Technical Documentation of the Iodine-131 Thyroid Dose and Risk Calculator for Nevada Test Site Fallout

Version 3.0
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Center for Risk Analysis

GEOMATRIX

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1.   INTRODUCTION

During the period of 1951 through 1970, approximately 100 atomic weapons were tested at the Nevada Test Site (NTS), releasing measurable amounts of radioactivity to the environment far beyond the borders of the site (NCI 1997). Essentially everyone in residence in the contiguous USA from 1951 through 1962 was exposed (approximately 160,000,000 persons), with the highest exposures resulting from the deposition of ^{131}I and its subsequent contamination of fresh milk (NCI 1997, IOM/NRC 1999, Simon and Bouville 2002, Gilbert et al. 2002, Bouville et al. 2002). Out of the approximately 100 detonations, about 95% of the total ^{131}I released from the Nevada Test Site originated from 61 events: 8 in 1951 (Ranger and Buster-Jangle series), 8 in 1952 (Tumbler-Snapper series), 11 in 1953 (Upshot-Knothole series), 13 in 1955 (Teapot series), 19 in 1957 (Plumbob series) and 2 in 1962 (Storax series) (Bouville et al. 2002). Exposure to ^{131}I occurred through inhalation of particles or gases in air and through the ingestion of contaminated water and vegetables, but by far the most significant route of exposure was ingestion of ^{131}I in fresh sources of milk. Once absorbed into the human body, iodine is preferentially taken up by the thyroid gland.

The National Cancer Institute (NCI) has been charged with conducting scientific research for assessing the risks of thyroid cancer associated with thyroid doses of ^{131}I received by the American people from the Nevada atmospheric nuclear bomb tests [Public Law 97-414 of 1983, Section 7(a)]. In 1997, the NCI produced a report that estimated ^{131}I thyroid doses as a function of diet, age, gender and location for representative persons residing in each of the 3,071 counties[1] of the contiguous USA (NCI 1997).

To support NCI's efforts in disseminating quantitative information about the thyroid dose and future lifetime risk of thyroid cancer incidence from exposure to ^{131}I in fallout following atmospheric nuclear bomb tests at the Nevada test site, an Internet-based computer code has been developed.

This report is the technical documentation of the Internet-based computer code, which summarizes the methods used to estimate the thyroid dose for an individual with given characteristics [starting from NCI's database of thyroid doses (Section 2)] and the methods used to estimate the future risk of thyroid cancer incidence [starting from the individual thyroid dose (Section 3)]. Section 4 presents the results of our quality assurance/quality control review of the code, and Section 5 describes the organization of the web-based programming files. Throughout this document, the Internet-based dose and risk calculator will be referred to as IRAD-NTS (**I**nteractive **R**isk **A**nd **D**ose for **NTS** fallout).

IRAD-NTS has been released to the public on NCI's website http://www.nci.nih.gov/i131) in July 2003 as version 2.0. In that version, the risk model

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[1] The word "county" is used in this report to represent the geographical region for which NCI calculated thyroid doses from exposure to ^{131}I in fallout from weapons testing in Nevada. In the vast majority of cases, the geographical region represents an administrative county. In a few cases, however, doses are listed for regions other than a county (e.g., some of the independent cities in Virginia).

for radiogenic thyroid cancer was obtained from an update (Land et al. 2003) of the 1985 RadioEpidemiological Tables published by NCI (NIH 1985). That risk model predicted the same excess relative risk (ERR) for males and females exposed to the same thyroid dose. In January 2006, the National Research Council of the National Academies of Sciences released a report of the BEIR VII committee that investigated the most recent epidemiologic data linking radiation and cancer (NRC/NAS 2006). The BEIR VII committee recommended a thyroid cancer risk model similar to that recommended by Land et al. (2003), but which predicts an ERR two times higher for females than for males. IRAD-NTS has been updated in 2006 to incorporate the thyroid cancer risk model recommended by the BEIR VII committee. This report describes the updated Internet-based computer code which is now referred to as IRAD-NTS Version 3.0.

