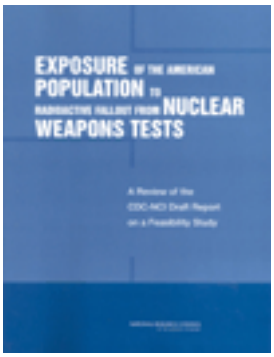

Exposure of the American Population to Radioactive Fallout from Nuclear Weapons Tests: A Review of the CDC-NCI Draft Report on a Feasibility Study of the Health Consequences to the American Population from Nuclear Weapons Tests Conducted by the United States and Other Nations

Committee to Review the CDC-NCI Feasibility Study of the Health Consequences from Nuclear Weapons Tests, National Research Council

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EXPOSURE OF THE AMERICAN POPULATION TO RADIOACTIVE FALLOUT FROM NUCLEAR WEAPONS TESTS

A Review of the CDC-NCI Draft Report on a Feasibility Study of the Health Consequences to the American Population from Nuclear Weapons Tests Conducted by the United States and Other Nations

Committee to Review the CDC-NCI Feasibility Study of the Health Consequences from Nuclear Weapons Tests
Board on Radiation Effects Research
Division on Earth and Life Studies
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Preface

The years since World War II have seen the testing of hundreds of nuclear weapons. Many of those tests have led to the injection into the atmosphere of substantial amounts of radioactive material, some of which has fallen to Earth. As public awareness and concern mounted over the possible health hazards associated with exposure to this "fallout," studies were initiated to assess the extent of the hazard. The studies failed to allay public concern, and further studies were begun in the 1980s to reevaluate the radiation exposures of the population after the weapons tests in Nevada. In 1983, Public Law 97–414, Section 7(a) directed the secretary of health and human services to conduct research into and develop estimates of the thyroid doses received by the American people from ^{131}I (iodine-131) in fallout from the Nevada atmospheric tests. To that end, in 1983, the National Cancer Institute (NCI) established a task group to assist it in a program of technical and scientific work. The work of the task group was centered on ^{131}I and the fallout arising from the weapons tests conducted by the United States. Its findings appeared as an NCI report titled *Estimated Exposures and Thyroid Doses Received by the American People from Iodine-131 in Fallout Following Nevada Atmospheric Nuclear Bomb Tests* (NCI, 1997). That publication did not address the risks associated with other radionuclides found in fallout or the contribution to exposures of global fallout stemming from weapons testing outside the US by the US and other nations, and these omissions became a matter of public concern.

In 1998, scientists at the Centers for Disease Control and Prevention (CDC) and the NCI were asked by the US Congress to assess the feasibility and public health implications of a detailed study of the health consequences for the American people of radioactive fallout from aboveground nuclear-weapons tests conducted in 1951–1962 by the United States and other nations.

In March 2002, the National Research Council's Committee on An Assessment of the Centers for Disease Control and Prevention Radiation Studies from DOE Contractor Sites was called on to review a two-volume draft technical report of CDC-NCI titled *A Feasibility Study of the Health Consequences to the American Population from Nuclear Weapons Tests Conducted by the United States and Other Nations.* The draft report presents preliminary estimates of radiation doses of a set of important radionuclides received by the American people in the coterminous 48 states as a result of atmospheric nuclear-weapons tests. Because the purpose of

the project was to determine only the feasibility of a more-detailed study that might be carried out, those dose estimates are based on an initial review of the open literature and available dose-assessment methods.

The Research Council committee examined all the technical aspects of the CDC-NCI draft report, but, at the request of CDC, it focused its attention on the following four questions:

"1. Are the methods and sources of information used in the technical report to estimate radiation doses and health effects from fallout appropriate for this study?
2. Are the methods and results clearly presented in the main text of the technical report?
3. Are the findings presented in the report supported by the data and analyses provided?
4. Do the Options for Future Work presented in Chapter 6 represent an appropriate range of options for public health activities that could be pursued as a result of this study?"

The present report sets forth in detail the committee's response to its general charge and to the four questions specified above.

We deeply appreciate the dedication and hard work of the study director, Isaf Al-Nabulsi, and the administrative assistance of Dianne Stare and Doris Taylor. We also appreciate the contributions of members of CDC and NCI—specifically, André Bouville, Ethel Gilbert, Charles Miller, and Steve Simon—to the committee's understanding of some aspects of the feasibility study. Finally, we acknowledge our indebtedness to Lynn Anspaugh and Harold Beck, who as consultants to the feasibility study, constituted a source of information for the NRC committee.

William J. Schull
Chair

Acknowledgments

This report has been reviewed in draft form by persons chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making the published report as sound as possible and to ensure that the report meets institutional standards of objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following for their participation in the review of this report:

Harry M.Cullings, Hiroshima, Japan

John M.Flack, Detroit, MI

R.J.Michael Fry, Indianapolis, IN

F.Owen Hoffman, Oak Ridge, TN

Shawki Amin Ibrahim, Fort Collins, CO

Kenneth J.Kopecky, Seattle, WA

Michael T.Ryan, Charleston, SC

Joseph V.Smith, Chicago, IL

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by David G.Hoel, Medical University of South Carolina and Maureen M.Henderson, University of Washington (Professor Emeritus) appointed by the National Research Council. They were responsible for making certain that an independent examination of the report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of the report rests entirely with the authoring committee and the NRC.

Contents

EXECUTIVE SUMMARY

The National Research Council was asked by the Centers for Disease Control and Prevention (CDC) to review the draft report titled *A Feasibility Study of the Health Consequences to the American Population from Nuclear Weapons Tests Conducted by the United States and Other Nations*. The draft report, which was prepared at the request of the US Congress, presents a limited evaluation of the potential public-health impact of atmospheric nuclear-weapons testing and suggests ways in which a more detailed evaluation could be performed. To review the report, the National Research Council formed a committee consisting of members of its Committee on An Assessment of the Centers for Disease Control and Prevention Radiation Studies from DOE Contractor Sites and other experts.

The committee to Review the CDC-NCI Feasibility Study of the Health Consequences from Nuclear Weapon Test was asked by CDC to address the following specific questions:

"1. Are the methods and sources of information used in the technical report to estimate radiation doses and health effects from fallout appropriate for this study?
2. Are the methods and results clearly presented in the main text of the technical report?
3. Are the findings presented in the report supported by the data and analyses provided?
4. Do the Options for Future Work presented in Chapter 6 represent an appropriate range of options for public health activities that could be pursued as a result of this study?"

Before addressing those questions, the committee offers general conclusions and recommendations.

The committee believes that the CDC-NCI (National Cancer Institute) working group performed a very competent feasibility assessment of the geographic distribution of probable doses to the population, the projected risks associated with those doses, and a potential communication plan. However, the committee has identified some weaknesses in the feasibility study and the draft report and has a number of suggestions for improvements.

Implicit in the feasibility study is the question of whether it is worth while to perform a substantially expanded study of all radionuclides. The committee believes that although a more detailed study is technically possible, neither the data nor the consequences appear to justify it. The measurement data on which the dose estimates rest are limited;[1] additional dose refinements are unlikely to transform the existing sparse data into precise exposure estimates. Improvements in methods are always possible, but the quality of the data and the very low doses involved do not justify such efforts. To obtain substantially better estimates of exposures from NTS (Nevada Test Site) fallout would require the location of a body of exposure data that is much more extensive and of better quality than the available measurements; it is doubtful that such data exist. However, if extensive additional exposure data are found, the question about performing a more detailed dosimetry and risk assessment should be revisited.

If further dose-reconstruction work were to be proposed, however, it should be evaluated according to specific scientific and public-health criteria. The first would be improvement in the accuracy of exposure estimation at the individual or geographic level (to the extent of making new epidemiologic studies feasible, for example). Given the measurement data available, there is little hope that further dose reconstruction can achieve that; compellingly better estimates of doses are unlikely to be possible unless a substantial new body of dose-measurement data is discovered. A second would be sufficient improvement in the dosimetry to permit substantial risks to be addressed with meaningful studies. There is no evidence that either external or internal fallout exposures other than to ^{131}I (iodine-131) could be large enough to produce detectable increases in individual risk in any feasible epidemiologic study, and fine tuning of the dosimetry will not change that situation. There could be a third criterion: to improve the characterization of the uncertainty of individual exposure estimates. But the ability to make major improvements in that arena also is speculative. The lifetime risk of a death due to cancer is about 20% absent the fallout radiation exposure. The fallout putatively raises that risk to about 20.03% (with a credibility interval of about 20.01% to 20.09%), which is of little health consequence. However, if new exposure data were found to indicate that exposures were substantially higher, this could trigger a need for additional studies. Nevertheless, the committee believes that there is insufficient justification for a more detailed study of the amounts and effects of fallout radionuclides other than ^{131}I.

The committee supports continuation of the identification, cataloging, and preservation of fallout-related documents, that is, the archival work described in the draft report. In addition to its value for evaluating exposure to fallout, the committee believes that such work is well justified as a record of a historically important period in the nation's history. If substantial new knowledge of radiation biology and markers of radiation injury are developed, data that are of limited current interest may be able to support the testing of new hypotheses that relate low doses of radiation to human-health effects. The ability to collect, document, extract, archive, and effectively use fallout records depends on the knowledge possessed by the diminishing number of scientists from that era who are still available and who can help to identify and interpret the data. It is not that the type of data available cannot be analyzed now, but that the scientists of

[1] The basic limitation occurs because in the 1950s there were fewer than 100 monitoring stations across the United States to make the measurements. Interpolation and extrapolation of such measurements in more than 3000 US counties is necessarily imprecise, given the vagaries of the weather, the principal controlling factor. Only if there had been several thousand monitoring stations with data could exposures be estimated much better.

that era have knowledge unobtainable except through experience of the instruments and methods used at the time, their practical limitations, the conditions under which they were used, the reasons for recording or not recording various observations, the interpretation of records that are ambiguous without first-hand knowledge, and the likely location of useful observations among large quantities of otherwise irrelevant records. Without the participation of those scientists, the possibility of deriving much value from archival material for future testing of hypotheses on radiation effects will be seriously compromised.

The committee's findings with respect to the four questions previously enumerated are summarized in the paragraphs that follow.

Are the methods and sources of information used in the Technical Report to estimate radiation doses and health effects from fallout appropriate for this study?

METHODS USED TO ESTIMATE DOSES AND HEALTH EFFECTS

The dosimetric modeling for the feasibility study has been built on the substantial body of work that was previously performed to estimate the amounts of radionuclides released by the Nevada Test Site (NTS) atomic-bomb tests, the amounts deposited within 100 miles of the site, and the amount of ^{131}I fallout throughout the coterminous United States. That work greatly facilitated the modeling for the feasibility study. Moreover, the estimates of exposure to global fallout given in the draft report are based on a large body of measurement data from locations around the world. Those data and estimates notwithstanding, considerable uncertainty remains in the estimates in the draft report. That uncertainty appears to be largely irremediable because historical fallout measurements were made at fewer than 100 US sites. It seems likely that only marginal improvements in the dose estimates could be made by further refinements in the modeling unless some important new data were found that would substantially improve the quantity and quality of dose information or unless an extensive program of soil sampling and analysis were carried out.[2]

As to the health hazards produced by the exposures, the authors of the draft report used conventional risk coefficients for lifetime cancer mortality in characterizing risk. Those coefficients are based on the linear non-threshold hypothesis that presumes that any exposure to radiation increases one's risk of cancer. Specifically, the International Commission on Radiological Protection (ICRP) risk coefficient of 5% Sv^{-1} was used to derive total cancer-mortality risk. That coefficient includes a factor to indicate that fractionated or low-dose-rate exposures are assumed to be only 50% as effective in cancer induction as high-dose, acute exposures. This is consistent with current methods but still has its limitations, including the use of linear extrapolation to doses that are so low that no available data could either validate or invalidate the assumption. In particular, such an approach may overestimate cancer risk in that it excludes the possibility of reduced risk per unit dose with small exposures to radiation. The US population was treated as a whole without specific attention to more-susceptible subgroups or subgroups at risk of higher exposures, other than an analysis of children born in 1951 at the

[2] Such a program, although reducing the uncertainties for some radionuclides concentrations, could not substantially reduce the uncertainties in total doses.

beginning of the NTS testing. If a more detailed analysis of doses is undertaken, consideration should be given to estimating risk for subgroups that might be at higher risk, such as children who drank goat's milk.

The feasibility study estimated health effects on the basis of external exposure from both NTS and global fallout for total cancer. In addition, it estimated exposures and risks of thyroid cancer and leukemia on the basis of both external and internal radionuclide exposure. It did not estimate the risk posed by internal radionuclide exposure for other cancers, because the contribution of internal exposure to cancer of organs and tissues other than the thyroid and bone marrow was generally only a small fraction of that from external fallout. The committee concurs with that approach.

The risk-estimation models considered uncertainties associated with several factors: dose uncertainties, uncertainties in risk estimates, extrapolation to low doses and low dose rates, transfer of risk estimates from the Japanese to US populations, uncertainties in relative biological effectiveness for various kinds of radiation, and temporal projections of risk. The authors of the draft report did not consider several other types of uncertainty, such as uncertainties in selection of the particular risk model (for example, the shape of the dose-response curve) used, interindividual variation in radionuclide uptake and metabolism, or the existence of sensitive populations. The approach used in the feasibility study for uncertainty characterization tacitly assumes that a cancer risk exists at very low doses and dose rates. The validity of that assumption is contentious; however, it seems justified in this instance because the result helps to guard against the underestimation of risk.

One limitation of the findings presented in the CDC-NCI draft report is that to calculate the plausible range of risk estimates, the authors relied on a general estimate of the "credibility interval" of risk estimates per unit of dose derived from other studies and the assumption of a "credibility interval" for the dose estimates. The basis of assuming a factor of 3 for the "credibility interval" for the dose estimates was not explained, but it should be, because it is a key factor in generating the ranges of putative risks given in the report. Nevertheless, this is a report of a scoping study, and it was not feasible to conduct a detailed uncertainty analysis based on the specific uncertainties that went into the dose estimates of the study. If a more comprehensive study is performed, a thorough uncertainty analysis of both doses and risk will be needed.

To summarize, the methods used to estimate doses and health effects are reasonable for a feasibility study, although there are some limitations.

Sources of information

The draft report identifies many sources of information that were used in the feasibility study in the calculations of dose from weapons tests, and the methods used. It also identifies other sources of potentially informative data that were unavailable when the feasibility study occurred. Some of those data are in well-archived repositories, but many are poorly stored and cataloged. Cognizant of the possible loss of useful information on the magnitude of exposure to

ionizing radiation, the Department of Energy has ordered a moratorium on the destruction of energy-related documents of potential epidemiologic utility and has shipped all such documents to Federal Records Centers. Other relevant agencies, including the Department of Defense, have not declared a moratorium on the destruction of possibly relevant records; the Navy and Air Force, for example, have extensive documents of potential importance if additional analyses are undertaken. We recommend that CDC urge Congress to prohibit the destruction of all such records relevant to fallout and to permit appropriate access to them.

Are the methods and results clearly presented in the main text of the Technical Report?

The committee believes that the particular findings that the authors of the draft report chose to emphasize and the manner of presentation were not optimal and were in some cases misleading. The primary emphasis with respect to risk is on the population-summed risk, that is, the total number of expected excess cancer deaths in the exposed population over a lifetime, on the basis of the collective dose to that population. The number is presented with little context. A valuable context would be comparisons of the magnitude of the risk (the expected number of lifetime excess cancer deaths) posed by fallout with the corresponding risks associated with natural background radiation and with the total number of cancer deaths expected in the lifetime of the exposed population. In addition, the expected number of excess cancer deaths in the population is not readily translatable into an individual's excess risk posed by fallout. The risk to individuals and the associated uncertainty are the most important objective pieces of information for members of the population in interpreting the personal implications of their fallout exposure. They are also key pieces of information for public-health purposes in that individual risk, and not population risk, drives considerations of whether special preventive screening programs would be recommended.

Most other aspects of the methods and results are clearly presented, with a few exceptions. The committee notes, however, that the report contains only an abbreviated presentation of the dosimetry methods used in the feasibility study. Such brevity may be appropriate for a general audience, but those with technical dosimetry expertise need fuller specification of the methods to permit evaluation and critique of credibility. It is therefore recommended that the authors of the draft report improve the completeness and clarity of the dosimetry chapter and its linkage to the four dosimetry appendixes.

