or swallowing ______________ (less common)
Hoarseness______________________________
Swollen lymph nodes______________________

3. Based on the information provided, who do you think is at risk for thyroid cancer from the Nevada tests? What are the major factors that make someone more at risk?

PROBE: Different geographical areas
Age
Milk consumption

4. How concerned are you personally about your risk for developing thyroid cancer as a result of these tests and exposure to the fallout? What makes you particularly concerned?

At the present time, there is no scientific evidence that the amount of I-131 exposure that people received from the Nevada Site is related to any other types of thyroid disease besides thyroid cancer. Research is being conducted to find out if the amount of I-131 exposure people received could be related to other thyroid disorders. Here are descriptions of SOME of the symptoms of two disorders that some people have claimed could be related to the I-131 exposure from the Nevada Test Site. (SHOW BOARD)

Hypothyroidism
A condition in which the thyroid gland becomes underactive. The thyroid gland is located in the neck and affects heart rate, blood pressure, body temperature, metabolism, and childhood growth and development.

Symptoms:
Lack of Energy, Tiredness
Depression
Feeling Cold
Dry, Coarse, Itchy Skin
Dry, Coarse, Thinning Hair
Muscle Cramps
Constipation
Weight Gain

Hyperparathyroidism
A condition in which the parathyroid glands become overactive. The parathyroid glands are located next to the thyroid and affect the body's supply of calcium.

Symptoms:
Calcium Deposits
Osteoporosis or Loss of Bone Density
Muscular Weakness
Nervousness
Irritability
Racing Heart
Increased Perspiration
Thinning of Skin
Fine, Brittle Hair
Frequent Bowel Movements
Weight Loss

5. How concerned are you personally about your risk of developing any of the non-cancerous thyroid diseases I mentioned as a result of the Nevada tests? What makes you concerned?

6. In comparison to other types of health risks like heart disease or stroke, how concerned are you about getting thyroid cancer? How about non-cancerous thyroid diseases?

7. Is the information I provided you with confusing or clear? What would need to be done to make it easier to understand?

8. Would you like more information to determine how important a health issue the I-131 fallout from the Nevada tests is for you? Why or why not? What information?

IV. EDUCATIONAL CAMPAIGN (40 minutes)

1. What, if anything, do you think should be done about I-131 and any potential health risks?

PROBE: Public Education
Screening
Compensation for Medical Expenses

2. Who should be responsible? (IF GOVERNMENT: PROBE FOR LOCAL, STATE OR FEDERAL, IF FEDERAL PROBE FOR AGENCIES) What about these entities makes them responsible?

In 1999, the Institute of Medicine (IOM), a panel of experts from the National Academy of Scientists congressionally mandated to advise the federal government on medical issues, released medical screening recommendations for people who may have been exposed to I-131 released from the Nevada Tests. The panel concluded that the available science does NOT warrant medical screening tests within the general population or within any subgroups of the population.

The reasoning behind this recommendation is that very few people get thyroid cancer and those that do are very likely to be cured. In addition, the current method of thyroid cancer screening can produce false positives, meaning that people may be inaccurately diagnosed with thyroid cancer and consequently subjected to unnecessary fear, medication and surgery.

For these reasons, the IOM felt that the evidence suggests that more harm to the public would be

3. What are your opinions about this recommendation?

Do you think there is a need for a public information campaign to educate people about their possible exposure to I-131 and the potential risks associated with that exposure?

4. In your opinion, who needs to be informed about the possible risks associated with the I-131 emitted from the nuclear tests? Should everyone in the U.S. be the focus, or should information be targeted to those who may have been more exposed? Why?

5. IF GENERAL PUBLIC: What information do you think the general public needs to get?

IF THOSE MORE EXPOSED: What information do you think people who were heavily exposed need to get?

6. What information do you think you personally need about the I-131 emitted from the Nevada tests and its possible health effects?

7. What do you think would be the most effective ways to get this information to people?

PROBE:
- Television/radio
- Newspapers/magazines
- Conferences/meetings
- Interpersonal communication
- Brochures
- Internet

8. What health care professionals, if any, do you think should be involved in reaching out to people? What about these people makes them important?

9. If an educational effort is to be launched, some organization or organizations need to be responsible for implementing the effort. Are there any organizations or types of organizations that you particularly trust to implement these efforts? What about those organizations makes you trust them?

(PROBE: Government agencies, non-profit organizations or advocacy groups?)

10. Are there any organizations or types of organizations that should NOT be involved in implementing these efforts? What makes them untrustworthy?

11. Do you think people will trust a public education campaign that is conducted by the federal government? Would it matter what specific federal agencies are involved? Why?