IRAD-NTS is programmed using Analytica® programming software with an Internet-based user interface designed using VBScript and JavaScript scripting languages. The user interface allows an individual to enter his or her personal information (i.e., birth date, gender, milk diet, and location during weapons testing in Nevada) and to obtain estimates of the thyroid dose received and of the resulting future lifetime risk of thyroid cancer, with information about the uncertainty inherent in these estimates. The calculator has user-friendly input screens, presents the dose and risk estimates in an easy-to-read manner, and puts the risk from exposure to NTS fallout into perspective using comparisons with other cancer risks. Uncertainties in the doses and risks are fully accounted for by using Monte-Carlo simulations for error propagation.

The Analytica® computer code and the Internet-based user-interface programming files accompany this document in electronic form. The electronic computer files are internally documented so that they can be easily interpreted and updated.

2.   THYROID DOSES FROM NEVADA TEST SITE FALLOUT

2.1   Making use of the NCI thyroid dose database

The NCI database of thyroid doses consists of estimates of individual doses for representative individuals residing in each of the 3,071 counties of the contiguous United States. The dose estimates are provided for each nuclear test (shot) and for each test series for 13 different age-at-exposure categories for each county. The age groups are the following: fetus (11-20 wks; 21-30 wks; 31-40 wks), infant (0-2 mo; 3-5 mo; 6-8 mo; 9-11 mo), child (1-4 yr; 5-9 yr; 10-14 yr; 15-19 yr), and adult (male and female). The estimated doses depend on whether the individual drank commercial milk, milk from a backyard cow, milk from a dairy goat, or was breast-fed by his or her mother.

The doses from ingestion of milk are added to the doses from all other exposure pathways, which are assumed to be similar to all individuals of the same age and gender who were residing in the same county. For a given age group and type of milk ingestion (i.e., cow or goat milk), there are 3,097 electronic files (see file naming convention; Figure 1), one for each of the 3,071 counties, with additional files to account for fourteen counties that have been subdivided in two or more areas because of large heterogeneity of fallout (e.g., Clarke County, NV, has been divided into Clark1, Clark2, Clark3; see Section 2.3.1).

Each file contains the doses from each nuclear test, for different milk categories. For cow milk, doses are reported for average and for high commercial milk consumption rate[2], for high backyard cow milk consumption rate, and for no milk consumption. Figure 2 shows the structure of a typical dose input file. For goat milk, doses are reported for average and for high goat milk consumption rate, as well as for no milk consumption. The files for exposure as an infant contain also the doses from ingestion of mother's milk (breast-feeding) obtained by assuming that the mother consumes an average amount of cow milk (i.e., 0.8 liters of cow milk per day; $L\ d^{-1}$). The doses for *in-utero* exposures are organized by the consumption rate of the pregnant woman. To describe the uncertainty, each dose is described as a lognormal distribution with the geometric mean (GM) and the geometric standard deviation (GSD) provided in the database files.

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[2] An "average amount" of milk is 1 to 3 glasses per day. A "high amount" of milk is 4 or more glasses per day.