A table and discussion outlining the sources of uncertainty in the dose estimates should be presented, including the basis for using a factor of 3 to define the range of uncertainties in dosimetry. If a more detailed study is to be conducted, the various sources of uncertainties in dose estimates should be incorporated into the modeling of risk, but the committee views such modeling as beyond the compass of this feasibility study.

The potential merits and limitations of a more detailed study of fallout dosimetry and risks are not adequately described in the draft report. It does not state the expected types and magnitude of changes that would occur if a more detailed study were conducted and the public-health value of a more detailed study also was not evaluated.

Are the findings presented in the report supported by the data and analyses provided?

The dosimetric findings of the feasibility study presented in the CDC-NCI draft report are generally supported by the data and the analytic methods used. It was beyond the National Research Council committee's resources to check the models and the use of data in detail. However, given that the overall results are in general agreement with the body of measurement data available, the committee concludes that the dosimetry estimates are acceptable for the feasibility study commissioned by Congress. The committee is also in general agreement with the findings and conclusions in the draft report. The report could be construed as more responsive to the original request if it had included in the risk estimates the risks associated with other internally deposited radionuclides, but such contributions to risk would probably have been relatively small compared with external exposures.

The draft report indicates that the dose and risk estimates stemming from the feasibility study are population averages and therefore should not be used to estimate risks to specific individuals. The committee concurs with that caveat; to generate adequate estimates of individual risks, one needs to account for a person's age, dietary sources and habits, geographic locations at particular times, and other factors.

Do the options for future work presented in Chapter 6 represent an appropriate range of options for public health activities that could be pursued as a result of this study?

The draft report identifies five options for future study, which can be summarized as follows:

(1) Do no additional fallout-related work.
(2) Retrieve and archive the historical documentation related to radioactive fallout from nuclear-weapons tests conducted by the United States and other nations.
(3) Conduct a more detailed dose reconstruction for radioactive fallout from global nuclear-weapons tests for ^{131}I, the most important radionuclide identified in the feasibility study.
(4) Conduct a more detailed dose reconstruction for multiple radionuclides in radioactive fallout from both NTS and global nuclear-weapons tests.
(5) Conduct a detailed study of the health effects of nuclear-weapons test fallout, including in a single project dose estimation, risk analysis, and communication of the results to interested parties.

The feasibility study considered an appropriate range of options, albeit it did not identify the benefits associated with each option or what policy, health, or scientific decisions would be affected by each.

The five options above intermix three separate issues requiring decisions:

- Should effort be devoted to retrieving and archiving additional documentation concerning fallout? If so, how much effort?

The committee recommends that documents from a certain number of the sites most likely to have valuable information be retrieved, examined, and archived; the selection of the sites should be based on the knowledge of dosimetrists with experience from the 1950s. What the effort produces will determine whether it should be continued. The current destruction of old records for inventory-reduction purposes and the attrition of dosimetrists who are knowledgeable about the 1950s era mean that the need for document archiving and interpretation is urgent.

- Should an expanded study of the magnitude of fallout-related doses and health effects be mounted? If so, what should its scope be?

The committee favors a prompt publication of the results of the feasibility study, to be followed by a reanalysis of the ^{131}I fallout data and the data relating ^{131}I dose and thyroid-cancer risk. The justification for redoing the ^{131}I analysis is that it could include new dosimetry and uncertainty information available from recent research from Chernobyl and other sources and could correct errors in the earlier NCI study that have come to light. Those alterations would probably not make large changes in the key results, but they would lend more credibility to the risk estimates. Apart from the ^{131}I-related risk of thyroid cancer, the draft report indicates that the likely risks associated with the other fallout radionuclides are small, so the increased precision gained by performing a full-fledged dose and risk estimation will probably be of little added value. Developing more precise estimates than given in the feasibility study about total collective dose to the American people from all radionuclides, and resulting total risk of all cancers may be reasonably motivated by academic and historical interest in this extraordinary chapter in our nation's history, and to show that the US government is not attempting to keep veiled in secrecy the true consequences of the era of nuclear testing. However such an interest in collective dose would not imply that a full dose reconstruction for all radionuclides (to give dose estimates at a county-by-county level as was done for ^{131}I) is scientifically justifiable. In the view of the committee the very low levels of exposure to radionuclides other than ^{131}I, combined with uncertainties concerning their temporal and geographic distribution, imply that the resulting estimates would be without scientific (e.g. epidemiologic) or public-health consequence.

- What should be the scope of a communication plan associated with the present NCI-CDC draft report or with a possible future report?

An effort must be made to communicate the feasibility study's important findings to interested Americans. The goal is to inform the public on fallout and health-related issues. The committee recommends that a comprehensive and understandable public summary be developed and made part of the final report of the feasibility study report and that it be disseminated widely and in particular be placed on the NCI and CDC Web sites. The two agencies should also send the public summary as a separate document to previously identified stakeholders and others who have expressed interest, issue a press release about it, and announce its availability on various e-mail lists of interested organizations.

The public summary should be developed with all due speed. Stakeholders were frustrated about delays in the release of the draft report, and they remain frustrated about delays in releasing materials from the NTS ^{131}I communication effort. Long delays in releasing reports of radiation studies have contributed to distrust in those expressing opinions to the committee.

Information from the feasibility study should be included in the NTS ^{131}I communication effort.

The committee commends the NTS ^{131}I communication plan for involving stakeholders and other interested members of the public on many levels. In its efforts to involve stakeholders, it set an example that should be followed for public dissemination of information from the feasibility study. The NTS ^{131}I communication plan sponsored a well-developed risk-communication conference to which it invited various stakeholders and many distinguished US leaders in health communication, risk perception, and risk communication. The conference provided excellent information about the communication effort being planned. The committee recommends that a risk-communication conference be conducted by CDC to help it develop effective means of involving the public in formulating and communicating information about radiation and health issues.

1

INTRODUCTION

BACKGROUND AND CONTEXT

Over 500 atmospheric nuclear-weapons tests were conducted at various sites around the world during 1945–1980 (see Table 1). Five nations—the former Soviet Union, the United Kingdom, France, the People's Republic of China, and the United States—were responsible for the radioactive debris, some long-lived and some short-lived, that those tests injected into the atmosphere. The debris, generally termed "fallout" because eventually some of it falls to Earth, resulted in increased radiation doses (adding to those occurring naturally) to people living throughout the world. The longer-lived nuclides resulted in essentially permanent changes in the ambient or natural radiation background throughout much of the world, whereas the shorter-lived radionuclides contributed to dose primarily in regions near the test sites. The amount of debris injected into the atmosphere and hence the later fallout associated with a particular test and its geographic distribution were functions of local and test-specific factors—such as height, yield, and material in the vicinity[3]—and of the meteorologic conditions prevailing at the time of the test (see, e.g., Beck and Bennett, 2002, Carter and Moghissi, 1977).

[3] That is, materials vaporized by the bomb or activated by neutron bombardment, such as a metal tower on which the bomb was detonated, or soil vaporized in the blast.

Table 1. Summary of atmospheric nuclear tests by major site and country (Adapted from Table 2, Volume 1, Annex C, UNSCEAR 2000)

Country	Test Site	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 USSR	Novaya Zemlya	91	239	247
	Semipalatinsk	116	7	
	Others	12	1	
	Totals	543[a]		440

[a]Includes 22 safety tests of the United States, 12 safety tests of the United Kingdom, and five safety tests of France not listed above.

The feasibility study under review did not consider all the weapons tests indicated in Table 1 but was restricted to aboveground tests during 1951–1962, so it embraces only the atmospheric weapons tests conducted by the United States, the former USSR, and the United Kingdom. The authors of the draft report offer as a rationale for that restriction the assertion that "it is generally acknowledged that the most important contributions to the radiation doses arose from atmospheric nuclear tests conducted by the United States, the United Kingdom, and the former USSR during the pre-1962 time period." To support that statement, they note that "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)."

Although the detonation of a nuclear weapon produces more than 900 fission products, only about 165 radionuclides have half-lives long enough to contribute to fallout and thus to constitute a potential threat to human health. The threat arises from exposure of a person to radioactive materials deposited on the ground, termed external or ambient exposure, and through the inhalation or ingestion of radioactive materials, called internal exposure.

External exposure to fallout from the NTS tests was evaluated in the feasibility study by estimating the deposition density of some 43 radionuclides throughout the United States and

applying previous methods (Hicks, 1981; Beck, 1980). For evaluating global fallout from other tests, a similar approach was used for the 18 most important radionuclides (for such global fallout, the shorter-half-life radionuclides are much smaller contributors). The committee considers that approach appropriate for a feasibility study.

An NTS-weapons-test fallout study before the one under review showed that more than 95% of the dose stemming from ingested radionuclides is attributable to 22 radionuclides,[4] and that inhalation generally contributes little to the dose to the general public (Ng et al., 1990). Accordingly, the draft report has ignored inhalation as an exposure route and for estimates of internal dose from fallout from the NTS tests has focused its attention on the 20 major contributing radionuclides (of those listed in Table 2) for which deposition density estimates were available.[5] For global fallout, internal dose estimates were made for the five radionuclides considered to be most important (^{3}H, ^{14}C, ^{90}Sr, ^{131}I, and ^{137}Cs). The committee views those approaches as appropriate for a feasibility study.

[4] The counting of radionuclides adopted here differs from that in the feasibility study. For example, in Appendixes E and G of the feasibility study, $^{239+240}Pu$ is counted as a single radionuclide.

[5] Appendix E of the feasibility study is based on an electronic database produced from an earlier draft of Appendix D in which deposition-density estimates for ^{135}I and ^{239}Np were not made. The internal dose estimates include the effects of daughter nuclides produced in the body.

Table 2. Radionuclides for which deposition densities were calculated for NTS weapons tests (adapted from Table 3.2, and Table 2 of Appendix D, of the draft report)

Nuclide	**Half-life (parent)**
Sr-89, 90 (Y-90[a]), 91	52, 10400, 0.4 d
Y-91, 91m (=0.65* Sr-91), 93	59, [a], 0.4 d
Zr-95 (Nb-95[a]), 97 (Nb-97[a])	64, 0.7 d
Nb-97m (=0.96* Zr-97)	[a]
Mo-99	2.8 d
Tc-99, Tc-99m (=0.96*Mo-99)	7.8E7d[a],
Ru-103 (Rh-103m[a]), 105 (Rh-105m[a]), Ru-106 (Rh-106[a])	39, 0.2, 368 d
Rh-105	1.5 d
I-131, 132 (=1.03* Te-132), 133, 135	8, [a], 0.9, 0.3 d
Te-132	3.3 d
Cs-136, 137	13, 11000 d
Ba-140	13 d
La-140	1.7 d
Ce-141, 143, 144 (Pr-144[a])	32.5, 1.4, 284 d
Pr-143	14 d
Nd-147	11 d
Pm-147	956 d
Np-239	2.36 d
Pu-239, 240, 241	24131, 6569, 14.4 y
Am-241	430 y

[a]In equilibrium with parent

THE CONGRESSIONALLY REQUESTED FEASIBILITY STUDY

As public awareness and concern mounted over the possible health hazards associated with exposure to the fallout from weapons testing, studies were initiated to assess the extent of the hazard. The studies failed to allay public concern, and further studies were begun in the 1980s to reevaluate the radiation exposures of the population after the weapons tests in Nevada. In 1983, Public Law 97–414, Section 7(a) directed the secretary of health and human services to conduct research into, and develop estimates of, the thyroid doses received by the American people from ^{131}I in fallout from the Nevada atmospheric tests. To that end, in 1983 the National Cancer Institute (NCI) established a task group to assist it in a program of technical and scientific work. The work of the task group, which extended for more than a decade, was centered on ^{131}I and the fallout arising from the weapons tests conducted by the United States. Its findings appeared in 1997 as an NCI report titled *Estimated Exposures and Thyroid Doses Received by the American People from Iodine-131 in Fallout Following Nevada Atmospheric Nuclear Bomb Tests* (NCI, 1997). That publication did not address the risks associated with other radionuclides found in fallout or the contribution to exposures of global fallout stemming from weapons testing outside the US by the US and other nations, and these omissions became a matter of public concern.

In 1998, the Senate Appropriations Committee asked the Department of Health and Human Services to assess the feasibility and public-health implications of a detailed study concerning the health consequences for the American people of radioactive fallout from nuclear-weapons tests. The request resulted in a collaborative effort involving staff at the Centers for Disease Control and Prevention (CDC) and NCI to

1. Locate documents related to nuclear-weapons fallout
2. Develop preliminary dose and risk estimates for the population
3. Review the epidemiologic literature
4. Review and outline communication strategies.

The feasibility study reviewed here summarizes the findings of that collaborative effort and sets out a series of options related to future work.

THE NATIONAL RESEARCH COUNCIL'S INVOLVEMENT

On March 27, 2002, the National Research Council was asked by the Centers for Disease Control and Prevention (CDC) to review the CDC-NCI draft of *A Feasibility Study of the Health Consequences to the American Population from Nuclear Weapons Tests Conducted by the United States and Other Nations*. Specifically, CDC sought a review of all technical aspects of the draft, including answers to the following questions:

"1. Are the methods and sources of information used in the technical report to estimate radiation doses and health effects from fallout appropriate for this study?

2. Are the methods and results clearly presented in the main text of the Technical Report?
3. Are the findings presented in the report supported by the data and analyses provided?
4. Do the Options for Future Work presented in Chapter 6 represent an appropriate range of options for public-health activities that could be pursued as a result of this study?"

To that end, the National Research Council formed a committee, the Committee to Review the CDC-NCI Feasibility Study of the Health Consequences from Nuclear Weapons Tests, consisting of members of its Committee on An Assessment of the Centers for Disease Control and Prevention Radiation Studies from DOE Contractor Sites and other experts. The committee constituted to review the CDC-NCI draft report has expertise in health physics and dose assessment (pertaining to both external radiation and internal emitters), radiation chemistry, radiobiology, nuclear medicine, ethics, risk communication, epidemiology, biostatistics, modeling, and risk assessment. The review began in April 2002, and the goal was to produce a consensus report by January 30, 2003. The present report contains the results of the review of the CDC-NCI draft report.

At the initial meeting of the new National Research Council committee in Washington, DC, on April 26–27, 2002, representatives of CDC (James Smith and Charles Miller) and of NCI (André Bouville, Steve Simon, and Ethel Gilbert) were present. They enlarged on the draft and the methods used in arriving at the conclusions set forth in it, and they responded to questions raised by the committee. Lynn Anspaugh and Harold Beck, consultants for the feasibility study, were also present to address committee questions related to dose reconstruction. The review committee met again in Washington on July 15–16 in closed sessions to begin the drafting of its findings and recommendations. Two further meetings were held: in Des Moines, Iowa, on September 12–13, 2002, and in Washington on November 14–15, 2002. The first of those two meetings involved further fact-finding and was open to the public; the second was closed and involved preparation of the final report. Information obtained from the public and outside experts was used in the committee's deliberations and is woven into the report.

2

THE COMMITTEE'S REVIEW

The National Research Council committee conducted a general review of the CDC-NCI draft report, evaluating its merits and limitations and addressing the particular questions directed to it by CDC. The committee believes that the CDC-NCI working group performed a very competent scoping assessment of the geographic distribution of probable doses to the population, the projected risks associated with those doses, and potential communication plans. However, the committee has a number of suggestions for improvements and has identified some weaknesses of the feasibility study and the draft report that are detailed below.

TECHNICAL APPROACH AND CONTENTS OF THE DRAFT REPORT

The draft report of the CDC-NCI feasibility study consists of two volumes; the first presents the study's general findings and suggestions regarding further research, and the second sets out in a series of eight appendixes the technical details that support the main text. Collectively, the two volumes represent a substantial amount of work, including the development and application of methods that have produced a credible dose reconstruction from a variety of data that were, in general, not originally collected for such a purpose. However, the draft should make clear, perhaps in the introduction, that this type of analysis cannot be used to identify either individual doses or individual risks and that collective dose calculations are not meaningful in the context of the very low exposures involved (NCRP, 1995). That caveat could be important in later communications with the public. Moreover, without a context, presenting dose information as absolute values has little meaning to the general public or even to the general scientific community. Some method of presentation that shows relative values would be useful. Comparisons with natural background and its geographic variations and with discretionary exposures, such as flying or the use of nonemergency medical radiation, might be helpful. (For example, the French have recently opened a Web site—http://www.sievert-system.org/ (the site was accessed on January 2, 2003)—where anyone can estimate the amount of radiation received during any flight of the French airlines.)