V. ADDITIONAL CONSIDERATIONS (10 minutes)

1. In your opinion, what are the **main** reasons why the public should be informed about the Nevada Test Site, I-131 exposure, and any potential health problems?

IF NECESSARY, PROBE: Some people think the government has an obligation to let people know about the exposure from the Nevada Test Site primarily because some people could have been harmed by the fallout. Other people think that regardless of the level of harm people experienced the government has an obligation to inform the public because the public has a right to know about its government's actions. Which of these best represents your views? Why?

2. Based on everything you know now, what if anything, would justify the Nevada atomic bomb testing?

IF NECESSARY, PROBE: People were exposed to radioactive material while nuclear weapons were being tested for the purpose of defending our country. What do you think about this?

3. Do you think the government would have intentionally exposed people to radioactive material or do you think the government probably didn't know about the negative health effects that may be associated with the exposures until after the tests were already conducted?

4. What else do you think needs to be done to address the issue of I-131 fallout from the Nevada Test Site that we have not talked about?

5. How do these ethical considerations impact your trust in the government as a whole and different government agencies.?

6. Is there anything else that you think needs to be done to address the issue of I-131 fallout from the Nevada Test Site that we have not talked about?

VI. CLOSING (5 minutes)

1. CHECK WITH OBSERVERS FOR ADDITIONAL QUESTIONS.

2. Those are all of the questions I have. Do you have any final comments?

3. Thanks for your participation today. I have some bookmarks that can provide you with current information about what we've discussed this evening. Feel free to take one before you leave.

OMB# 0925-0046
Exp. Date 8/31/00

Moderator's Guide for I-131 Focus Groups with Physicians

I. EXPLANATION AND INTRODUCTIONS (10 minutes)

1. **Thanks** for coming today. Your participation is very important to us; your insights will help us develop a national public health program.

2. My name is ______ and I work for ______, an independent research company. I do not work with the sponsor of these groups, so please feel that you can give me your **honest** opinions – **positive and negative.**

3. What we're doing today is called a focus group. You may have guessed that all of you are **primary care physicians**, and for the next 2 hours, we're going to talk about the **environment and the health of your patients**.

4. I'm interested in all of your ideas, comments, and suggestions. There are **no right or wrong answers**. It's important that I hear what everyone thinks, so please speak up, especially if your view is different from something someone else says.

5. We'll **audio-tape** and **video-tape** this discussion. In addition, program planners sitting behind this mirror will **observe**. We're taking these steps because everything you say is important to us, and we want to make sure we don't miss any comments.

6. Please **talk one at a time** and in a voice at least as **loud** as mine so that the recording equipment can pick up everything that is said.

7. Later, we'll go through all of your comments and use them to write a report. Remember that all of your comments are **confidential**. Your name will not be used in the report.

8. If you need to use the bathroom, please go **one at a time**.

9. Please turn off any **beepers, pagers, or cell phones** that you may have.

10. Before we begin the discussion, please **introduce** yourself. Please tell us your:

- First name
- Number of years you've been practicing in the Omaha/Burlington area

II GENERAL AWARENESS, KNOWLEDGE, AND CONCERN (25 minutes)

1. What are some of the environmental issues that you've heard about, if any at all? Where does nuclear radiation fit into the list of issues? (SPEND ONLY A MINUTE AND THEN MOVE ON)

2. What words, images, or feelings come to mind when I say the word nuclear radiation?

3. What, if anything, have you heard about nuclear weapons tests conducted in the United States? (TRY TO OBTAIN PLACES AND DATES OF ATOMIC BOMB TESTING AND TYPES OF NUCLEAR RADIATION RELEASED)

About 100 atomic bomb tests were conducted in the state of Nevada during the 1950s and 1960s. These tests released different types of radioactive material into the atmosphere. The rest of this discussion will pertain to these tests and the nuclear radiation fallout.

4. What, if anything, have you heard about these Nevada bomb tests conducted during the 1950s and 1960s and the resulting nuclear radiation fallout?

   PROBE: Types of radiation released?
   IF AWARE OF MORE THAN ONE MATERIAL: Are you concerned about some of the radioactive substances more than others? What makes you more concerned?

5. What, if any, questions do you have about these tests and the nuclear radiation released?

6. What, if any, concerns do you have about these tests and the nuclear radiation released?

   PROBE: Any concerns about health or non-health related consequences?

7. Have you and your patients discussed the Nevada bomb tests and health problems resulting from the I-131 fallout radiation? If so, how often? What have you talked about? Who typically initiates the conversation—you or your patients?