Filename: _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

2-digit state code

County

Milktype flag:
d = cow milk
g = goat milk

Age group code

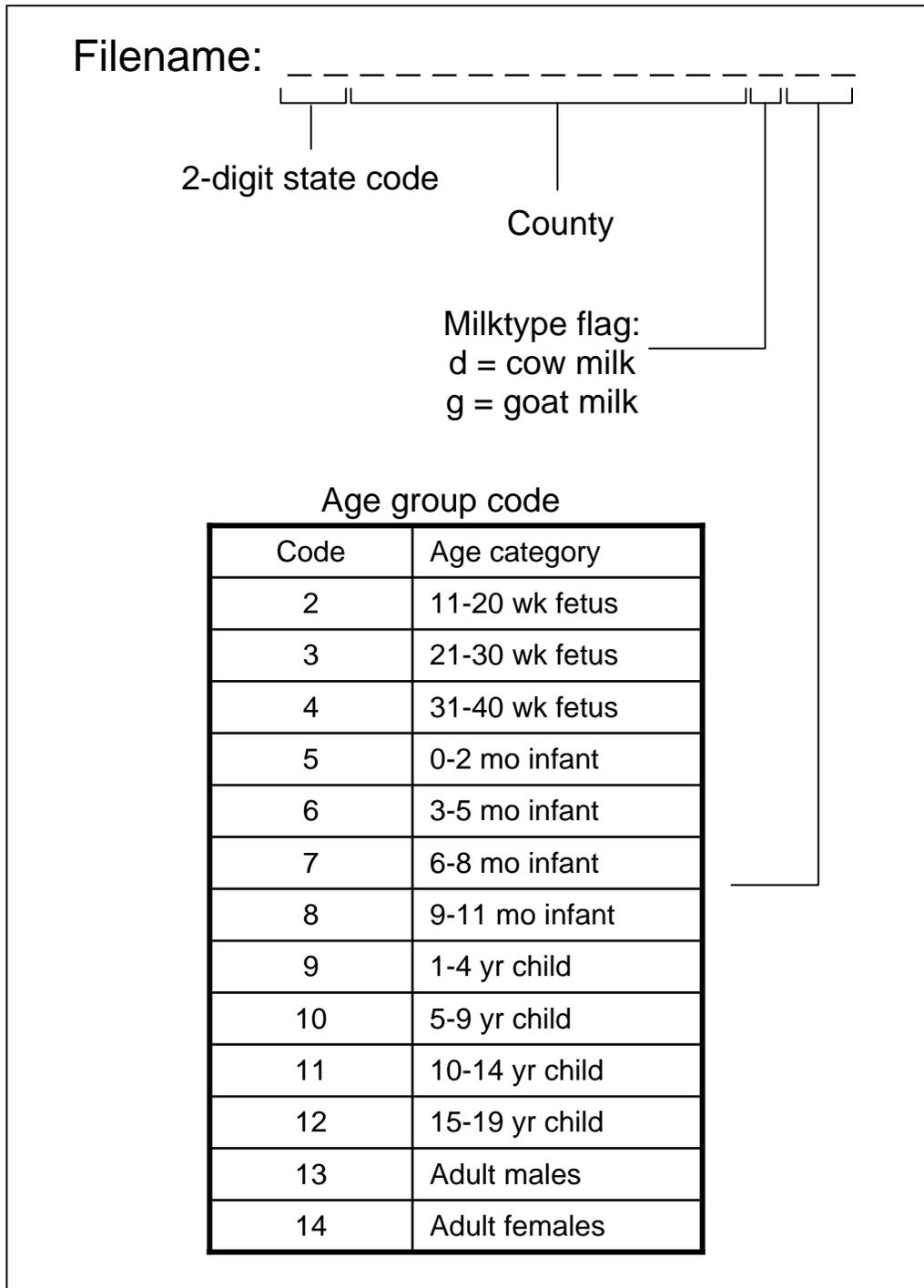| Code	Age category
2	11-20 wk fetus
3	21-30 wk fetus
4	31-40 wk fetus
5	0-2 mo infant
6	3-5 mo infant
7	6-8 mo infant
8	9-11 mo infant
9	1-4 yr child
10	5-9 yr child
11	10-14 yr child
12	15-19 yr child
13	Adult males
14	Adult females