The maps showing county-by-county distribution of radioactive dose is an important aid to public understanding of exposure distributions but could be improved in two ways. First, the display of doses for each county projects a false precision in that distinct boundaries (county boundaries) may be identified as separating various doses. Sophisticated viewers of such a map understand that there is considerable overlap in potential exposure between adjacent but differently coded counties, but this may not be recognized by the general public. A smoothed color-graded contour plot with state or county borders overlaid would be useful in representing visually the true state of limited knowledge about small-scale local differences in exposure.

Second, the maps lack a contextual framework. It would be useful to compare graphically, using histograms or other visual presentation tools, the distribution of fallout exposures relative to estimates of natural background radiation either over the country as a whole or by region (East, Midwest, West, and South). That should be done for selected birth cohorts and for selected organ doses to illustrate, for example, that thyroid doses from fallout to children born in 1950 are estimated to be higher than thyroid doses from background for many regions of the country. In contrast, for almost all other organ doses or age cohorts, the estimated doses from fallout are smaller by an order of magnitude or so than background throughout the country, and this should be depicted graphically as well.

The committee notes that the main text of the draft report does not always appear to reflect what was done as stated in the appendixes. For example, the committee finds it disturbing that a footnote on page E-36 alludes to a probable error in the ^{131}I deposition values associated with four or more weapons tests that is not mentioned in the main text; nor is the impact of this error on estimated doses described. This error, although it would affect the estimated doses, would not alter the draft's basic conclusion about the feasibility of the study of the health consequences of exposure to the fallout from weapons testing in the United States or elsewhere. It would have been helpful if, in the presentation of their conclusions, the authors had set out a summary of the possible changes that might occur with further refinement and had essayed an evaluation of how much better the results might be if a major effort were made.

ASSESSMENT OF THE DOSE RECONSTRUCTION

To estimate radiation doses to the US public due to fallout from nuclear-weapons tests conducted at the NTS and global fallout from nuclear-weapons tests conducted at other sites around the world, it is necessary to estimate the deposition density of fallout radionuclides across the United States as a function of time during and after the period of testing. With this information in hand, calculations of external and internal doses can be based on a number of assumptions such as route of exposure, lifestyle, age, and diet. Recognizing that they were preparing a feasibility study, not a complete detailed analysis of exposure to all radionuclides under all conditions, the authors of the draft report note that the dose estimates given are relatively crude values based on approximate evaluations. The calculations, of moderate complexity, are based on data obtained from readily available publications in the open literature. Some of the data sources and analytic approaches used are discussed below as are some of the key results. Calculations related to the NTS are discussed first, and then those related to global fallout.

Deposition Density of Nevada Test Site Fallout Radionuclides

In the draft report, estimates of deposition of fallout radionuclides from NTS tests are based on county-by-county estimates of the deposition of ^{131}I released from NTS weapons tests that were published as part of the earlier NCI study on the exposure of the American public to ^{131}I from nuclear-weapons tests (NCI, 1997). Because of the importance of these results to the calculations and conclusions in the draft report, the committee briefly describes here the nature of the estimation procedure used in the earlier NCI study.

Iodine-131

The development of the ^{131}I estimates from the source data (which consisted of gummed-film data supplemented by cloud-tracking information and rainfall estimates) posed a complex statistical data-processing problem (NCI, 1997). Much of the deposition estimate was based on a general-purpose statistical interpolation method known as kriging. The kriging method requires specification of user-defined parameters that determine specifics of the statistical model used for the interpolation and also required covariate data (in this case, rainfall). It may be of more than just academic interest to determine the degree to which the deposition calculations depend on the choice of input parameters by the NCI investigators. However, the calculations were done with software written specifically for this task rather than with commercially available programs. The publication and archiving of the computer codes and the source data used in the kriging calculations is strongly recommended.[6]

Regardless of the statistical analyses used, it is important to remember that the underlying data on which average county deposition values are based for the 3,000-odd counties in the United States were obtained from 100 or fewer fallout-collector (gummed-paper) stations throughout the country. That is an inherent limitation in any further refinements of any future analysis.

Given initial deposition, the data used in the 1997 NCI study to estimate thyroid exposure to ^{131}I involved a reconstruction of the milk and food pathway, of which a key element was the development of a county-by-county estimate of milk production and a distribution matrix for flows of milk between counties (NCI, 1997). The development of the distribution matrix involved considerable detective work. The data from which the matrix was generated need to be published and archived. The feasibility study used a simplified approach that assumed that the milk and food pathways throughout the United States are similar to those near the NTS.

[6] The kriging program used in the NCI study is not included in the published NCI report, for the stated reason that it was not developed by NCI. The committee finds such a reason for not publishing the code inadequate. The meteorologic programs used for the tests for which no gummed films were available were also not published, for the same stated reason. They, too, should be published and archived.

Other Radionuclides

With the ^{131}I deposition data in hand for each county, deposition densities for an additional 42 fallout radionuclides were estimated by using calculated ratios of these radionuclides to ^{131}I as a function of time after each test was conducted, as provided by Hicks (1981). The deposition densities were then used to calculate external and internal radiation doses received by members of the public. The most-detailed calculations were for persons who were adults in 1951. Some specific calculations were also made for persons who were born on January 1, 1951, to compare with the adult values. This birth cohort was estimated in the 1997 report to be one of the more highly exposed groups to NTS-related ^{131}I, although other birth cohorts (1952–57) may have had even higher exposure to this radionuclide.

External Doses from Nevada Test Site Fallout

The calculations of external dose were based on radionuclides deposited on the ground. It was assumed that persons spent 20% of their time outdoors and the other 80% in structures that reduced their radiation exposure to 30% of the outdoor value. In this way, the daily external dose was calculated as 44% of what it would have been for a person remaining outdoors 100% of the time.

For fallout that arrived soon after a test, the short-lived iodine radionuclides contributed substantially to the external dose. A few days later, the main contributors were ^{132}I, ^{140}Ba, ^{95}Zr-^{95}Nb, and ^{103}Ru. Because of the short half-lives of those radionuclides, most of the external dose from NTS fallout was received during the year after a given test. Of the six test series covered in the feasibility study, two, UPSHOT-KNOTHOLE in 1953 and PLUMBOB in 1957, accounted for about half the total population-weighted external dose from NTS fallout.

Internal Doses from Nevada Test Site Fallout

During the timeframe of about 1979–1987, a major effort was conducted to calculate external and internal doses from the NTS tests. That effort, the Off-Site Radiation Exposure and Review Project (ORERP), covered the population living in Nevada, Utah, Arizona, New Mexico, and portions of several other states (Church et al., 1990). The following relationship was used in the draft report to calculate absorbed dose or equivalent/effective dose (see Volume 2, Appendix E, page 7; for further references):

$$D=P\times I\times F_g,$$

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

The factors I were estimated in the ORERP study for the integrated intakes in states near the NTS and were used in the feasibility study for all other counties in the coterminous United States. In essence, the parameters for all of the United States were assumed to be those found earlier to be appropriate for Nevada. Those assumptions were made to facilitate calculations in the feasibility study. As noted in the draft report, the method led to a calculated collective thyroid dose of 2,000,000 person-Gy. Calculations in the earlier NCI (1997) study, using a geographic area-specific method, led to a collective thyroid dose of 4,000,000 person-Gy. The difference, which apparently arises from the assumptions listed above,[7] may indicate an uncertainty of similar size for the values of all the other radionuclide doses computed in the feasibility study because they are all based on the use of ratios of each radionuclide's deposition to that of ^{131}I, values for which were available from the NCI (1997) report. A factor of 2 in a study with wide geographic variation is reasonable agreement, particularly for a feasibility study with simplifying assumptions. Refinement of the approach is not likely to add much value to the dose information obtained, particularly because of the generally low doses that are calculated. Even if the estimated doses in the draft report proved to be low by a factor of 2, the corrected doses for radionuclides other than ^{131}I would still be too small to be of significance for health.

Deposition Density of Global Fallout Radionuclides

The characteristics of fallout from weapons tests at other sites around the world were different, in large part because of the nature of the tests. In general, they were tests of weapons with much larger energy yields from both fission and fusion components. The high-yield explosions injected much of the radioactive material into the stratosphere, where it traveled

[7] Appendix E of the draft report speculates that a major contributor to the difference was the implicit assumption of a constant initial retention (of 0.39 m^2/kg) of fallout radionuclides on vegetation, whereas this measure is known to vary with distance from the NTS (because particles of different sizes fall out at different distances) and with season (for unknown reasons).

around the globe largely staying within latitudinal bands; that delayed its fallout for months or years. During the prolonged stratospheric retention, the short-lived radionuclides decayed substantially before the fallout occurred. Thus, for the most part, the deposition of global fallout involved longer-lived fission products, such as ^{90}Sr and ^{137}Cs, and radionuclides produced by other processes in the explosions, ^{3}H and ^{14}C. Beyond that general picture, there were sporadic observations of localized deposition of the short-lived radionuclide ^{131}I (and other short-lived radionuclides presumably were also deposited), apparently because of local meteorologic conditions.

Many of the determinations of deposition density of global fallout radionuclides in the United States are based on soil samples collected periodically from a network of about 30 stations and analyzed for ^{90}Sr and perhaps ^{89}Sr. The extension of the results to other years has been based heavily on a model developed by Bennett (1978). The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) has been active in assessing global fallout for many years. The authors of the draft report used information provided in UNSCEAR (1993) to establish a list of important radionuclides to study. The deposition density of ^{90}Sr in each of the 3000-odd counties was estimated as being proportional to average rainfall. Deposition densities for other radionuclides were calculated from the ratios of the amounts of each of these radionuclides present relative to the amount of ^{90}Sr present according to Bennett's model.

External Doses from Global Fallout

Given the fallout deposition densities calculated above, external doses were computed for each county for each year from 1953 to 1972, together with a single calculation for external dose for 1973–2000. The calculations showed that ^{137}Cs and ^{95}Zr-^{95}Nb accounted for 70% of the total external dose from global fallout. The resulting population-weighted external doses over the years 1953–2000 totaled 0.74 mGy/person compared with the population-weighted external dose of 0.5 mGy/person from NTS fallout. Thus, fallout of longer-lived radionuclides resulted in protraction of the period over which the external dose was received, and the total external dose was about 50% higher than the external dose received from NTS fallout.

Internal Doses from Global Fallout

As was true for the NTS fallout, ingestion of contaminated foodstuffs was the major contributor to the calculated internal doses from global fallout. Previous reports showed that there were five major contributors to the internal dose: ^{3}H, ^{14}C, ^{90}Sr, ^{131}I, and ^{137}Cs. The ORERP approach described above was used to calculate the doses for ^{90}Sr, ^{131}I, and ^{137}Cs. Special models were used to describe the disposition of ^{3}H and ^{14}C throughout the environment.

DOCUMENT LOCATION AND RETRIEVAL

The draft report identifies many sources of information that were used in the feasibility study (or in the studies on which the feasibility study relied) in the calculation of doses from weapons testing and the methods used. It also identifies other sources of potentially informative data that were unavailable when the feasibility study was performed. Some of those data are in well-archived repositories, but many are poorly stored and cataloged. The committee recognizes the potential value of such data to fallout research that may be undertaken in the future and recommends that CDC extend programs to identify and preserve records and materials. Such a program would have several elements as listed below:

1. *Finding relevant data*

A number of sources of information should be considered when searching for relevant data on fallout from nuclear-weapons testing. The national laboratories under the jurisdiction of the Department of Energy (DOE) have all monitored fallout in their areas, and this information and that from the laboratories' special studies need to be archived. Special attention is needed to identify and catalog unique data stored at laboratories that have been heavily involved in fallout research, such as the Environmental Measurements Laboratory (EML) and the Lamont Geophysical Laboratory. In 1982, the US Public Health Service collected its documents on nuclear fallout, and they contain material of potential importance, such as data on fallout radionuclides in milk. The US Navy and US Air Force also have extensive documents of likely importance. The extensive measurements made of ^{131}I in animal thyroid glands should be compiled.

There are other sources of information of probable utility for future studies of fallout. For example, during the years of nuclear-weapons testing, Congress held many hearings on the health effects of, and need for, further nuclear-weapons testing. The published hearings are out of print, but CDC has found extensive collections of them in several locations such as the Coordination and Information Center in Las Vegas, university libraries, and libraries at DOE national laboratories, Atomic Energy Commission repository libraries, and EML. The records of hearings are valuable in two ways: they contain useful information themselves, and they point to where more information can be found.

In addition, attention should be given to the availability of fallout-related information available from UNSCEAR and foreign laboratories that have had active programs in fallout measurement and analysis.

2. *Safeguarding and storing data*

Data searches and cataloging will not be possible if the underlying records and related materials are destroyed. Recognizing that, DOE has placed a moratorium on the destruction of possibly relevant records. At present, there is no such moratorium on the destruction of DOD

fallout-related records. We recommend that CDC urge Congress to prohibit the destruction of relevant records held by federal agencies and to permit appropriate access to them.

The implementation of the modern-day dosimetry system used to estimate radiation doses for the atomic-bomb survivor study rests on data on individual survivors that were collected in the 1950s (Roesch, 1987). That speaks to the importance of archiving historical data for future dose-reconstruction purposes. How such data are stored is a key to ensuring their availability to future investigators. Conscious of changes in computer storage media and the importance of archival material, CDC has embarked on the laudable project of transferring data stored on magnetic tape, punched paper tape, and punched cards to modern computer-readable media. That should be done at all sites where archival fallout information is stored.

3. *Ensuring continued accessibility to the data*

When relevant data and analytic reports have been found and cataloged, it will be important for their contents and locations to be made known to interested potential users. The establishment and maintenance of public reading rooms would be highly desirable to provide continued public access to copes of reports and catalogs of sample data and other resources (like original samples).

ASSESSMENT OF THE ESTIMATES OF CANCER RISK

The CDC-NCI investigators estimated risks posed by the external exposure generated by the fallout radionuclides and by the internal doses from ^{131}I. As the basis of their risk estimates, they used the estimate of five excess cancer deaths per 100 persons per sievert of dose to the whole body, which was derived by the International Commission on Radiological Protection (ICRP, 1991) and takes into account that the exposures were protracted rather than acute.

A linear non-threshold (LNT) model was assumed for projecting possible cancer risks in the feasibility study. While this seems to be a reasonable assumption based on available epidemiologic data from higher doses and high dose-rates, such as in the Japanese atomic-bomb study, no data are available to definitively substantiate or contradict the LNT model at the low levels of dose and low dose-rates contributed by NTS and global fallout. Experimental data are also not definitive: some suggest linearity, but others suggest no effect or even the possibility of a protective effect, at low doses of radiation. The available data generally do not suggest that the risk at low doses is greater than that predicted by the LNT model. The LNT model is widely used and is generally appropriate in this case because it represents a prudent approach to health protection of the public in the absence of definitive information on radiation risks at low exposure levels.

One limitation of the findings presented in the draft report is that to calculate the plausible range of risk estimates, the authors relied on a general estimate of the "credibility interval" of risk estimates (draft report, p. 155) per unit of dose—namely, a factor of 3 less or

more than the central estimate—and on the assumption of a similar factor of 3 of a "credibility interval" for the dose estimates (draft report, p. 156). The basis of the factor of 3 for the dose estimates was not explained; it should be, because it is a key factor in generating the ranges of putative risks that are given in the draft report. The feasibility study could not conduct a detailed uncertainty analysis based on the specific uncertainties that go into dose estimates. Such an approach is acceptable as a rough guide, but if a more comprehensive study is performed, a thorough uncertainty analysis of doses and risks would be needed.

In a number of places in Chapter 4 of the draft report there is considerably more emphasis on population risk (posed by collective dose) than on individual risk. While collective dose and resulting collective risk may be of interest from a historical, academic, or political standpoint, the critical information for exposed people is their degree of risk, which has more important implications for individual health than does how many people in the population are expected to have adverse effects. It is therefore more useful to put the primary emphasis on individual risk than on population risk, when this is possible. Page 130 of the draft report indicates that "population risk" will be useful for developing public-health policy, although it does not state how. Arguably, the individual-risk information is more useful because it helps to clarify whether preventive actions (such as cancer screening because of high risk) might be useful in a way that collective dose or risk cannot be. That said, we recognize that there are even greater complexities in estimating individual risk than collective risk since apportioning the collective risk to individuals is dependent upon dose reconstruction techniques with many uncertainties, and the individual increments in risks, so derived, are small. Explaining the consequence of a small and uncertain increment in individual risk to an individual is inherently problematic.