8. Relative to their other health concerns, how concerned are your patients about experiencing health problems as a result of being exposed to I-131?

9. How concerned about I-131 health effects is your community in general?

10. From what sources have you gotten any information you might have? IF MEDIA: From what sources did the media get their information? For example, do you remember any specific individuals, experts or organizations that the media quoted or mentioned? (PROBE FOR AWARENESS OF NCI AND IOM REPORTS)

III REACTIONS AFTER SEEING ARTICLE (30 minutes)

Now, I'm going to give you a newspaper article and fact sheet to read about the Nevada nuclear bomb tests. The article actually appeared in newspapers across the country, perhaps even in your area. Some of this information you may already know. Please read all the information carefully as we will be discussing this material in detail next. (SHOW ARTICLE)

I'd like to mention one other thing. The newspaper article mentions that people were most likely to be exposed to I-131 radiation if they lived around Nevada, specifically the states of Montana, Idaho, Utah, South Dakota, and Colorado. FOR NEBRASKA GROUPS: Please note that Nebraska is near this region and was also a highly exposed state. FOR VERMONT GROUPS: Please note that Vermont was another highly exposed state, because weather patterns carried the radiation north and east of Nevada.

1. What are your initial reactions to this article and the additional information I've given you? (LEAVE OPEN DISCUSSION AROUND EMOTIONS/FEELINGS OR THE INFORMATON ITSELF)

2. When might people living in the U.S. have been affected by I-131? During the 1950s and 1960s when the tests were conducted? Now, in the 1990s? In the future, when it's 200 and beyond?

You may or may not have a thorough understanding of thyroid cancer. To ensure that all of us have the information we need to get through tonight's discussion, I'd like to give you some information about thyroid cancer. (SHOW BOARD)

Thyroid Cancer
This type accounts for 1% of all cancers.

Symptoms:
Lump in the neck (most common)
Tight or full feeling in the neck
Difficulty breathing or swallowing (less common)
Hoarseness
Swollen lymph nodes

PROBE: Different geographical areas
Age
Milk consumption

4. Given the identified risk factors, how concerned are you that any of your current patients may be at risk of developing thyroid cancer?

At the present time, there is no scientific evidence that the amount of I-131 exposure that people received from the Nevada Site is related to any other types of thyroid disease besides thyroid cancer. Research is being conducted to find out if the amount of I-131 exposure people received could be related to other thyroid disorders. Here are descriptions of SOME of the symptoms of two disorders that some people have claimed could be related to the I-131 exposure from the Nevada Test Site. (SHOW BOARD)

Hypothyroidism
A condition in which the thyroid gland becomes **underactive**. The thyroid gland is located in the neck and affects heart rate, blood pressure, body temperature, metabolism, and childhood growth and development.

Symptoms:
Lack of Energy, Tiredness
Depression
Feeling Cold
Dry, Coarse, Itchy Skin
Dry, Coarse, Thinning Hair
Muscle Cramps
Constipation
Weight Gain

Hyperparathyroidism
A condition in which the parathyroid glands become **overactive**. The parathyroid glands are located next to the thyroid and affect the body's supply of calcium.

Symptoms:
Calcium Deposits
Osteoporosis or Loss of Bone Density
Muscular Weakness
Nervousness
Irritability
Racing Heart
Increased Perspiration
Thinning of Skin
Fine, Brittle Hair
Frequent Bowel Movements
Weight Loss

5. Do you believe these concerns about non-cancerous thyroid conditions are warranted by available information on I-131 and its effects on human health? Or are these concerns needlessly raised?

6. Additional research into the non-cancerous thyroid conditions due to I-131 exposure is being conducted. How worthwhile do you think this effort is?

7. How concerned are you about your patients' risk of developing any of the non-cancerous thyroid disease I mentioned as a result of the Nevada tests? What makes you concerned?

8. In comparison to other types of health risks, how concerned are you about your patients' risk for thyroid cancer as a result of I-131 exposure? Non-cancerous thyroid diseases? (DETERMINE WHETHER PARTICIPANTS ARE MORE CONCERNED ABOUT THYROID CANCER OR NON-CANCEROUS THYROID DISEASES)

9. What other information would you need to make a good determination of whether you have patients that are at heightened risk for I-131 related problems?

IV. EDUCATION CAMPAIGN (45 minutes)

1. What, if anything, do you think should be done to educate the public about I-131 and potential health risks?

PROBE: Public education
Screening
Compensation for medical expenses (RESERVE ANY DISCUSSION AROUND ADDITIONAL TYPES OF COMPENSATION FOR SECTION V)

2. Who should be responsible for implementing these efforts? (IF GOVERNMENT: PROBE FOR LOCAL, STATE OR FEDERAL, IF FEDERAL PROBE FOR AGENCIES) What about these entities makes them responsible?

