Appendix B

Summary of the National Cancer Institute Report

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

B.1 The National Cancer Institute Report

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

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

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

B.2 Estimating Exposures and Thyroid Doses

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

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

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

B.2.1 Geography

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

B.2.2 Age

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

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

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

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

B.2.3 Diet, particularly milk consumption

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

B.2.4 Estimating thyroid doses for specific individuals

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

B.2.5 Uncertainties and model validation

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

B.3 Estimating Risks

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

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

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

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

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

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

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

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

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

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

B.4 Subsequent Activities

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

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