More perspective is needed on the NTS and global fallout-dose effects. We recommend two ways to provide such perspective. First, present the estimated incremental cancer risk posed by fallout as a percentage of the current observed cancer risk. For example the current lifetime cancer-death risk is about 20%, and the risk posed by fallout is about 0.03% (with a claimed credibility interval of about 0.01–0.09%), so the lifetime cancer risk would be raised from 20% to 20.03% (with an estimated range of 20.01–20.09%). Second, compare the estimated risk posed by fallout with that posed by lifetime exposure to natural background radiation, and its variations from place to place. It will then be possible for the reader to understand that the fallout risk is small compared with the risk we all presumably incur from exposure to natural background radiation. A comparison of the fallout risk with putative background radiation risks for the residents of the eastern seaboard and residents of Rocky Mountain states would also be illuminating, given the variation in background radiation for these two populations.

Expanding on this theme, for the 3.8 million children born in 1951 (representing the most heavily exposed Americans), the authors of the draft report estimate that fallout will lead to about 2,000 excess cancer cases and about 1,000 excess cancer deaths (which represents an excess risk of death of one in 3,800) on the basis of extrapolation of existing epidemiologic data with a linear "non-threshold" (LNT) model. The draft report compares that number of excess cases with the total lifetime risk in this cohort dying of cancer, (20%, or 760,000 total cancer deaths). An additional comparison of the excess-cancer calculations for fallout with the total number of deaths due to background radiation in this model would highlight the dependence of the calculation on the use of an LNT model. Not only would the comparison help further to put fallout-related risk into perspective by comparison with the "natural" radiation risks that people

must accept as a part of everyday life, but it would help to distinguish between cancers whose risk from fallout will potentially increase compared with background risk (specifically thyroid cancer) and the remaining cancers, whose risk it will not increase. For example, a simplified calculation based on an LNT model leads to an estimate that about 2% of all cancer cases (or 28,120 excess cases in the 1951 birth cohort on the basis of an estimated "spontaneous" lifetime cancer risk of 37%[8] without any added radiation exposure) might be due to background radiation. That estimate is based on the assumptions that exposure to external background radiation amounts to an average of 1 mSv/year in the United States and that there is an excess lifetime cancer risk of 10% per sievert of background exposure. The excess risk per unit dose is calculated as half the excess risk per sievert seen in the youngest atomic-bomb survivors who experienced acute rather than chronic exposures (see the following site that was accessed on December 10, 2002; http://www.rerf.or.jp/eigo/radefx/late/cancrisk.htm).

From this example calculation, NCI's estimate of 2,000 excess cancer cases due to fallout is seen to amount to about 7% of the roughly 28,100 excess cancer cases that are due to natural background radiation. The corresponding fractions—cases caused by fallout divided by cases due to background radiation—are even smaller when computed for other age cohorts, the members of which were either exposed to less radiation from fallout or exposed at ages at which they were less sensitive.

One implication of the example calculation is that even in the most heavily exposed age cohort it will be impossible to detect differences in total cancer incidence (or mortality) due to fallout with current methods of observational epidemiology. Epidemiologic analysis of the US population for increases in overall cancer rates by predicted fallout exposure is extremely unlikely to add scientific information about the existence of excess cancer risks or about the validity of the LNT model used to predict them. In fact, comparing the cancer rates seen in the naturally higher versus naturally lower background-radiation regions in the United States yields little evidence of the predicted 2% excess cancer rate due to background radiation (Eckhoff et al., 1974, Jacobson et al., 1976). Attempting to detect fallout risks that are more than an order of magnitude smaller than background-radiation risks in a smaller cohort restricted to the most-exposed people is impractical with any epidemiologic method currently available.

A useful illustration to show that very-low-dose radiation exposure is not an overwhelming factor in cancer causation would be a comparison of the rates of cancer observed in residents of the eastern seaboard with those in residents of the Rocky Mountain states, where background radiation is higher. The failure of this and other observational analyses to detect the cancer increases due to background radiation that are predicted by the LNT model in the Rocky Mountain region, although not a disproof of the model because other causes of cancer also are known to vary regionally. Nevertheless this comparison will make the point that the model is used by the authors to extrapolate to magnitudes of risk that are far outweighted by risks due to other factors. Putting aside thyroid dose due to ^{131}I, the current estimates for the other radionuclides yield population external dose estimates that are only a small fraction of the external doses due to background radiation. Assuming a conservative LNT model, translating

[8] This differs from the 20% cited above because that refers to risk of death, whereas the 37% refers to total risk of cancer (not necessarily death from cancer.

these doses into increases in the number of cancer cases in the US population yields a total number of expected excess cases that may appear large in absolute numbers but is very small when compared either with the number of total cancers in the population or with cancers attributable to background exposure according to the same LNT model. A more detailed dose reconstruction is very unlikely to change that result even if internal deposition is included. On the basis of those considerations, fine tuning of the calculation of population dose estimates is an academic exercise with little obvious public-health significance. The committee is sensitive to the fact that other reasons than public health significance may motivate further refinement of estimates of total population dose—e.g. to show, by dint of good effort, that the US government is not attempting to keep veiled in secrecy the true consequences of nuclear testing. We do not think, however, that detailed dose reconstruction, at anything like the level of detail given for ^{131}I in the 1997 NCI report, would be scientifically meaningful, when applied to radionuclides other than ^{131}I.

In the single case of thyroid cancer, however, the situation is markedly different. The attributable fraction of thyroid cases in the most exposed cohort may be a substantial portion of total thyroid-cancer risk and is considerably larger than the perhaps 8% of cases that may be attributed to background exposure. Land's calculations in 1997 (see Appendix B in IOM-NRC, 1999) estimated a potential increase of 40% in thyroid-cancer incidence in the most exposed people. Unlike increases in the other cancers, such increases in thyroid cancer should be detectable in two types of studies: those which compare rates of thyroid cancer by geographic region and those which compare rates in the most exposed birth cohort with rates in the least exposed birth cohort. However, fallout is not the sole cause of increases in thyroid-cancer rates that have been seen in recent decades. Between the 1930s and 1950s, the medical use of radiation directed to the head and neck was common. The procedure delivered a high dose at a high dose rate to the thyroid, particularly of children. The practice was largely discontinued during the 1950s, once the dangers were recognized. Such medical exposures, rather than fallout, appear to be principally responsible for the increases in thyroid cancer seen beginning in the 1930s (Pottern et al., 1980). If the thyroid doses from fallout can be estimated with sufficient accuracy, the committee believes that it would be useful to compare these doses at the individual or collective dose level or both with the thyroid doses from some of the earlier therapeutic procedures.

Although the draft report mentions the thyroid-cancer, thyroid-adenoma, and hypothyroidism risks in Chernobyl-exposed children several times, it does not mention the Hanford results. The Hanford Thyroid Disease Study had doses similar in magnitude and duration to those projected in the draft report, and it is the best-conducted study of ^{131}I (with exceptional subject location and participation rates and uniform, high-quality screening), so its results merit a summary.

The feasibility study apparently used a linear model to estimate leukemia risk. It is unclear, however, whether the basis of the linear model is a linear extrapolation from high dose down to zero dose or the linear component of a linear-quadratic model (in which the linear component dominates at low doses); the latter is much preferable for the feasibility study. A risk discussion is needed that describes the low-dose extrapolation issue and that notes that it is uncertain whether there is any increased risk of leukemia. At least one analysis of the atomic-bomb survivor data finds evidence of a zero-effect threshold below 0.2 Sv (Hoel and Li, 1998)

and thus disagrees with the analyses produced by the Radiation Effects Research Foundation (Pierce et al., 1996; Preston et al., 1994), which estimate that 14% of the leukemia cases in survivors exposed below 0.2 Sv were due to exposure on the basis of a linear-quadratic model fit. The committee notes also that the term *leukemia* encompasses a variety of hematologic disorders that involve the white cells and that have seemingly different dose-response relationships (Preston et al., 1994).

The discussion of risk estimates for other cancers in the draft report (Section 4.2.1.3) needs to be elaborated. There is no discussion of the degree of concordance among the primary studies of the principal tumor sites, nor are any risk estimates or any references given. The discussion is therefore not very informative or convincing to readers who are unfamiliar with radiation epidemiology.

The discussion of noncancer-risk estimation indicates in passing that the estimate of a dose threshold of 0.1–0.2 Gy for hypothyroidism is likely to yield an overestimate of risk in that most data show hypothyroidism risk only at appreciably higher doses (UNSCEAR, 1993; IOM-NRC, 1999); that it is an overestimate ought to receive more emphasis. Given that these were both protracted and fractionated exposures, a dose threshold as low as 0.1–0.2 Gy for hypothyroidism seems implausible. In addition, it could be stated more strongly on the basis of available data on the radiation-related risk of major nonmalignant chronic diseases (such as cardiovascular, respiratory, digestive, and genitourinary), that no excess risk of these diseases is expected to be posed by NTS and global fallout.

THE VALUE OF FURTHER REFINEMENTS OF THE 131I NEVADA TEST SITE CALCULATIONS AND UNCERTAINTY ANALYSIS

Dosimetric Refinements

Improvements in some aspects of the 1997 NCI report on ^{131}I exposures from the NTS are possible based partly on what has been learned from the Chernobyl experience. In particular, parts of the pasture-milk pathway of exposure are probably better known now than they were in the 1980s and early 1990s (when the dose reconstruction for the NTS ^{131}I exposure was performed), because of analyses of the database of thyroid-dose measurements in many Chernobyl-exposed people. In addition, it may be technically possible, partly because of the Chernobyl experience, to conduct a more thorough analysis of additional aspects of the uncertainty in thyroid dose than was included in the 1997 report. The uncertainty analysis also might be improved by providing a better differentiation between uncertainties that are shared and those which are unshared from county-to-county and from person-to-person. The review of the 1997 NCI report by a 1999 Institute of Medicine (IOM)-National Research Council committee included many specific comments regarding the uncertainty analysis, some of which could be reexamined in more detailed studies along with other sources of uncertainty. The following are some examples:

1. During the estimation of uncertainties in dose due to the interpolation of deposition, the kriging methods used to interpolate the gummed-film measurements could have been modified to include a reasonable distribution of errors in the gummed-film measurements (see page 31 of IOM-NRC, 1999); the incorporation of such methods would reduce to some degree the between-county variability in average-dose estimates and lead to a "flatter", probably more realistic, map of exposure as a function of geographic location. This is a standard consequence of statistical approaches for measurement error: estimates of true exposure are pulled together toward a common mean when measurement errors are factored into the calculations.
2. A better distinction could be made between the variability in herd averages (over large numbers of the various breeds of milk cows) of milk-transfer coefficients and the variability in milk-transfer coefficients estimated from a very small number of animals of a particular breed (see pages 34–35 of IOM-NRC, 1999).
3. Uncertainty in the estimates of milk distribution between producer and consumer counties could potentially be included in the analysis (see the discussion of the Vol(i,j) terms on page 37 of IOM-NRC, 1999). Allowing considerations of this source of measurement error would probably tend to smooth the estimates (pulling them toward a common mean), the amount of smoothing being dependent on the degree of uncertainty considered in the Vol(i,j) terms.
4. Information about interindividual variability in dose-conversion factors could be included (see page 39 of IOM-NRC, 1999) perhaps again on the basis of the Chernobyl experience.

That said, it is probably the case that improvements are apt to be only at the margins in the sense that estimates of the doses and uncertainties are unlikely to be markedly more precise. The net effects of additional uncertainty analysis are likely to be a decrease in the variability in the county-dose estimates between countries (this is expected from points 1–3 above) and a small increase in the already wide uncertainties in individual dose estimates. What is very unlikely to be achieved as a result of further work on dose reconstruction is a substantial increase in the correlation between true dose (the average for either a county or an individual) and estimated doses, because ultimately the exposure estimates must be based on data that have fundamental limitations—such as the gummed-film network for estimating deposition—and because there are gaps in our knowledge of the milk-distribution patterns that existed in the 1950s and early 1960s. Only if the correlation between true and estimated dose were substantially improved would the re-examination of the ^{131}I exposures lead to better risk estimates of the effect of the NTS exposures on public health.

Epidemiologic Refinements

The only radionuclide whose exposure is examined in the draft report and for which the combination of dose estimate and assumed dose-response relationship may produce a number of excess cancer cases that is potentially detectable in epidemiologic work in the United States

appears to be ^{131}I—specifically as released from the NTS and as related to the risk of thyroid cancer. Several unique aspects of the exposure and of thyroid cancer contribute to that specificity. The existence of a highly specific pasture-milk pathway, concentration of iodine in the thyroid gland, a remarkable dependence of risk of thyroid cancer on age at exposure, and apparent continuing risk decades after exposure add up to a pattern of risk in the US population that may still be detectable. Exposure to ^{131}I from global fallout was estimated in the feasibility study to be much less important as a cause of thyroid cancer because, owing to its short half-life, much of the ^{131}I had decayed before reaching the United States. Other cancers are much harder to study because the potential excess is spread out over a much wider group of organs and because doses to other organs were generally much lower than doses to the thyroid.

Even for thyroid cancer, many uncertainties remain. Thyroid cancer clearly was induced by ^{131}I exposure in the Chernobyl studies, but the exposures there were higher than those produced by Nevada Test Site fallout. Estimation of an excess of thyroid cases relies on interpolation, assuming that linear models are valid down to levels of excess risk undetectable by epidemiology. In addition, the overall magnitude of exposure (total dose to the population) is uncertain, as are the details of the geographic distribution of ^{131}I throughout the country.

The Utah Thyroid Disease Study found evidence of excess thyroid disease (cancer and benign tumors) in areas relatively close to the NTS (Kerber et al., 1993). At least two other sources of information regarding NTS exposure and its influence on thyroid-cancer risk have to be considered. The first is the broader geographic distribution of ^{131}I from the NTS and its relationship to the incidence of and mortality from thyroid cancer, examined using passive registry systems in place today. The second is comparison of age-specific rates of thyroid cancer in groups of US residents whose age at the time of the NTS releases placed them into a "high-risk" or "low-risk" exposure-age category. Gilbert et al. (1998) exploited the wider geographic distribution of dose, relating county-average exposures to the geographic distribution of thyroid-cancer cases and deaths; the IOM-NRC review of the 1997 NCI report of exposure to ^{131}I did a simple overall comparison of age-specific rates of thyroid cancer. Although the analyses all have substantial limitations, they are useful and are highly complementary in that the information contained in each analysis is almost independent of that in the others.

All those analyses found some evidence of increases in thyroid-cancer rates that suggest effects of exposure. The Utah study indicated statistically significant increases only when thyroid cancers were combined with benign thyroid tumors (Kerber et al., 1993). The Gilbert et al. (1998) study, using the 1997 NCI estimates of NTS ^{131}I dose, found evidence that thyroid-cancer mortality, but not incidence, was related to county-specific thyroid-dose estimates. And the IOM-NRC review of the 1997 NCI report found roughly a 10% increase in age-specific thyroid-cancer incidence when rates at ages 25–29 years or at ages 35–39 years in an "exposed" age cohort (born in 1948–1952) were compared with rates in two "relatively unexposed" age cohorts (born in 1959–1963 or born in 1938–1942). However, temporal variations in other sources of radiation exposure (e.g., dental x-rays; therapeutic x-rays for common benign conditions) were not evaluated in the IOM-NRC review, although such temporal variations could be the cause of the observed increase.