In 1999, the Institute of Medicine (IOM), a panel of experts from the National Academy of Scientists congressionally mandated to advise the federal government on medical issues, released medical screening recommendations for people who may have been exposed to I-131 released from the Nevada Tests. The panel concluded that the available science does NOT warrant medical screening tests within the general population or within any subgroups of the population.

The reasoning behind this recommendation is that very few people get thyroid and those that do are very likely to be cured. In addition, the current method of thyroid cancer screening can produce false positives, meaning that people may be inaccurately diagnosed with thyroid cancer and consequently subjected to unnecessary fear, medication and surgery.

For these reasons, the IOM felt that the evidence suggests that more harm to the public would be done than good with screening.

3. What are your opinions about this recommendation? How important is it to educate the public about I-131 and the potential health risks?

4. In your opinion, who needs to be informed about the possible risks associated with the I-131 emitted from the nuclear tests? Should everyone in the U.S. be the focus, or should information be targeted to those who may have been more exposed? Why?

5. IF GENERAL PUBLIC: What information do you think the general public needs to get?

   IF THOSE MORE EXPOSED: What information do you think people who were heavily exposed need to get?

6. What role, if any, should physicians play in a campaign to educate the public about I-131 health implications?

7. Based on what you know now, is it important for you to inform your patients? Why or why not?

8. What barriers might you encounter? What support might you need?

   PROBE: Time
   Money
   Tips on how to talk to patients
   Materials (What types?)
   Further information

9. What other types of health care professionals should be involved in an educational effort?

10. If an educational effort is to be launched, some organization or organizations need to be responsible for implementing the effort. What organizations or types of organizations would you particularly trust to implement these efforts? What about those organizations makes you trust them?

    PROBE: Government agencies
    Non-profit organizations
    Advocacy groups
    Medical associations

11. What organizations or types of organizations should NOT be involved in implementing these efforts? What makes them untrustworthy?

12. How much do you think people will trust a public education campaign that is conducted by the federal government? What specific federal agencies should be involved? Why?

V. ADDITIONAL CONSIDERATIONS (5 minutes)

1. In your opinion, what are the **main** reasons why the public should be informed about the Nevada Test Site, I-131 exposure, and any potential health problems?

   IF NECESSARY, PROBE: Some people think the government has an obligation to let people know about the exposure from the Nevada Test Site primarily because some people could have been harmed by the fallout. Other people think that regardless of the level of harm people experienced the government has an obligation to inform the public because the public has a right to know about its government's actions. Which of these best represents your views? Why?

2. Based on everything you know now, what if anything, would justify the Nevada atomic bomb testing?

   IF NECESSARY, PROBE: People were exposed to radioactive material while nuclear weapons were being tested for the purpose of defending our country. What do you think about this?

3. Do you think the government would have intentionally exposed people to radioactive material or do you think the government probably didn't know about the negative health effects that may be associated with the exposures until after the tests were already conducted?

4. What else do you think needs to be done to address the issue of I-131 fallout from the Nevada Test Site that we have not talked about?