Further "inexpensive" epidemiologic work with existing data seems to be warranted by

the results seen so far. Specifically, the approach of the Gilbert et al. (1998) study cited above could be expanded to include comparisons by birth-cohort of age-specific incidence and mortality at the county level. It is particularly important to see whether the apparent excess of incident cases in the "exposed" birth cohort (born in 1948–1952) holds up when data from other sources (including non-SEER registries) are included in the analysis and whether the apparent increase in mortality by geographic region holds up in age-specific comparisons. The statistical power of such analyses is an important issue, especially if null results are found since thyroid cancers are frequently misdiagnosed or undiagnosed partly because detection of disease is to some extent dependent upon screening practices which may differ both geographically and temporally. However, a simplistic calculation provided by the IOM-NRC review of the 1997 NCI report indicates that reasonable power is expected to detect the large potential increases in age-specific incidence estimated by NCI (see Appendix B in IOM-NRC, 1999). Moreover, the power of these analyses continues to increase with additional follow-up by the tumor-registry system in the United States. Those attempting to interpret such data, however, should keep in mind the limitations of ecological data, the inaccuracies and surveillance biases in diagnosing thyroid cancer, and the fact that mortality is a poor surrogate for thyroid cancer incidence because of the low case-fatality rate. In addition, care would need to be taken to ensure that radiodiagnostic or radiotherapeutic exposures do not confound the analysis.

Although not directly incorporated as one of the feasibility study's proposals, it is worth commenting here on the feasibility of further screening-based epidemiologic investigation of NTS fallout. The committee is not in favor of such investigation directed at the effects of ^{131}I fallout, except perhaps for a re-screening of participants in the Utah study. An extension of screening to other areas of the country would face a dilemma. If people of the same general geographic region and age at exposure are used in the screening, there will be little ability to distinguish between those who received low exposure and those who received high exposure, because estimation of individual dose is known to be highly uncertain (with uncertainty of at least a factor of 3 within an age and a geographic region). However, if people from various regions are compared, dose estimates would depend primarily on geographic region alone. That implies not only that regional differences in underlying rates of disease would confound the results, but also that a study large enough to have good statistical power would probably only recapitulate results that are much more easily obtained by comparing regional differences in age-specific rates with existing tumor-registry data. Moreover, no screening of disease prevalence could be designed that would exploit the predicted differences in age-specific rates of disease between different birth cohorts. Such birth-cohort comparisons may, in fact, have more power than even screening-based geographic comparisons.

COMMUNICATION WITH THE PUBLIC ABOUT EXPOSURE AND CANCER RISK

The draft report provides important information about the possible health consequences to the American population arising from exposure to radiation resulting from the NTS and global fallout. At the public session of the committee's meeting on September 12, 2002, in Des Moines, Iowa, members of the public spoke about their continuing concerns about the health effects of fallout. They asked for a full and timely disclosure of information related to their and

their family members' exposure. In so doing, they invoked a legacy of denial, secrecy, and injustice on the part of government agencies and officials. In his statement to the committee, Senator Tom Harkin (Democrat, Iowa) expressed the concerns of his constituents: "Many people are wondering and asking me, could their cancer, or that of their relatives, have been caused by fallout? . . Is there anything they can do to protect themselves now?"[9] Senator Harkin emphasized the need for public education and attention to these issues.

Overview of the Proposed Communication Plan

Plans to communicate with the public occupy a major chapter and a long appendix in the draft report. Various communication issues were evaluated, and alternative plans were presented. The most thoroughly discussed plan would accompany Option 5 for future work and includes a major educational effort that would build on a communication plan already under development, the ^{131}I/Nevada Test Site Communication Plan. This effort, about exposures to radioactive iodine at the NTS, is sponsored by NCI and has been in development for more than 2 years.

More modest communication goals are outlined for Options 3 and 4. Those options depend on adapting the plans, methods, and materials already being developed by the ^{131}I/Nevada Test Site Communication Plan and adding information from the feasibility study. This would be done in phases that could include the addition of iodine doses from global fallout for Option 3 and additional radionuclides from both the NTS and global fallout for Option 4. The goal of these more limited communication plans seems achievable, although in Option 4 supporting information about different radionuclides would have to be added to the communication plan, particularly for affected populations in the eastern part of the United States.

The committee is concerned about the lack of communication planning for Option 1. It appears that for this option only a highly technical final form of the report would be used to communicate the feasibility study's findings to the public. The committee strongly believes that a public summary should be prepared for this option, and this is discussed in more detail below.

The 131I/Nevada Test Site Communication Plan

Much of the communication planning in the feasibility study is based on experience with the ^{131}I/Nevada Test Site Communication Plan, which seeks to communicate to the public the results of NCI's report *Estimated Exposures and Thyroid Doses Received by the American Public from Iodine-131 in Fallout Following Nevada Atmospheric Nuclear Bomb Tests* and which has been evolving and under test for more than 2 years. The plan involves providing materials for various public audiences and educating health professionals. In its thorough and well-developed outline, the plan has followed the basic rules for health and risk communication with attention to audience analysis, risk perception, social and political considerations, and the need for health follow-up advice and procedures.

[9] Statement to the committee of Senator Tom Harkin on nuclear testing fallout report September 12, 2002.

To help to develop the plan, NCI sponsored a conference in January 2000 that involved many people from affected communities, activist groups, state and federal government agencies, and health and risk communication researchers. In particular, the conference included many stakeholders in the ^{131}I fallout areas. It produced excellent recommendations for proceeding with the plan's development, including major community involvement (see Appendix H of the draft report).

The 2000 NCI conference was followed by research efforts with a series of lay focus groups (including representatives of various stakeholder groups) and interviews with experts to refine approaches and methods for the plan.

According to NCI representatives at the committee's open meeting in September 2002, the public communication plan will include a general brochure about ^{131}I exposure, a brochure intended to serve as "a decision aid for people exposed to ^{131}I", and a PowerPoint presentation specially designed for American Indian audiences. Those will be placed on the NCI Web site and distributed in print. The committee saw them in draft form at the September meeting. NCI plans to distribute the materials through community groups, state government health agencies, and health professionals. In addition, an educational plan for health care professionals related to health effects of fallout exposure is described in the draft report of the feasibility study.

Would Adapting the 131I/Nevada Test Site Communication Plan Work for the Feasibility Study?

The ^{131}I/Nevada Test Site Communication Plan could provide a good base on which to build a communication program for the feasibility study. The committee strongly suggests timely disclosure in the development of communication materials for the feasibility study.

The draft report says that materials from the ^{131}I/Nevada Test Site Communication Plan would be distributed, evaluated, and perhaps modified before materials from the feasibility study are added. The committee believes that this would result in too great a delay and that information from the feasibility study should be added as quickly as possible to the ^{131}I/Nevada Test Site Communication Plan brochures and Web materials now under development in order to give citizens a more complete picture of their fallout exposure. The materials could be revised later if problems arose. The committee encourages CDC to take note of the frustration expressed by Senator Harkin and several members of the public about the delay in disseminating the results on health effects of fallout exposure and to make every necessary effort at timely disclosure.

Communication Issues for Option 1

In the feasibility study, Option 1 is limited to the release of a final version of the report of the feasibility study. The draft report of the feasibility study is a generally well-written technical report. Efforts were made throughout to define technical terms as they were used and to explain complicated subjects. The draft report also includes helpful, brief summaries at the beginning of each chapter and a glossary. Those facts notwithstanding, a public summary of the study would

be essential for disseminating its findings to interested members of the public.

The public summary should include the following elements:

1. It should place the projected health effects of NTS and global fallout in the context of other risks.
2. It should explain that, given the available data, the feasibility study cannot provide individuals with their estimated radiation doses and should explain why it cannot do so. It should describe the feasibility study's limitations in a way that the nontechnical public can understand.
3. It should discuss the uncertainties in the feasibility study, why they arise, and their implications for the data discussed in the report of the study.

Accuracy, understandability, readability, and consistency of the message are important for the public summary. Tables, charts, and other illustrations could play a major role in helping members of the public to understand the radiation information.

The committee recommends that a modest communication plan for the distribution of the public summary be developed to plan for its timing, form, distribution network, and possible public involvement, including that of stakeholders and third parties, such as state health agencies.

COMMENTS ON THE OPTIONS FOR FUTURE WORK

The draft report sets forth five options for future work. The authors make no recommendation as to which option they believe to be the most appropriate. Rather, they advance a rationale for the selection of each option, discuss the technical issues associated with it, and describe its probable cost and staffing requirements. The draft report does not identify the benefits associated with each option, nor does it indicate what policy or public-health decisions might be aided by selecting it. The five options identified in the draft report are summarized as follows:

"Option 1. Do no additional fallout-related work.

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

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

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

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

The committee notes that those options are neither mutually exclusive nor exhaustive. They encompass three decisions that need not proceed in the lock-step fashion that the options indicate. Each decision affects choices that can be made independently of the others. The committee suggests that the decisions and choices be framed in some such fashion as the following:

Decision 1: Retrieve and archive documents

Elective 1: Do nothing more.

Elective 2: Archive documents from a certain number of sites believed to be the most likely sources of additional data.

Elective 3: Conduct a comprehensive retrieval and archiving of information from many data sources.

Decision 2: Expanded scientific study

Elective 1: Do no further analysis of doses and risks (inasmuch as the risks from all the radionuclides except ^{131}I are very low).

Elective 2: Redo the ^{131}I analyses of the 1997 NCI report to correct the data and programs where errors have been discovered and to include improvements in dosimetry methods or parameters and in uncertainty-analysis methods that have become available since the 1997 report.

Elective 3: Await the results of the retrieval and archiving of documents. If new data are found that would appreciably change doses and risks, proceed to full-fledged dose and risk assessment.

Elective 4: Proceed with more detailed modeling of doses and risks associated with all radionuclides. If important new data are discovered through the retrieval and archiving of documents, incorporate them. Model the dose and risk uncertainties, incorporating state-of-the-art statistical methods to provide a thorough assessment of uncertainties.

Decision 3: Communication plan

Elective 1: Provide no additional communication effort. The committee believes that this elective is unacceptable.

Elective 2: If the draft report becomes the final product of the feasibility study, develop a public summary as rapidly as possible to add to the feasibility study, to put on the NCI and CDC Web sites, and to distribute as a stand-alone item.

Elective 3: Update materials from the ^{131}I NTS Communication Plan to include results of the feasibility study related to other nuclides at NTS and global fallout. The updating should be as rapid as possible.

Elective 4: Develop an extensive communication plan to make both the feasibility study itself and its results transparent and readily accessible to the American public. The NTS ^{131}I communication project can be used as a blueprint, but both speed and accuracy are important.

3

COMMITTEE RECOMMENDATIONS

In this chapter, the committee sets forth its recommendations. For convenience, it does so under four subject areas.

Estimates of dose from Nevada Test Site and global fallout

The committee recommends that changes be made in the draft report to clarify the assumptions, methods, and uncertainties related to dose estimation. Tables should be used to lay out the sources of uncertainty in the dosimetry and in the estimation of risk. The basis of a "credibility interval" of a factor of 3 for dose estimates should be described in the text in a manner analogous to description of the credibility interval for the risk estimation (given some dose).

CDC and NCI should consider performing a reanalysis of the ^{131}I exposures to the American public that would incorporate new dosimetry-related information from Chernobyl and elsewhere, the contribution of global fallout, a more comprehensive uncertainty analysis, and correction of acknowledged errors in the previous dosimetry. However, the committee does not recommend an expanded study of exposure to radionuclides other than ^{131}I inasmuch as the human doses were much lower than those of ^{131}I, they confer essentially non-detectable increases in individual risk, and the risks are of little public-health significance.

Document location and retrieval

The committee recommends an effort to retrieve and archive additional relevant information about the nuclear-weapons testing program. That means collecting data preserved in various repositories that have not been cataloged and may be in danger of imminent destruction.

CDC should also

- Continue its search for documents not held by governmental agencies and take steps necessary to ensure their preservation.
- Enroll other government agencies, especially the Department of Defense, in the effort to identify, preserve, and publish information.
- Make copies of key documents, the data derived from them, and relevant computer codes or other calculation tools and make them all publicly available, including archiving and providing public access to all the databases and spreadsheets generated by the feasibility study and mentioned in it and its appendixes, together with inputs and calculation tools used for other studies performed for NCI and CDC.

The committee also recommends that CDC urge Congress to declare a government-wide moratorium on the destruction of documents that are potentially pertinent to measuring fallout in the United States and to mandate declassification of historical fallout-related records.

Estimates of cancer and non-cancer risks

The committee recommends that more emphasis be placed on levels of individual risk and the associated uncertainty and less on population risk from collective dose. Although collective dose and population risk may have some public health utility if the doses are significant in the context of doses and risks from other sources, they fail to show the size of the risk that individuals are likely to experience, which is the key consideration for concerned citizens and for most public-health implications. It is also important that the executive summary and text compare putative lifetime risks posed by fallout with risks posed by natural background irradiation and with natural lifetime risks. Such comparisons will help to provide a perspective for the general public to better understand the risks related to fallout.

The potential that the dose-response association might have a substantial upward quadratic component or a threshold should be considered in modeling the risk of leukemia posed by fallout radiation.

There is no evidence that radiation doses of the magnitude sustained from NTS or global fallout cause any of the major non-cancer diseases (cardiovascular, respiratory, digestive or genitourinary). A conclusion to this effect would therefore be appropriate.

Communication with the public about exposure and cancer risk

The committee recommends that CDC follow these steps related to communication issues

1. Develop a detailed public summary and a communication plan for its distribution. The public summary should provide information that can be readily understood by the lay public, including comparison of background radiation with the radiation doses

discussed in the report of the feasibility study and a description of the important uncertainties (related to dose and risk) that apply to the feasibility study.

2. Phase information from the feasibility study into the ^{131}I/Nevada Test Site Communication Plan in a timely fashion to give interested American citizens a more complete picture of their exposure to NTS and global fallout with appropriate explanations of relative health risks.
3. If Option 5 is adopted and important new scientific work develops, produce a timely major educational effort that builds on the efforts of the communication plan for the ^{131}I/Nevada Test Site study.
4. Make studies on radiation exposure of US citizens transparent and accessible to interested individuals. The committee recommends that interested citizens take part in the study process and, with scientific and social science experts, serve as members of advisory boards for such studies.
5. Hold a follow-up conference, similar to the one sponsored by NCI on risk communication (January 2000), as part of the continuing CDC effort to develop effective guidelines for communicating radiation risk to the American public.

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Appendix A

SPECIFIC COMMENTS

The terms *representative persons* (for example, in the abstract and on page 2) and *representative individuals* (as on page 57) should be avoided; they have connotations that some person—in fact, maybe most people—actually received the dose in question.

The term *population weighted* needs clarification and definition.

It should be made clear that the uncertainty of the fission-to-fusion ratio most likely led to an overestimate of the dose.

Page 25

Change "designated" to "detonated".

Table 3.1

Give a reference.

Page 39, last paragraph

"Therefore, the doses that are presented in this report are those arising from the decay of gammaemitting radionuclides deposited on the ground…" Such references to dose give the false impression that doses are well known (that is, are without significant error). It is recommended that references to dose in the report be indicated as "dose estimates" where appropriate.

Equation 3.1

There is confusion related to the subscript R. As the equation is written, there is a need for a different subscript for E, perhaps E_i to refer to the "effective dose from radionuclide i". Then the subscript R can be used with w as specified by ICRP as the *radiation*-weighting factor. This change is required because a radionuclide can emit radiation with different weighting factors. With those suggested changes, the equation will correctly read that the effective dose of a given radionuclide is summed over all radiation and tissue-weighting factors.

Page 44

"If further work is conducted, it should include ^{239}Np in the internal dose calculations." What is the basis for this recommendation? What fraction of internal dose has been omitted because ^{239}Np is omitted here?

Page 46, second paragraph

It is stated that "the total deposition of Cs-137 from all Nevada Test Site tests considered in this report through 1962 is shown in Figure 3.1." The information presented in the figure is displayed as deterministic (that is, without any error or uncertainty). It is recommended that the uncertain nature of the information presented be mentioned.

Page 48

"For most of the country, the amount of cesium was 10 to 20 times the amount of plutonium deposited." That must mean on an activity basis. It should read, presumably, "…the activity of cesium was…." In addition, Table 3.5 indicates that the activity ratio applies for $^{239+240}$Pu, not including ^{241}Pu.

Page 50

"…all Nevada Test Site tests, 34% of the ^{137}Cs produced was deposited in the contiguous United States." Were similar calculations made for the other nuclides? It might be useful to make a similar observation for the other radionuclides, and comment (if necessary) on the differences between the fractions deposited for each radionuclide.

Page 50, Figure 3.5

Results for the fraction of total ^{137}Cs deposited in the United States from the NTS by year of test are presented as exact values (without error). It is recommended that the results be more appropriately described as approximations. This recommendation also applies to other inappropriate deterministic statements in Chapter 3 related to calculated results.