VI. CLOSING (5 minutes)

1. CHECK WITH OBSERVERS FOR ADDITIONAL QUESTIONS.

2. Those are all of the questions I have. Do you have any final comments?

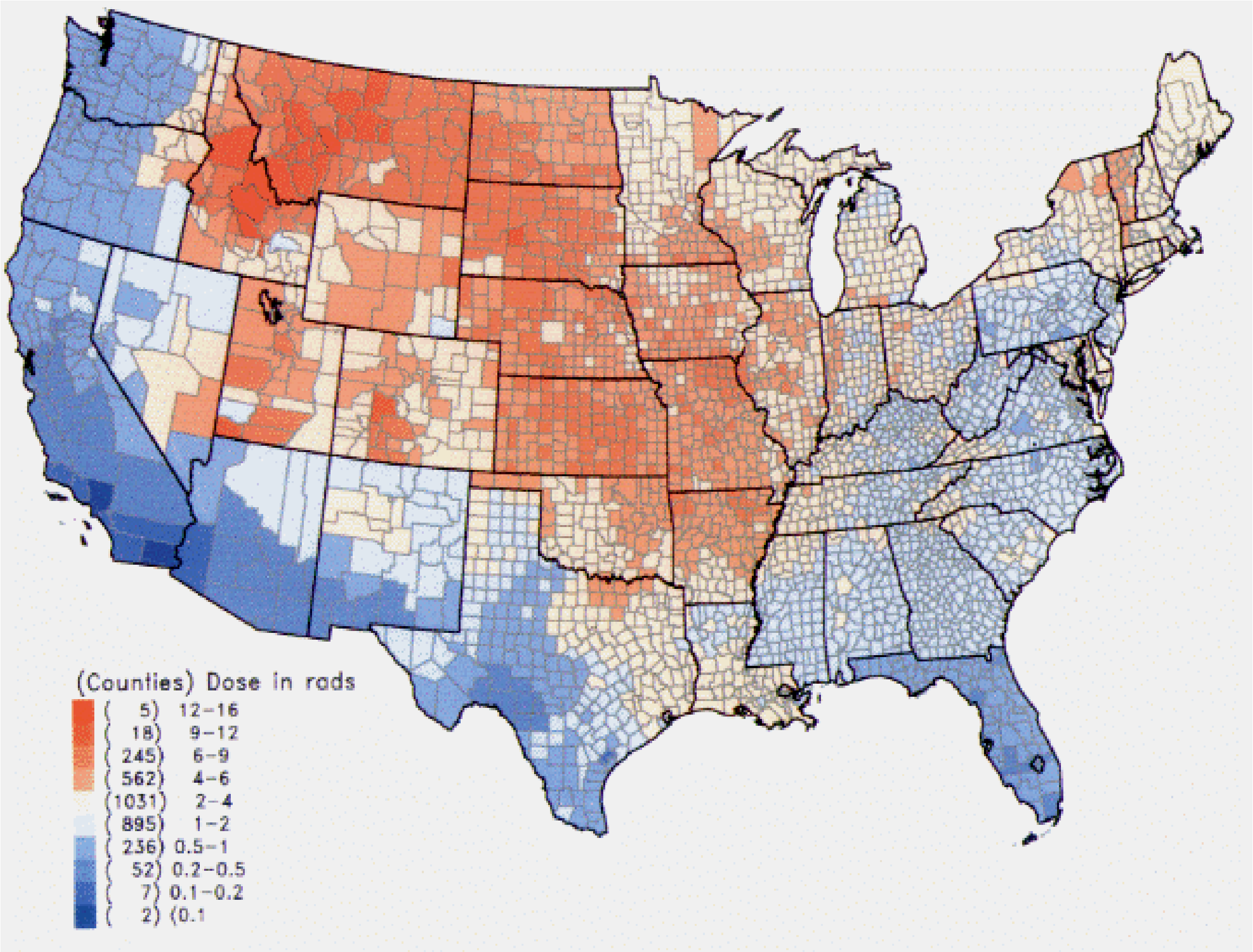
3. Thanks for your participation today. I have some bookmarks that can provide you with current information about what we've discussed this evening. Feel free to take one before you leave.

Additional Facts

- Thyroid cancer accounts for 1% of all cancers
- Some areas near the Nevada Test Site were highly exposed to I-131 radiation. Other areas farther from Nevada also were highly exposed because weather patterns carried the radiation north and east of Nevada

Study Estimating Thyroid Doses of I-131 Received by Americans From Nevada Atmospheric Nuclear Bomb Tests

Figure 1
Per capita thyroid doses resulting from all exposure routes from all tests



H.6 “Tools for Research”

Table H.1 "Tools" typically utilized for communications planning research.

Research Method	**Description**	**Pros**	**Cons**	**Common Uses**
Surveys/Questionnaires (self-administered)	Questionnaires or survey forms are filled out by the respondents themselves. Clarity in question design and instructions for completion are important.			
By mail	Questionnaires or survey forms are sent to potential subjects for them to complete on their own time and mail back to researcher.	• Generalizable results (if sufficiently large, probability sample with high response rate) • Can be anonymous (especially useful for highly sensitive topics) • Respondents can answer questions when most convenient for them • Can collect both program data and personal data (e.g., participant characteristics) • Does not require staff time to interact with target population • Can be used to access difficult-to-reach populations (e.g., the homebound, rural populations) • Can incorporate visual material (e.g., can pre-test prototype materials)	• Not appropriate for respondents who cannot read or write • Low response rate diminishes value of results. May require follow-up by mail or telephone to increase response rate (increases total costs). • Respondents may return incomplete questionnaires • Limited ability to probe answers • Respondents may self-select (potential bias) • May take long time to receive sufficient numbers of responses • Does not yield reliable assessments of attention-getting ability or recall of message • Postage may be very expensive if sample is large	• Obtain baseline data • Acquire self-reported information on behaviors, behavioral intentions, attitudes • Determine message's reach, attention-getting ability • Test knowledge, comprehension

Research Method	**Description**	**Pros**	**Cons**	**Common Uses**
By handout	Respondents are asked to complete survey at a location frequented by the target population (e.g., during a conference, in a classroom, after viewing an exhibit at a health fair).	• Can more readily improve response rate because there is an opportunity to use face-to- face persuasion tactics • Can collect both program data and personal data (e.g., participant characteristics)	• Not appropriate for respondents who cannot read or write • Must be able to reach respondents in person at a central location or a gathering	• Obtain baseline data • Acquire self-reported information on behaviors, behavioral intentions, attitudes • Test knowledge, comprehension
By Computerized Self-administered Questionnaires (CSAQ)	A questionnaire is programmed and displayed on a computer screen with respondents keying in their answers. Requires that respondents have access to programmed computers and that they be somewhat familiar and comfortable with using computers.	• Useful for complex questionnaires because complex “skip patterns” can be preprogrammed • Can control sequencing of questions • Can provide quick summary and/or analysis of results by eliminating the step of data entry from paper questionnaires or interviews	• Not appropriate for audiences who cannot read or those unfamiliar or uncomfortable with computers • Requires expensive technical equipment that may not be readily available or may be cumbersome in many settings	• Test knowledge, comprehension • Acquire self-reported information on behaviors, behavioral intentions, attitudes • Pre-test visual material • Determine if audience attends to, comprehends, and remembers contents of message.
Surveys/Questionnaires (administered by interviewer)	A trained interviewer asks survey questions of respondents. Allows respondent to ask for clarification and allows interviewer to control question sequence.			

Research Method	**Description**	**Pros**	**Cons**	**Common Uses**
By telephone	Respondents are contacted via telephone by trained interviewer. Respondents may be selected in advance from a list or contacted randomly (increases generalizeability of results).	• Generalizable results (if sufficiently large, probability sample with high response rate) • Appropriate for those of lower literacy • Interviewer available to clarify questions for respondent and probe answers • Decreased likelihood of incomplete questionnaires	• Requires interviewer training • Low response rate diminishes value of results • Potential respondents who do not have a phone cannot participate • Respondents often hang up if they believe the survey is part of a solicitation call	• Obtain baseline data • Determine message’s reach, attention-getting ability • Acquire self-reported information on behaviors, behavioral intentions, attitudes • Test knowledge, comprehension.
By computer-assisted telephone interviewing (CATI) technology	Respondents are contacted via telephone by a trained interviewer who has the questionnaire displayed on a computer terminal. The interviewer enters data directly into the computer.	• Generalizable results (if sufficiently large, probability sample with high response rate) • Can program allowable codes for responses which interviewer can use to correct mistakes during interview • Can program help menus to assist interviewer • Computer controls question sequence, allowing complex “skip patterns” • Provides a more efficient means of generating a probability sample	• Considerable development work and lead time are needed before survey implementation • Requires much interviewer training • Not useful for small samples because the workload costs of CATI exceed the benefits	• Obtain baseline data • Test knowledge and comprehension • Obtain self-reported information regarding attitudes and behaviors.

Research Method	**Description**	**Pros**	**Cons**	**Common Uses**
Face-to-face	One-on-one, in-person interview is used to collect information on knowledge, attitudes, and/or behaviors.	• Generalizable results (if sufficiently large, probability sample with high response rate) • Appropriate for those of lower literacy • Useful with difficult-to-reach populations (e.g., homeless, low literacy) or when target audience cannot be sampled using other data collection methods • Interviewer available to clarify questions for respondent and probe answers • Decreased likelihood of incomplete questionnaires	• Can be more labor intensive than self-administered or telephone data collection • Less appropriate for sensitive or threatening questions (respondents may not answer truthfully in person)	• Obtain baseline data • Determine message’s reach, attention-getting ability • Acquire self-reported information on behaviors, behavioral intentions, attitudes • Test knowledge, comprehension

Research Method	**Description**	**Pros**	**Cons**	**Common Uses**
Central location intercept interviews	Potential respondents are approached in a public area by a trained interviewer and invited to participate in the survey. Usually conducted in a high-traffic area (e.g., mall, student union) or other area frequented by target population. Requires highly structured, pre-determined questions that primarily use multiple-choice or close-ended questions.	• Can connect with harder-to-reach respondents in locations convenient and comfortable for them • Can be conducted quickly • Cost-effective means of gathering data in relatively short time • Increased number of respondents within intended population if appropriate location chosen • Larger sample size than focus groups • Eliminates group bias that is possible in focus groups	• Requires interviewer training • Quota sample, not probability sample • Not appropriate for sensitive issues or potentially threatening questions • Cannot easily probe for additional information (too time consuming)	• Test program messages, materials
Written responses to requests for information (e.g., diaries, activity logs, anecdotal accounts)	Information is requested in a specific format from individuals implementing a program or from participants themselves. Information may relate to such issues as quality of program components or how components are used by target population.	• Can allow respondents more flexibility in their replies • Can enable researchers to receive reports on behavior over time, rather than a “snapshot”	• Requires considerable effort on respondents’ parts • Incoming data may be voluminous and challenging to code and compare • Not appropriate for respondents who have poor writing	• Track program implementation • Learn what questions program participants had • Learn what technical assistance was needed by program staff