Page 51ff, Section 3.2.2

The discussion in this section relating exposure, external dose, effective dose, and absorbed dose is confusing. It switches illogically between exposure and dose, with non sequiturs. There is also a disconnect between the radionuclide-weighting factors of Equation 3.1 (not discussed in the text) and the radiation-weighting factors discussed later in the text.

Page 52

"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)." That statement must apply to situations where the deposition is on well-characterized surfaces. For deposition on surfaces in general, the uncertainty is probably higher.

Page 53

It is recommended that where effective dose is introduced it be pointed out that the effective dose is a hypothetical dose in that it is based on use of the hypothetical linear no-threshold risk model.

Page 54, lines 18–20

The authors should note that this relationship applies only to low-LET radiations.

Page 54, first full paragraph

This paragraph is confusing, coming just after a discussion of the relation of effective dose to absorbed dose (Equation 3.1 and following text). The reader is given an approximate relation between exposure and effective dose, and then external dose related to effective dose ("numerically equal").

Page 54, first full paragraph

Does this mean the roentgen-to-sievert conversion is 0.0066, or should it be 0.0093?

Section 3.2.2

The section on external dose should be rewritten for clarity. There is an amalgamation of SI and traditional units, which is confusing.

Page 55

The discussion indicates that an assumption of about 80% indoors leads to an effective dose of about 44% of the outside dose. It does not, however, state what assumption was actually used for the feasibility calculations. The discussion is further confused by the later paragraph that indicates a range of 4-fold lower to 4-fold higher; the report should probably illustrate circumstances in which the effective dose is twice the outside dose.

Page 55, third paragraph

"The actual dose to a person who lived in the United States during the years of fallout should generally lie within a range from one-fourth as large as these estimates provided here to about four times larger than these estimates." How could such a conclusion be considered reliable on the basis of the limited study conducted?

Page 57, top of page

It is not clear how a person's diet would affect estimates of external dose, which is what is discussed immediately before and after the statement. The statement made here is strictly correct in that it refers to estimates made throughout the report, but it is misleading in context.

Page 58, Table 3.4

It is not clear what the footnote in this table is to refer to or why it may be important.

Pages 59–60

The discussion of what was done for this feasibility study is misleading. Page 59 states that "the general ORERP method is described here because it was used for these feasibility calculations." That is incorrect. Page 60 implies that various mathematical models were used as components of this feasibility study (or possibly as components of the ORERP method), but in fact published data that summarize the outputs of such mathematical models were used (even in ORERP). For example, the dose coefficients F_g are obtained from such mathematical models. However, the models were not themselves part of this feasibility study, as implied; the dose coefficients F_g were obtained from ICRP publications. Similarly, the integrated intakes, I, were not obtained by running the PATHWAY model, as implied in the discussion here. Instead, they were *interpolated* from some published outputs of the PATHWAY model. The discussion should be reformulated to indicate what was done.

Page 62, line 2

Change ^{91}S to ^{91}Sr.

Page 67, line 9

The text says that the thyroid doses to adults are generally lower by a factor of 10 than doses to a child born on January 1, 1951. However, Table 3.6 indicates that the differences in population-weighted values are only a factor of 6. Are the two statements correct and consistent?

Page 69, 2 lines below Table 3.7

Change "10 tests" to "16 tests".

Page 81, lines 8–10

Clarify what is meant by "somewhat conservative".

Page 86, line 5

Change "east" to "west".

Table 3.14, Footnote a

The U.S. Census bureau (http://eire.census.gov/popest/archives/pre1980/popclockest.txt) indicates that the 1960 population of the United States was 1.81×10^8, not 1.63×10^8. Some explanation of the difference is desirable.

Page 102, Figure 3.24

The legend of Figure 3.24 and the Y-axis legend do not agree. It looks as though they should both refer to μSv PBq^{-1}.

Page. 109, line 8 below Table 3.21

Delete "of" between "significant" and "amounts".

Page 116, line 14

"Larger" than what?

Page 129, end of second paragraph

This sentence hints at, but does not say, that there may be no risk of heart disease and a variety of other nonneoplastic diseases at the doses under consideration. It should be explicitly stated.

Page 131, lines 1–2

It is an overstatement to say that the uranium-miner data constitute the only exception to the inferior contribution of radiation studies other than the atomic-bomb data. As one counterexample, the Canadian multiple-fluoroscopy study has more moderate- to high-dose data with respect to lung and breast cancer than the atomic-bomb study does.

Page 136, first full sentence

The committee suggests that the mechanistic rationale of Dilwyn Williams (2002) be mentioned as a reason for the age difference in radiosensitivity, namely, that the thyroid epithelial cells have the capacity for only a finite number of replications and that radiation exposure occurring when the cells are in replicative senescence in early adulthood will induce little or no cancer.

Page 138, last full sentence

The evidence that "the rate of increase in risk [of benign tumors] with dose is generally similar to that for cancer" is extremely small. One could make a case on the basis of various studies that benign-tumor risk is greater than, equal to, or less than the cancer risk, but the generality of any assertion would not be very convincing.

Page 139, middle of page

It is stated that "thyroid adenomas do not appear to have a malignant potential." That is controversial; as some thyroid pathologists (such as Dilwyn Williams) believe the contrary, and a recent pooled study of thyroid-cancer etiology showed that thyroid-cancer risk is associated with a history of thyroid nodules (Franceschi et al. 1999).

Page 139, regarding benign thyroid tumors

"There are no data that provide quantitative information on risk estimates" is an overstatement. One can derive quantitative information (albeit of variable quality) from a variety of studies, such as those on tinea capitis (Ron et al., 1989), the thymus (Shore et al., 1993), lymphoid hyperplasia (Pottern et al., 1990), thyrotoxicosis (Dobyns et al., 1974), NTS fallout (Rallison et al., 1990), high-background areas (Pillai et al., 1976; Wang et al., 1990), the Nagasaki atomic bomb (Nagataki et al., 1994), thymus and cervical adenitis (Maxon et al., 1980), and tonsils and nasopharynx (Royce et al., 1979).

Page 141, middle paragraph

"The excess non-neoplastic disease in the atomic-bomb survivors is seen at a level below that given for medical purposes" is a misstatement. It is not seen below medical diagnostic-procedure levels; "for medical purposes" should be changed to "for radiotherapy".

Page 141, middle paragraph, last sentence

It is not just the "lack of a clear dose-response curve" that limits quantitative assertions but also the lack of support for an effect at low to moderate doses in animal studies. It would be more appropriate for the sentence to indicate that no effect has been demonstrated at low to moderate doses.

Page 142, end of middle paragraph

It is suggested that the last sentence read, "non-cancer health effects, and there is no clear evidence of any risk at low doses."

Page 143, top of page

The discussion highlights the uncertainties in the risk projections and raises the question of whether, given the uncertainties, they "can be useful for developing public health policy." The text then proposes to address the question by providing "preliminary example estimates of population risk." In the case of radionuclides other than ^{131}I, for which the incremental risk from fallout exposure is small, population risk provides little or no useful information for setting public-health policy, because "collective dose" does not convey the important fact that risk to the individual is almost negligible.

Page 144, end of first paragraph

This statement implies that the relationship between lifetime risk and radiation dose is linear. Earlier, it was stated that the leukemia risk was nonlinear. If linearity is to be assumed, the assumption should be explicitly stated and justified.

Page 145, first full paragraph

This discussion of using the "average risk" fails to note that the average risk represents the

average lifetime likelihood that people in a particular group will develop cancer and thus is itself more important than the "estimated number of radiation-induced cancers in the population."

Page 146, third paragraph, last sentence

The statement that "statistical uncertainty tends to be larger when risks are small than when they are large" is true if the magnitude of uncertainty is viewed on a relative basis (the ratio of the uncertainty to the risk) but not on an absolute basis. Similarly, the statement beginning on page 148, four lines from the bottom, should be "The relative uncertainties…"

Page 146, bottom, and page 147, top

Other important potential biases in studies of radiation effects that are not mentioned are selection biases and surveillance biases.

Page 148, first paragraph, last sentence

That a threshold "hypothesis is not supported by currently available data" is an overstatement. Consider bone cancer, lymphoma, soft-tissue sarcoma, and possibly skin cancer. For each of those, the case for a threshold is moderately strong.

Page 149, next-to-last line

Why does the discussion of RBE refer to "tissue damage" rather than disease risk? Tissue damage has its own set of parameters that are not necessarily congruent with, for example, those of cancer induction.

Page 150, first paragraph

The text mentions the likelihood that relative risk decreases over time, but this is not explored in the context of the risk estimates set forth to describe the possible effect of a temporal decrease in risk in reducing lifetime radiation risk. With regard to thyroid cancer, the most important cancer considered in this report, there is a highly significant reduction in thyroid-cancer relative risk with time; if factored in, it reduces the lifetime risk of thyroid cancer after childhood exposure by about 40–60% (Shore & Xue, 1999).

Page 150, four lines from bottom

To say merely that quantifying uncertainty "requires subjective judgments" makes it appear that the process is simply guessing. It might be better to indicate that judgments are based on the weight of available scientific evidence and attempt to characterize uncertainty on the basis of that evidence with bounds that reflect the available data.

Page 151, end of second paragraph

The sources of uncertainty in dose estimates should refer to the location in Chapter 3 where this information is given, and additional uncertainties in risk estimation (such as statistical variability, uncertainties about DDREF, and the shape of the dose-response curve) should be clearly summarized here, rather than requiring the reader to try to find them in Chapter 3.

Page 151, last full sentence

This sentence is ambiguous. Is it saying that only NTS thyroid doses would be received in childhood, so that the global thyroid doses that would be received mainly a decade or more later

would not have much effect? (That would be true only of those who were born in the early 1950s, not of other birth cohorts.) Or is it saying that thyroid doses from global fallout were much lower than those from NTS fallout? The sentence needs to be reworded to be clear and accurate.

Page 153, bottom, and page 154, top

The sentence juxtaposes the estimated 11,000 lifetime cancer deaths from fallout with the 500,000 yearly "spontaneous" cancer deaths—an inappropriate comparison because one is yearly and the other is lifetime. Although it next mentions the lifetime "spontaneous" cancer deaths, the text is misleading. The next sentence uses a figure of 22,000 excess cancer cases but gives nothing to compare that number with.

Page 154, middle paragraph, line 6

It should read "(a lifetime risk of about 1 in 16,500)".

Page 155, Table 4.1

This table should include a column to give the percentage of cancers that are estimated to be caused by fallout (or perhaps more understandable wording would be, for example, "one of every 3,300 cancers was possibly caused by fallout"). The table (or a separate table) should also present a similar summary for the total population of 163–250 million who are described in the text.

Page 156

There seems to be a discrepancy: the top of the page gives a median estimate of 7,400 cancer deaths, but the last paragraph says 11,000.

Page 157, line 2

That the total-body doses were low and had relatively little variation by geographic region, age, and so on, "makes it more difficult to identify groups with particularly large risk" conveys the idea that the object of the exercise is to find groups with large risks. It might be better worded, "means that there are unlikely to be groups with large risks associated with fallout radiation". Similar wording on page 166, last line, should also be changed; the present wording suggests that small regional variations in whole-body dose are unlikely to be correlated with regional variations in radiation-induced disease gradients.

Page 157, third paragraph

The statement that "increased rates of leukemia have been reported in persons living downwind of the Nevada Test Site (Stevens et al., 1990)" stretches the finding. The result was not statistically significant except in one subgroup. Similarly, an earlier study of childhood leukemia among NTS "downwinders" found no excess leukemia (Lyon et al., 1979).

Pages 157–158, Section 4.3.3.3

The section does not mention the possibility of a threshold or a quadratic curve for leukemia, as shown in the atomic-bomb study.

Page 162, last paragraph

Differences in the natural frequency of disease—for example, high gastric cancer and low prostatic and breast cancer in the Japanese as contrasted with Caucasians pose a challenging problem. The statement that little can be done to reduce "uncertainties in using estimates from Japanese atomic bomb survivors for a United States population" appears to be premature. There has not yet been a thorough attempt to analyze the atomic-bomb study and the available studies in Western populations in parallel for a number of tumor sites so as to permit better extrapolations across populations. The current Biological Effects of Ionizing Radiation (BEIR VII) report may improve the state of affairs appreciably, although admittedly this is a difficult problem.

Page 163, first sentence

The claim that data were presented to describe the relationship between radiation and benign tumors of the thyroid, stomach, and other sites and heart disease is specious. No such data were presented.

Page 163, end of second paragraph

What is the basis for the speculation that "individuals with pre-existing disease could be more radiosensitive"? What pre-existing disease and what type of cancer are being referred to? Perhaps different genetic polymorphisms or mutations, and conditions such as ataxia telangiectasia and Bloom's syndrome?

Page 165, middle paragraph

It would be appropriate to add the Hanford study results to the statement of no evidence of a radiation-related increase in nonneoplastic thyroid disease in Chernobyl.

Page 167, end of first paragraph

The text states that the "most likely non-cancer health outcomes are those affecting the thyroid gland" but does not state that other noncancer relationships are very unlikely.

Appendix 1 of Appendix D

This appendix presents an example related to exposure evaluation, using a method to evaluate cumulative exposure to external gamma radiation over the interval 20 d to 200 d relative to time of arrival (TOA). For gamma radiation from ^{137}Cs deposited in soil, the exposure rate at time t during 20 to 200 days after TOA is given by

$$I(t)=[Cs(20d)]\times(6.15E\text{-}03)\times(24)\times\exp(-\lambda t),$$

where Cs(20d), in mCi/km^2, is the deposition density for ^{137}Cs (per unit ^{131}I) 20 d after detonation; the parameter value 6.15E-03 is in μR/h per mCi/km^2; and the value 24 converts days to hours. While t is not explicitly defined, the equation and the value given of 6.15E-03 (Beck, 1980) requires that it be the time since 20d after TOA. The integral from 20 d to 200 d, I(mR), is indicated to be

$$I(Mr)=\{[Cs(20d)]\times(6.15E\text{-}03)\times(24)\times1/\lambda\times[\exp(-20\lambda)-\exp(-200\lambda)]\}/1000.$$

Since t is time after 20 days from TOA, the second expression contains a systematic error: the cumulative exposure for the interval is underestimated by a factor of exp(20λ). If this is truly a calculation error, rather than simply a documentation error, it could be large. However, this appears not to be a problem for ^{137}Cs, in that λ is small. The impact of the error would depend on how many of the short-lived radionuclides considered had substantial gamma emissions. External gamma-ray exposure-calculation methods used should be checked for the possibility of the indicated systematic error. If it is determined that such an error exists, its impact should be evaluated for each gamma-emitting radionuclide of interest.

The committee suggests that the glossary include radioactive elements referred to in the text with only chemical symbols and include explanations of various models (such as linear no-threshold and linear-quadratic). The models are important in interpreting data in Chapters 3 and 4.

APPENDIX B

COMMITTEE ACTIVITIES

To undertake the review, the Research Council established a committee consisting of members of its Committee on an Assessment of the Centers for Disease Control and Prevention Radiation Studies from DOE Contractor Sites and other experts.

CDC asked the National Research Council to review the CDC-NCI draft report *A Feasibility Study of the Health Consequences to the American Population from Nuclear Weapons Tests Conducted by the United States and Other Nations*. In accordance with the policies of the National Academy of Sciences, the committee conducted its fact-finding activities in public meetings and met in closed session only to consider findings and recommendations. At its first meeting, the committee examined its own composition to make certain that necessary expertise and perspectives were represented and that no important conflicts of interest or bias existed. The expertise sought in this group included health physics and dose assessment (pertaining to both external radiation and internal emitters), radiation chemistry, radiobiology, nuclear medicine, ethics, epidemiology, biostatistics, modeling, and risk assessment and communication. The committee's task is outlined in the beginning sections of its report.

The committee met four times in 2002: on April 26–27 in Washington, DC; on July 15– 16, in Washington, DC; on September 12–13, in Des Moines, Iowa; and on November 14–15, in Washington, DC. Two of the meetings included information-gathering sessions. Members of the public were given the opportunity to ask questions or make comments about the CDC-NCI draft report.