Research Method	**Description**	**Pros**	**Cons**	**Common Uses**
Review of existing data (e.g., program registration rolls, grocery store receipt tapes, hospital discharge records)	A structured evaluation of information previously collected by local, state, or national agencies is undertaken. Existing sources of health data (statistics, tracking records, treatment patterns) may be available on the World Wide Web or through government agencies, local or university libraries, health departments, clinics or hospitals, police departments, schools, research or nonprofit organizations. Organizations may collect data not originally intended as health data, but useful nonetheless. Examples include grocery store receipts and event attendance records. Analysis of existing data is useful for all forms of evaluation	• Use of existing data means less effort in data collection • May be inexpensive if owner of data provides them at little or no cost • Possible sources of data are plentiful	• Diminished ability to control data points and data collection methods	• Conduct needs assessment • Track the number of people engaging in a behavior in a given locale (e.g., accessing free mammography screening services, purchasing sunscreen).

Research Method	Description	Pros	Cons	Common Uses
In-depth personal interviews	Qualitative data collection method involves less rigid question structure and interviewing style than quantitative methods.	• Can explore long or complex draft materials • Can be effective with those of lower literacy • Allows considerable opportunity to probe answers • Allows for intensive investigation of individual thought, opinions, and attitudes	• Time consuming • Requires level of trust between interviewer and respondent, especially when dealing with sensitive or threatening material • Interviewer must be highly skilled in active listening, probing, and other interviewing skills • Interviewer must be knowledgeable about and sensitive to a respondent's culture or frame of reference	• Develop concepts or messages • Test long or complex draft materials • Conduct a needs assessment.
Focus groups	This tool is a qualitative method of data collection wherein a skilled moderator facilitates discussion on a selected topic among 6 to 10 respondents, allowing them to respond spontaneously to the issues raised. Lasts for 60 to 90 minutes per session. For focus group research to be most valuable, the moderator must cover the research topics, establish an environment in which all points of view are welcome, and follow up on unexpected but potentially valuable topics that are raised.			

Research Method	**Description**	**Pros**	**Cons**	**Common Uses**
Face-to-face	When focus groups are conducted in person, participants and the moderator gather, usually around a table. Observers (members of the research team) sit behind a one-way mirror or unobtrusively back from the table and take notes. Groups may also be recorded by audio- or videotape.	• Interaction in the group can help elicit in-depth thought and discussion • Considerable opportunity to probe answers • Can yield richer data than surveys about the complexities of audience’s thinking and behavior • In-person groups give moderator more opportunity to read nonverbal cues and use nonverbal cues to control the flow of discussion than in telephone focus groups • Rapport can be fostered more easily among in-person groups than telephone groups	• Findings not generalizable • Respondents may be concerned about lack of anonymity • Can be labor intensive and expensive, especially if groups are conducted in multiple locations	• Explore complex topics with target audience prior to program (e.g., what helps/hinders healthy eating) • Learn about feelings, motivators, past experiences related to a health topic • Test concepts, message, materials, and artwork • Can generate and test hypotheses.

Research Method	**Description**	**Pros**	**Cons**	**Common Uses**
By telephone	When focus groups are conducted by telephone, the moderator and participants speak by conference call with observers listening and taking notes. Telephone groups may be recorded by audiotape. Typically, 6 to 8 people participate.	• Interaction in group can help elicit in-depth thought and discussion • Considerable opportunity to probe answers • Can yield richer data than surveys about the complexities of audience’s thinking and behavior • Telephone focus groups can be more easily convened than in-person groups when participants’ occupations/lifestyles afford little free time (e.g., doctors, mayors); reduce travel burden on research staff; and can allow for broad geographic representation • Allow for project staff and partners to listen from their homes or offices	• Findings not generalizable • Respondents may be concerned about lack of anonymity • Telephone groups tend to work best when participants have tangible materials to which they can respond (e.g., pretesting materials). • Long distance phone bills for groups can be expensive, especially if many people listen in • Productive sessions by phone cannot usually be sustained more than 1 to 1½ hours	• Explore complex topics with target audience prior to program (e.g., what helps/hinders healthy eating) • Learn about feelings, motivators, past experiences related to a health topic • Test concepts, message, materials, and artwork • Generate and test hypotheses.