FIRST COMMITTEE MEETING

On the first day of its first meeting, in open session, the committee and observers were briefed on the findings of the CDC-NCI feasibility study by Charles Miller of CDC and André Bouville, Steve Simon, and Ethel Gilbert of NCI. Lynn Anspaugh and Harold Beck, consultants for the study, were also present to address committee questions related to dose reconstruction. On the second day, the session was closed for the committee to begin to explore its plans to respond to its charge and develop its report.

SECOND COMMITTEE MEETING

The second meeting, 1 1/2 days long, consisted of a closed session for the committee to discuss its preliminary views on the CDC-NCI draft report and begin the drafting of its findings and recommendations.

THIRD COMMITTEE MEETING

The third meeting, a full-day session open to the public, was dedicated to gathering information and the views of the public and technical experts on the implementation, power, and presentation of the CDC-NCI draft report and on a variety of issues related to communication of the report to the public. Notices inviting the public to attend the meeting went to the NCI ^{131}I email list, Senator Tom Harkin's office, the press and news media in Iowa, and over 15 citizen advisory and public-interest groups. Almost 20 people attended the meeting, including members of the press from Iowa.

The public meeting was structured to solicit comment from technical experts and laypersons on three topics: dosimetry and uncertainty, archiving and evaluation of other data and other kinds of evidence that shed light on possible health effects, and communication of information in the final report in written and oral forms. Each topic was discussed for about an hour by the invited speakers and committee members and was then the subject of an extended open-microphone session. Attendees were invited to make oral statements or to provide written questions, concerns, and comments to the committee. Written submissions from those who could not attend the meeting were solicited.

The three topics were discussed as follows:

Dosimetry and Uncertainty

- Lynn Anspaugh, University of Utah (invited speaker)
- Jane Magers (Earth Care) and Dane Spencer (spoke during the open-microphone session)

Other Evidence and Contextual Information Related to NTS and Global Fallout Exposures

- Owen Hoffman, President and Director, SENES Oak Ridge, Inc. (invited speaker)
- Merle P.Prater (spoke during the open-microphone session)

Issues of Communication

- James Thomas, Paralegal, Short Cressman and Burgess (invited speaker)
- Margaret Farrell, MPH RD, Office of Communications, NCI (invited speaker)
- Margaret Rowland (Earth Care) and Perry Beeman (Des Moines Register) (spoke during the open-microphone session)

During an open-comment session, oral statements were presented to the committee by John Moreland (staff assistant in Senator Harkin's office), Lisa Ledwidge (Institute for Energy and Environmental Research), Susan Gordon (Alliance for Nuclear Accountability), and Dane Spencer. Written statements were provided to the committee by Robert K.Musil (Physicians for Social Responsibility), Trisha Pritikin, Seth Tuler, Rob Goble, Octavia Taylor, and Abel Russ.

The meeting, which ran from 9 a.m. to 5 p.m., provided a forum for the committee to listen to technical and public statements and opinions concerning the design, implementation, analysis, and communication of the CDC-NCI draft report. In addition to formal presentations,

informal communication between committee members, invited speakers, and members of the public occurred during the coffee breaks and at lunch. All the information gathered at the open meeting is part of the National Research Council's public-access file and is available, on request, to anyone interested in it.

FOURTH COMMITTEE MEETING

The fourth and final meeting of the committee consisted of closed sessions to review and discuss the fourth draft of this report.

GLOSSARY

ABBREVIATIONS, ACRONYMS AND DEFINITIONS

ABCC (Atomic Bomb Casualty Commission)	—the research program sponsored by the Japanese Ministry of Health and Welfare and the US Department of Energy charged with the responsibility for the study of the survivors of the atomic bombings from the inception of the investigations in 1947 until it became the Radiation Effects Research Foundation (RERF) in 1975. The successor was called RERF (see below).
Absorbed dose	—radiation energy deposited in a volume of tissue or other material divided by the mass of this volume. The SI unit of absorbed dose is J/kg; its special name is gray (Gy). In the USA, the unit 100 erg/g is often used with the special name rad. The conversion is 100 rad=1 Gy.
Absorbed dose rate	—absorbed dose per unit of time. High dose rates are usually more damaging to humans and animals than low dose rates. This is because repair of damage is more efficient when the dose rate is low. For the very low doses and dose rates that were associated with fallout from nuclear testing around the world, there are large uncertainties about risks of harm from radiation exposure, because these radiogenic contributions are at most very small when compared to contributions from other sources, e.g., “spontaneous” normal processes of living.
Activity	—the number of nuclear transformations occurring in per unit of time. The SI unit of radioactivity is the becquerel (Bq) (see below). AEC (Atomic Energy Commission)—the agency of the U.S. government that became the Department of Energy and the U.S. Nuclear Regulatory Commission (USNRC).
Alpha particle	—a charged particle having the same mass and charge as that of a helium nucleus stripped of its electrons. Alpha particles are emitted by some heavy elements that include uranium, plutonium, and radon. These particles have a very short range (about 60 μm in tissue) and in most cases will not penetrate a piece of paper.
Atom	—the smallest particle of an element that cannot be divided or broken up by chemical means. It consists of a central core of protons and neutrons, called the nucleus. Electrons revolve in orbits in the region surrounding the nucleus.
Ataxia telangiectasia	—a hereditary disease connected with decreased DNA repair capacity and, thus, with an increased sensitivity to ionizing radiation.
Atmospheric testing	—detonating a nuclear weapon or device in the atmosphere or close to the earth’s surface with release of radioactivity to the atmosphere as part of the testing program.
Atomic bomb	—a term sometimes applied to a nuclear weapon using fission energy only.

Background radiation	—the type of ionizing radiation to which a person is exposed from natural sources such as cosmic radiation originating in space, or terrestrial radiation due to naturally occurring radionuclides in the soil or air, or radiation from natural radionuclides incorporated in the makeup of the body.
Becquerel (Bq)	—the special name for the unit of radioactivity equal to the number of disintegrations per second (s^{-1}). The older special name for a different unit of activity was the Curie (Ci), which was equal to 3.7×10^{10} disintegrations per second; the becquerel introduced with the system international (SI) in 1981 is equal to 1 disintegration per second. Thus, 1 Ci is equal to 3.7×10^{10} Bq.
BEIR	—a series of National Academy of Sciences' studies conducted by committees on the biological effects of ionizing radiations (BEIR VII is the current study).
Benign	—a general category of tumors that does not invade surrounding tissue. Benign tumors are characterized by slow growth through expansion. Such tumors are usually not referred to as cancer.
Beta particle	—an electron (positive or negative) emitted during decay of some isotopes. Beta particles have a short range in air (less than a few meters) and even shorter range in more dense material (less than a few mm in tissue). Beta-emitting isotopes (e.g. strontium-90) deposited on the skin in large amounts can cause skin burns and other more serious effects. Many of the radioactive isotopes found in fallout are beta emitters.
CDC	—Centers for Disease Control and Prevention (http://www.cdc.gov/).
Cesium-137	—a beta-particle and gamma-ray emitting isotope of cesium. Cesium-137 is a major long-term pollutant of fallout from nuclear testing. It has a physical half-life of 30 years.
Chain reaction	—a reaction where fissile atoms (e.g., atoms of uranium-235) absorb neutrons, then split, releasing energy and more neutrons, which in turn cause additional atom splitting and neutron releases so that the process continues. Nuclear weapons tests that were conducted around the world were based on uncontrolled chain reactions. Fission fragments arising from the atom splitting are radioactive and appear in fallout.
CI (confidence interval)	—a range about a parameter estimated in a trial that, in some predetermined proportion of trials, will include the true value of that parameter. Commonly, this proportion is selected to be 67, 90 or 95%.
Collective dose	—see collective effective dose.
Collective effective dose	—quantity obtained by multiplying the average effective dose by the number of people exposed to a given source of ionizing radiation. It is usually expressed in man sievert (man Sv).

Correlation —the degree of association between two variables, such as height and weight. It is customarily measured by a unitless coefficient, known as the correlation coefficient that varies between -1 and +1. A correlation coefficient of 0 implies no association, whereas a value of -1 or +1 implies a perfect association, one variable increasing while the other decreases in the first instance, and both increasing in the second. It should be noted that the existence of a non-zero correlation coefficient is not sufficient (nor, strictly, is it necessary) to demonstrate causality.

Curie (Ci) —originally, the special name for the amount of radioactivity in 1 gram of radium-226. One curie was subsequently (for precision) redefined to equal 37 billion radioactive disintegrations per second. To convert the specification of an amount of activity in curie to that in microcurie, multiply by one million. Conversely, to convert from a specification in microcurie to curie, divide by one million. The curie is not an SI unit. The corresponding SI unit is the becquerel. One microcurie equals 37,000 becquerel.

Decay constant —the average fraction of atoms of a radioactive nuclide that decays per unit of time divided by that unit of time (s^{-1}).

DHHS —Department of Health and Human Services-(http://www.dhhs.gov/).

DOD —Department of Defense (http://www.dod.gov/).

DOE —Department of Energy (http://www.doe.gov/). The DOE is responsible for developing and producing nuclear weapons and for the sites at which weapons materials have been produced and handled.

Dose —general term for the quantity of energy absorbed from ionizing radiation in a volume of a material divided by its mass. See absorbed dose, equivalent dose, effective dose, and collective effective dose. Often used in risk assessment as an abbreviation for effective or organ dose.

Dose coefficient —a factor used to derive an organ or effective dose from radionuclide intake by members of the general public. It is usually expressed as a dose in Sv per unit intake in Bq, e.g., Sv Bq^{-1}.

Dose, equivalent —a quantity that expresses an equal biological effectiveness of a given absorbed dose on a common scale for all kinds of ionizing radiation. The equivalent dose is now most commonly expressed in sieverts (Sv), but has, in the past, been stated in rem. See rem and sievert.

Dose reconstruction —a scientific activity that estimates doses to people from releases of radioactivity or other pollutants. The reconstruction is usually done by determining how much material was released, how it was transported, and how people came in contact with it and the amount of radiation energy absorbed by their bodies.

Dose-response curve (or relationship)	—the mathematical representation of the change in an effect due to irradiation with increasing dose. For cancer induction, the most commonly used relationships assume this increase to be either linear, linear-quadratic, or quadratic with dose (see below for definitions of these terms).
DDREF	—dose and dose rate reduction effectiveness factor, a measure of the extent to which radiation-related damage accruing at a high dose rate is ameliorated when the dose rate and/or dose is low. This value will presumably vary with the endpoint measured, but it is not known precisely for such endpoints as incidence of, or death due to, cancer or any of the other effects seen also among the atomic bomb survivors.
DS86	—the currently employed system of dosimetry used to describe the exposure of the survivors of the atomic bombings of Hiroshima and Nagasaki; introduced in 1986.
Effective dose	—a calculated dose quantity obtained by multiplying the equivalent doses to various tissues and organs by a tissue/organ weighting factor appropriate to each and summing the products. The unit is J/kg; its special name is sievert (Sv). The expression “effective dose” has replaced the earlier “effective dose equivalent”.
Electromagnetic radiation	—the propagation of energy in the form of electromagnetic waves through space. Examples: light, radio-waves, gamma rays, x rays. All can be transmitted through a vacuum.
Electron	—an elementary particle with a mass 1836 times smaller than that of a proton and which carries negative charge. Electrons orbit around the nucleus and determine the chemical properties of an atom. Electrons are emitted by radioactive atoms in a beta decay.
EML	—Environmental Measurements Laboratory in New York City, formerly known as the Health and Safety Laboratory (HASL).
Equivalent dose	—a quantity obtained by multiplying the absorbed dose by a radiation-weighting factor to allow for the different effectiveness of the various types of ionizing radiations in causing late effect harm in tissue. The equivalent dose is theoretical and has replaced the earlier dose equivalent. The equivalent dose is often expressed in sievert (Sv). It is also sometimes expressed in rem (an older unit). One hundred rem equals 1 Sv.
Erg	—Unit of work done by the force of one dyne acting through a distance of one cm. (units, dyne-cm or gm-cm^2/sec^2).
Excess mortality	—the amount by which the number of deaths observed in a group exceeds the number expected.
Expected baseline mortality	—a baseline standard of mortality that would be expected absent the exposure under study; can be calculated from standard population rates or from an unexposed comparison population.

Exposure (radiation) —is a measure of the amount of ionization produced by x rays or gamma rays as they travel through air. The unit of radiation exposure is the roentgen (R), named for Wilhelm Roentgen, the German scientist who in 1895 discovered x rays.

Fallout —radioactive material (particles, vapors, and gases) from a nuclear explosion (e.g. atomic weapon or nuclear accident such as occurred at Chernobyl). The particles gradually fall from the sky and deposit on the ground and on other surfaces, while vapors may condense to form particles, and vapors and gases may stick to particles and similarly deposit. Small fractions of the materials may also be inhaled. Animals such as cows and goats can ingest the radioisotopes from fallout through grazing and pass the isotopes such as iodine-131 to humans via the food supply. Rainfall may help scour particles, vapors, and gases from the atmosphere as washout and rainout, which are efficient modes of radioactivity transfer from the atmosphere to the biosphere.

Fissile —isotopes that can split (break up) when hit by a low-energy neutron. The fissile isotopes uranium-235 and plutonium-239 are used in nuclear weapons.

Fission —the splitting (breaking apart or fissioning) of the nucleus of a heavy atom such as uranium-235 or plutonium-239. The fission, usually caused by the absorption of a neutron, releases large amounts of energy. Nuclear bombs used in Hiroshima and Nagasaki were based on nuclear fission induced by neutrons.

Fusion —a nuclear transformation characterized by the joining together of two light nuclei under extreme pressure and heat that results in the release of a substantially larger fraction of mass-energy conversion than occurs in fission.

Gamma rays —high-energy, penetrating electromagnetic radiation emitted in the radioactive decay of most radionuclides. Gamma rays are similar to x rays, but x rays have lower energy.

Gray —special name of the unit of absorbed dose J/kg (joules per kilogram), equal to 100 rad, named after the English biophysicist, Louis Harold Gray.

Half-life, physical —the average time it takes for one-half of any given number of unstable atoms to decay. Half-lives of isotopes range from small fractions of a second to more than a billion years. As an example, if on average 100 out of 200 radioactive atoms of a specified kind decay in 1 day (half-life=1 day), then of the remaining 100 atoms, 50 would be expected to decay during the second day. Similarly, 25 of the remaining 50 atoms would be expected to decay during the third day. This type of decay is called exponential.

Half-life, biological —the time required for the elimination of half of a substance, such as a chemical, from the body when the fraction of the remaining material removed each hour is approximately constant. For a biological half-life of 1 hour, 1/2 of the material would be expected to be eliminated during the first hour. Of the material that remained, 1/2 would be expected to be eliminated during the second hour. This represents 1/4 of the

initial material present. Thus, for each successive hour, the expected fractions of the initial material present that are removed would be 1/2, 1/4, 1/8 and so on. This type of decrease over time is called exponential.

Half-life, effective —the time required for the activity of a radioactive substance in the body to decrease to 1/2 its value due to the combined effects of biological elimination and radioactive decay. The effective half-life facilitates evaluating radiation dose from inhaled and ingested radionuclides and applies when the biological and physical half-lives are constant. For an effective half-life of 1 hour, 1/2 of the radioactivity would be expected to be eliminated during the first hour. Of the radioactivity that remained, 1/2 would be expected to be eliminated during the second hour. This represents 1/4 of the initial radioactivity present. Thus, for each successive hour, the expected fractions of the initial radioactivity present that are eliminated would be 1/2, 1/4, 1/8 and so on. This type of decrease over time is called exponential.

Half-life, radioactive —see half-life, physical.

High-LET radiation —radiation with linear energy transfer (LET) values above, say, 10 keV/μm. It produces much damage over a short distance in tissue or other material. In contrast, low-LET radiation produces only a small amount of damage when evaluated over the same amount of deposited energy. Alpha particles represent high-LET radiation. Gamma and x rays represent low-LET radiations. To produce a given amount of damage, it generally takes a larger absorbed dose of low-LET radiation than for high-LET radiation. Also, biological damage produced by low-LET radiation is often more efficiently repaired than damage produced by high-LET radiation.

IAEA —the International Atomic Energy Agency, one of the specialized bodies of the United Nations charged with the responsibility of overseeing and setting standards and recommendations for the operation of nuclear activities and for radiation safety in the member states. It is headquartered in Vienna, Austria, and its members have played a major role in the accumulation and dissemination of the information derived from the Chernobyl accident as well as other accidents involving exposure to ionizing radiation.