Research Method	**Description**	**Pros**	**Cons**	**Common Uses**
Theater testing	Quantitative data is collected from a large group of respondents (generally 60-100 people per session) who respond to audio-visual materials (e.g., commercials, PSAs). Some messages shown are controls and others are being tested, allowing for a more "real life" assessment of message concepts. Respondents answer questionnaires or respond electronically means.	• Can gather quantitative data from large group at once • Data available immediately • Showing "actual" audiovisual materials allows more realism than storyboards • Using control messages allows more realism	• Significant production costs associated with making draft materials available to test • Limited ability to ask open-ended questions • Rely on technological equipment that may not be readily accessible	• Test audiovisual materials with many respondents at once
Observational studies	Individuals are observed in a natural setting with minimal observer interaction (e.g., observing shoppers in a grocery store to see if they are reading posted nutritional charts)	• Can observe behaviors or program implementation directly	• Can be labor intensive; requires site visits • Many behaviors and program activities not easily observed • Presence of observer can alter behavior of those being observed • Ethics of observing people without their knowledge may be questioned	• Counting people accessing a service • Assessing the consistency with which a service is delivered (e.g., whether registration desk clerks mention a program to all potential participants) • Observing whether skills (e.g., testing blood sugar) have been learned correctly • Useful for observing behavior at baseline, during a program, and after it ends.

Research Method	**Description**	**Pros**	**Cons**	**Common Uses**
Readability testing	Estimates the educational level required for target population to adequately comprehend written materials (i.e., if a pamphlet's readability level is sixth grade, readers need to read at about the sixth grade level in order to comprehend the pamphlet.. Readability tests are available on many standard word processing packages or a test can easily be computed by hand.	• Inexpensive • Test can be performed very quickly	• "Rule of thumb" only, not predictive of readers' ability to understand content • Must be interpreted with caution because many additional factors can enhance or diminish comprehension of written material (e.g., the conceptual context of the material, reader's motivation or interest in the material, layout of concepts in a passage, use of graphics and symbols)	• Increase likelihood that materials will be comprehensible for those with lower literacy levels
Expert review	An analysis of program material or approaches is performed by individuals who are particularly knowledgeable in a content area. Reviewers may check such issues as scientific and technical accuracy or cultural appropriateness. Reviewers may be individuals such as medical research scientists, social workers, law enforcement officials, teachers, or community leaders.	• Inexpensive • Can help obtain support or "buy in" for your program	• Risk of experts seeking to take over or radically change program plans • Can be challenging to reconcile differing viewpoints	• Obtain input prior to program design from experts in a health field or who have experience working with your target audience • Ensure that your messages are scientifically accurate • Test program materials (e.g., ensure materials are culturally appropriate).

Research Method	**Description**	**Pros**	**Cons**	**Common Uses**
Gatekeeper Review	The appropriateness of draft program material for a target audience is assessed by individuals who can facilitate, complicate, or deny access to target population (e.g., those who control distribution channels). Gatekeeper commitment may be necessary to ensure that a program will be implemented as planned.	• Inexpensive • Can help obtain support or "buy in" for your program • Can ensure and smooth access to target populations	• Can cause setbacks if major revisions are needed (project staff can plan ahead and use formative research to avoid this) • Obtaining cooperation and getting priority attention can be challenging if gatekeepers are not especially invested in the population	• Ensure that messages will be disseminated and program plans carried out by obtaining gatekeeper approval prior to program dissemination • Obtain "buy in" from influential people who control distribution channels • Ensure that products conform to gatekeeper agency policies and goals (e.g., television station regulations for PSAs)
Media tracking (print, audio, or audiovisual media)	Content communicated by mass media outlets (e.g., television, radio, billboard advertisements) is tracked and analyzed systematically. A professional service typically is hired to do the tracking if the range of media sources extends much beyond the local level.	• Allows tracking of media that can be influential for the target audience • Allows health communicators to better understand patterns of media attention given their topic	• Review of data is time consuming • May require training of readers or video viewers if automated tracking is not used • Print and video clipping services are expensive	• Conduct needs assessment • Track changes in media treatment of a topic in response to an event or program • Identify issues addressed by media channels that focus on program's target audience • Discern whether media outlets are disseminating program messages as hoped or planned
Source: CDCynergy: Your health communication planning and evaluation tool. Version 1.0. Centers for Disease Control and Prevention; Office of Communication. July 1998.				