ICRP —the International Commission on Radiological Protection, a nongovernmental agency headquartered in the Sweden and the United Kingdom, concerned with radiation protection in the workplace and of the general population. It was founded by the International Congress of Radiology in 1928. It is generally viewed as the world's leading source of authoritative statements on radiation protection.

ICRU —the International Commission on Radiation Units and Measurements, a nongovernmental agency headquartered in Bethesda, MD, USA, concerned with recommendations regarding harmonized measurement of radiation and responsible for recommending nomenclature for quantities, units and their special names, e.g., Bq, Gy, Sv.

Incidence —the number of new cases of a specific disease occurring during a certain period of time. See prevalence.

Integrated intake —the estimated intake of a radionuclide summed over time in an area having a specific deposition density. Commonly specified in Bq per Bq m^{-2}.

Iodine-131 (^{131}I) —a radioactive isotope of iodine. Iodine is an element required in small amounts for healthy growth and development. It is mainly concentrated in the thyroid gland where it is needed to synthesize thyroid hormones. ^{131}I is used as a radioactive tracer in nuclear medicine and is found in fallout from nuclear testing. ^{131}I has been demonstrated to cause thyroid cancer in humans after moderate and high doses following the Chernobyl accident. Whether very low radiation doses causes thyroid cancer is uncertain. Iodine-131 has a relatively short half-life (8 days).

Ionizing radiation —any form of radiation that produces ionizations. Examples are alpha, beta, and gamma radiation. When ionizing radiation passes through tissue of the body, molecular, cellular, and tissue damage can occur depending on the dose and dose rate.

Irradiate —to expose to radiation.

Isotope —forms of the same chemical element that have different numbers of neutrons. Many isotopes are produced in nuclear reactors (e.g. radioactive iodine-131 and strontium-90) and particle accelerators. Stable iodine in the from of potassium iodide (KI) pills can be ingested to prevent humans from incorporating radioactive iodine in the thyroid following nuclear accidents. The field of nuclear medicine depends on a constant supply of radioactive isotopes (i.e., radioisotopes).

Joule —SI unit of energy, corresponding to the work done by one newton moving through one meter. (Symbol J)

Kerma —an acronym derived from the expression “kinetic energy released in materials”; these materials could be air, a body organ, or a structural component of a building. Kerma is expressed in gray.

Kriging —in the present context, an interpolation technique used to estimate the amount of ^{131}I deposition in areas (counties) where measurements were not available.

LET —short for Linear Energy Transfer. LET represents the average amount of radiation energy lost when traversing a small distance. It has units of energy divided by the short distance. For low-LET radiations such as X rays, gamma rays, and beta particles, little energy is lost when traversing a sheet of paper. For high-LET alpha particles emitted by plutonium isotopes, essentially all of the particle’s energy is lost in the sheet of paper.

Leukemia	—the term used to describe a group of malignant, commonly fatal blood diseases with certain common findings, notably a progressive anemia, internal bleeding, exhaustion, and a marked increase in the number of white cells (generally their immature forms) in the circulating blood.
Life Span Study (LSS)	—ongoing follow-up of the population exposed to atomic-bomb detonations in Hiroshima and Nagasaki, Japan, and progeny; conducted by the Radiation Effects Research Foundation (RERF).
Linear model	—the effect of exposure to ionizing radiation is assumed to be directly and simply proportional to dose.
Linear non-threshold model	—often referred to as the LNT model, is an empirical equation used to assign risk for cancer induction by a specified genotoxicant (including ionizing radiation). The equation has the form, risk=A+kD, where k is a risk coefficient, D is a measure of dose, and A represents the baseline risk, absent radiation. With this empirical model, any dose in excess of zero is presumed associated with an increased risk of cancer. Further, use of this model implies that doubling the dose will double the calculated excess risk. For low radiation doses and dose rates, there are large uncertainties about what are the true risks to humans and how they relate to dose.
Linear-quadratic model	—the effect of exposure is assumed to be not only related to the dose received but to the square of the dose as well.
Malignancy/malignant neoplasm	—a general category of neoplasm that invades surrounding tissue. A malignant tumor is generally characterized by invasive growth and is able to metastasize via the lymphatic and blood systems to distant tissue sites.
Microcurie	—one curie divided by one million. To convert microcuries to curies, divide by one million. To convert microcuries to becquerels, multiply by 37,000. To convert microcuries to kilobecquerels, multiply by 37. A kilobecquerel is 1000 becquerels.
Model	—a construct (generally mathematical) that attempts to describe the events that underlie some biological or physical phenomenon of interest, such as the occurrence of cancer following exposure to ionizing radiation.
Model uncertainty	—for low-dose radiation-risk assessment, the linear, non-threshold (LNT) model is often used. However, the LNT model is empirical so that it is unknown where the true risk lies for a given radiation dose to a specified organ. Uncertainty about what is the true risk model is called model uncertainty. Some researchers try to account for model uncertainty when evaluating risks. This can be achieved, for example, by using a variety of acceptable risk models and characterizing the variability of the risk derived using the different models.

Mortality	—a measure of the number of people who die of a disease or condition within a specified population in a certain period. This measure is usually a count or a rate (frequency).
NAS	—National Academy of Sciences. The National Academy of Sciences is a private, non-profit, self-perpetuating society of distinguished scholars engaged in scientific research. Upon the authority of the charter granted by the Congress in 1863, the NAS has a mandate that requires it to advise the federal government on scientific and technical matters.
NCI	—National Cancer Institute (http://www.nci.gov/).
NCRP	—the National Council on Radiation Protection and Measurements, a nongovernmental agency based in Bethesda, Maryland, with a charter similar to that of ICRP, but focusing in particular on issues related to radiation protection in the United States.
Neutron	—an uncharged particle that makes up part of an atomic nucleus. Uranium-235 and plutonium-239 atoms split (fission) when they absorb neutrons. This causes additional neutrons (and heat, in the form of motion of the neutrons and the fission fragments) to be released, potentially leading to a chain reaction. The controlled chain reactions that occur in nuclear power reactors and uncontrolled chain reactions that occur in nuclear weapons are due to neutrons being absorbed by atoms that then fission.
Nevada Test Site (NTS)	—the region in Nevada set aside for the continental atmospheric nuclear weapons testing program. Also referred to as the Nevada Proving Ground (NPG).
NRC	—National Research Council. The NRC is the principal operating agency of the National Academy of Sciences and the National Academy of Engineering to serve the federal government and other organizations.
NTS	—see Nevada Test Site.
Nuclide	—a species of atom characterized by the constitution of its nucleus. The composition is principally specified by the number of protons and neutrons, although is it strictly also necessary to take account of more esoteric factors (energy and spin states).
ORERP	—the acronym for the Offsite Radiation Exposure Review Project that sought to determine the exposures of individuals residing in a limited number of counties near the Nevada Test Site.
Organ dose	—the energy absorbed in a specific organ divided by its mass. This quantity is expressed in gray or its submultiples.
Prevalence	—the number of cases of a specific disease existing in a particular population or area at a certain time. The value is different numerically from incidence.
Proton	—an elementary particle with a single positive charge. Protons along with neutrons make up the nucleus of an atom.

Quadratic model	—the effect of exposure to ionizing radiation is assumed to be related to the square of the dose received.
Quality factor	—a factor, dependent upon the linear energy transfer, by which absorbed doses are multiplied to obtain a quantity that expresses the effectiveness for radiation protection purposes of an absorbed dose on a common scale for all forms of radiation. See also RBE.
Rad	—a unit of absorbed dose. It is equivalent to 100 ergs of energy per gram. In the more recent radiobiological literature the rad has been replaced by the gray (1 Gy=100 rad). See also gray.
Radiation	—energy transferred as particles or waves through space or other media. Sunlight is a form of radiation. Without that radiation, we would not exist. Thus, radiation is necessary for life on our planet, as we know it. However, moderate and large amounts of ionizing radiation are known to cause harm to humans and to the environment. Whether very small amounts of radiation cause harm is uncertain. All of us are exposed to low-level radiation originating within our bodies, from our planet, and from outer space. Many of us have been exposed to additional low-level radiation via smoke from forest fires, from cigarette smoke (direct or side stream), and via fallout from nuclear weapons tests.
Radioactive	—exhibiting radioactivity.
Radioactive decay	—the spontaneous disintegration of the nucleus of a radionuclide.
Radioactivity	—the spontaneous emission of radiation from unstable atoms.
Radionuclide	—a radioactive species of an atom. Radionuclides loose particles (e.g., alpha or beta) and energy through radioactive decay.
Radon-222	—a radioactive inert gas that arises from the decay of radium. Radon occurs naturally in many minerals and is a chief hazard of uranium mill tailings. Some radon can also be found in our homes. Radon decays into other isotopes that emit alpha radiation.
RBE (relative biological effectiveness)	—a factor used to compare the biological effectiveness of absorbed radiation doses due to different types of ionizing radiation for a defined biological endpoint, e.g., cell killing; this factor is experimentally determined using X- or gamma rays as the standard of comparison. Thus, if 1 Gy of fast neutrons produced the same amount of cell killing as 5 Gy of gamma rays, the RBE of neutrons for cell killing would be 5. Note the RBE will vary with the biologic endpoint used.
Regression	—in the present context, this word is used to indicate a mathematical procedure whereby a presumed mathematical relationship between two variables (e.g., Y=a+bX; variables X, Y; parameters a, b) is used along with data for the two variables to fit the mathematical relationship to the data. The regression procedure yields estimates of the parameters and their associated statistical error. After parameters have been estimated,

	the equation can then be used to predict expected values for one variable (e.g., Y) for specific values of the independent variable (e.g. X). The reliability of the prediction will depend on the appropriateness of the model used and on uncertainties associated with model parameter estimates.
Rem	—a unit of dose equivalent. The dose equivalent in rem is equal to the absorbed dose in rad multiplied by the quality factor, the distribution factor (which accounts for a nonuniform distribution of internally deposited radionuclides), and other necessary modifying factors. See rad, sievert, and dose equivalent.
RERF (Radiation Effects Research Foundation)	—the nonprofit research foundation sponsored by the governments of Japan and the United States that currently supervises the studies of the atomic-bomb survivors; the successor in 1975 of the Atomic Bomb Casualty Commission.
Risk	—probability of injury, harm, or damage.
Risk, absolute	—the excess number of deaths (or cases) above that "normally" expected in some population in the absence of exposure to ionizing radiation beyond that to which everyone is subjected because of the radiation emanating from the earth's crust or originating in outer space. Alternatively (depending on context) the increase in probability of injury, harm or damage due to some specified factor.
Risk, attributable	—the percentage of deaths or cases ostensibly assignable to a specific cause, for example to ionizing radiation, asbestos, chemical exposures, etc.
Risk coefficient	—slope of the linear, no-threshold risk curve (that is, the increase in risk per unit increase in dose). Is sometimes called a risk factor, which is different in meaning from its use in epidemiological studies. The term risk factor is often used in epidemiological research to indicate exposure co-hazards such as alcohol, cigarettes, radiation, etc.
Risk, relative	—the ratio of the risk in one population to that in another; for example, the ratio of the risk among individuals exposed to 2 Gy as contrasted with the background risk.
Roentgen	—the international unit of measurement of gamma or x-irradiation. It is based upon the number of ionizations produced by x-rays or gamma rays in a standard mass of air, and unlike the rad, it is not a measure of absorbed energy. It is named after Wilhelm Roentgen, the discoverer of X-rays.
SEER	—The Surveillance, Epidemiology, and End Results Program of the National Cancer Institute (http://seer.cancer.gov/). This program currently collects and publishes cancer incidence and survival data from 11 population-based cancer registries and three supplemental registries covering approximately 14 percent of the US population.
Sievert	—the sievert (Sv) is the special name of the SI unit for the quantity of dose equivalent. The dose equivalent is a hypothetical dose unit that in theory makes different radiations

	appear to be equally effective in producing biological effects in a given organ of the body even though the radiations may not be equally effective. Special weighting factors (i.e., radiation weighting factors) are used to convert absorbed dose to equivalent dose. Other weighting factors are used to convert equivalent doses to effective dose, which is more often used in risk assessment. With effective dose, a single number applies to the total body. With equivalent dose, different doses may be attributed to different organs. The name is derived from the Swedish physicist, Rolf M.Sievert.
SI units	—the international system of units. Special SI units for radiation include the becquerel (Bq), gray (Gy), and sievert (Sv).
Standard deviation	—square root of the variance (see below).
Strontium-90	—a beta-emitting isotope of strontium which element is chemically similar to calcium. Strontium-90 has a half-life of 28 years, is a common isotope produced in nuclear reactors, and is contained in fallout from nuclear testing.
Threshold	—some minimal dose to a population required to produce a specified biological effect; below this dose the effect dose not occur among any member of the population. Biological effects requiring threshold radiation doses are called deterministic effects.
TOA	—time of arrival.
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.
UNSCEAR	—the United Nations Scientific Committee on the Effects of Atomic Radiation, one of the specialized bodies of the United Nations charged with the responsibility of evaluating the effects of exposure to atomic (ionizing) radiation on behalf of the member nations.
Variance	—a measure of the spread or dispersion of a variable about its mean value. It is by definition the mean of the squared deviations of the values of the variable about their mean. The standard deviation is the square root of the variance.
X-rays	—High-energy lectromagnetic radiation with a wavelength that is much shorter than that of visible light, historically the rays produced in an electrical device, e.g., such as a diagnostic x-ray machine.
Yield	—the total effective energy released in a nuclear detonation and measured in tons of trinitrotoluene (TNT) equivalent.

Committee Biographies

WILLIAM J.SCHULL, PhD (Chair), is Ashbel Smith Professor Emeritus at the School of Public Health, University of Texas, Houston. His specialty is human genetics, and his primary research interest is radiation biology. In addition to a distinguished academic career, Dr. Schull previously served as the head of the Department of Genetics with the Atomic Bomb Casualty Commission (ABCC) in Japan and later went on to become one of the directors of ABCC's successor organization, the Radiation Effects Research Foundation. He is the recipient of numerous awards, including Japan's Order of the Sacred Treasure, Third Class. Dr. Schull is a member of several professional societies, including the American Epidemiological Society, the American Society of Human Genetics, the Radiation Research Society, and the Society for the Study of Human Biology.

BRUCE B.BOECKER, PhD, is a former assistant director of the Inhalation Toxicology Research Institute, Lovelace Biomedical and Environmental Research Institute, in Albuquerque, NM. He is currently a scientist emeritus of the Lovelace Respiratory Research Institute. Dr. Boecker earned his PhD in radiation biology from the University of Rochester and has conducted research at Lovelace since that time. He has been particularly interested in the conduct of laboratory experimentation to develop information that may be used to predict the consequences of accidental exposures of humans or to establish standards that ensure the safe and orderly conduct of activities that may result in release of toxic agents to the environment. His personal research efforts have been associated primarily with the toxicology of airborne material associated with activities in the nuclear fuel cycle. This research has spanned from studies of aerosol characteristics as they may influence patterns of deposition, retention, and dosimetry and risk assessments of different nuclear-energy systems. Dr. Boecker is also a certified health physicist and an emeritus member of the Radiation Research Society, Health Physics Society, and American Academy of Health Physics and an honorary member of the National Council on Radiation Protection and Measurements. He has received a Distinguished Scientific Achievement Award from the Health Physics Society.

A.BERTRAND BRILL, MD, PhD, is a research professor in the Departments of Radiology and Physics at Vanderbilt University. Dr. Brill earned his MD from the University of Utah and his PhD in biophysics from the University of California, Berkeley. He served in the US Public Health Service (PHS) in Japan at the Atomic Bomb Casualty Commission (ABCC) in the Statistics and Medicine Departments (1957–1959) and as the PHS representative to ABCC until 1964. Dr. Brill's specialty is nuclear medicine, and his major research includes radiation leukemogenesis, effects of radiation on thyroid function, and effects of diagnostic radioisotope studies, particularly exposures from ^{131}I. Dr. Brill is a member of the National Cancer Institute task group studying effects of the Chernobyl accident on thyroid-cancer induction in children. He is a former medical director in the Division of Radiological Health, US Public Health Service, and a former professor of radiology at the State University of New York at Stony Brook. He is a member of the Society of Nuclear Medicine Radiation Effects Committee, which he chaired for 10 years; the Medical Internal Radiation Dose Committee; and the American Thyroid Association.

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