Figure 1. Naming convention used for dose input files

Shot	State County	Commercial milk (1 to 3 glasses/day) GM GSD		Commercial milk (4+ glasses/day) GM GSD		Bkyd cow milk (4+ glasses/day) GM GSD		No milk GM GSD	
bj01d2.res:	AL AUTAUGA	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0
bj02d2.res:	AL AUTAUGA	4.7E-2	4.4	4.9E-2	4.4	6.9E-2	4.3	7.0E-3	3.3
bj03d2.res:	AL AUTAUGA	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0
bj04d2.res:	AL AUTAUGA	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0
bj05d2.res:	AL AUTAUGA	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0
bj06d2.res:	AL AUTAUGA	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0
ht01d2.res:	AL AUTAUGA	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0
ht02d2.res:	AL AUTAUGA	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0
ht03d2.res:	AL AUTAUGA	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0
ht04d2.res:	AL AUTAUGA	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0
ht05d2.res:	AL AUTAUGA	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0
ht06d2.res:	AL AUTAUGA	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0
ht07d2.res:	AL AUTAUGA	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0
ht08d2.res:	AL AUTAUGA	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0
ht09d2.res:	AL AUTAUGA	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0
pb01d2.res:	AL AUTAUGA	2.1E-2	5.5	2.2E-2	5.5	3.4E-2	5.4	3.2E-3	4.2
pb02d2.res:	AL AUTAUGA	3.9E-2	5.2	3.9E-2	5.2	5.0E-2	4.9	5.2E-3	3.9
pb03d2.res:	AL AUTAUGA	3.8E-2	4.8	3.8E-2	4.8	5.2E-2	4.6	4.8E-3	3.7
pb04d2.res:	AL AUTAUGA	9.1E-2	5.8	9.3E-2	5.8	1.3E-1	5.5	1.2E-2	4.5
pb05d2.res:	AL AUTAUGA	6.0E-3	6.4	6.2E-3	6.4	8.7E-3	6.0	9.2E-4	4.8
pb06d2.res:	AL AUTAUGA	4.2E-2	5.1	4.2E-2	5.1	6.4E-2	5.1	6.9E-3	3.7
pb07d2.res:	AL AUTAUGA	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0
pb08d2.res:	AL AUTAUGA	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0
pb09d2.res:	AL AUTAUGA	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0
pb10d2.res:	AL AUTAUGA	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0
pb11d2.res:	AL AUTAUGA	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0
pb12d2.res:	AL AUTAUGA	1.2E-1	5.0	1.2E-1	5.0	1.9E-1	4.9	1.7E-2	3.7
pb13d2.res:	AL AUTAUGA	2.3E-2	5.4	2.3E-2	5.4	3.7E-2	5.3	3.4E-3	4.1
pb14d2.res:	AL AUTAUGA	1.5E-3	7.1	1.5E-3	7.2	2.5E-3	6.8	2.3E-4	5.6
pb15d2.res:	AL AUTAUGA	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0
pb16d2.res:	AL AUTAUGA	6.8E-2	5.4	6.8E-2	5.4	1.0E-1	5.2	9.6E-3	4.1
pb17d2.res:	AL AUTAUGA	4.2E-2	5.1	4.2E-2	5.1	6.0E-2	4.8	6.3E-3	3.7
pb18d2.res:	AL AUTAUGA	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0
ra01d2.res:	AL AUTAUGA	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0
ra02d2.res:	AL AUTAUGA	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0
ra03d2.res:	AL AUTAUGA	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0
tp01d2.res:	AL AUTAUGA	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0
tp02d2.res:	AL AUTAUGA	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0
tp03d2.res:	AL AUTAUGA	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0
tp04d2.res:	AL AUTAUGA	5.0E-3	5.8	5.2E-3	5.8	7.7E-3	5.5	8.0E-4	4.4
tp05d2.res:	AL AUTAUGA	2.4E-3	4.9	2.4E-3	5.0	3.3E-3	4.7	4.0E-4	3.5
tp06d2.res:	AL AUTAUGA	4.5E-2	6.0	4.7E-2	6.1	6.5E-2	5.8	7.1E-3	4.6
tp07d2.res:	AL AUTAUGA	1.3E-2	4.7	1.3E-2	4.7	1.7E-2	4.4	1.7E-3	3.6
tp08d2.res:	AL AUTAUGA	1.2E-2	5.9	1.2E-2	5.9	1.6E-2	5.6	1.5E-3	4.5
tp09d2.res:	AL AUTAUGA	1.1E-2	4.6	1.1E-2	4.6	1.4E-2	4.5	1.7E-3	3.5
tp10d2.res:	AL AUTAUGA	1.6E-1	3.9	1.6E-1	3.9	2.1E-1	3.9	2.0E-2	3.1
tp11d2.res:	AL AUTAUGA	7.4E-2	5.0	7.7E-2	5.0	1.0E-1	4.7	9.7E-3	3.8
ts01d2.res:	AL AUTAUGA	1.2E-3	7.2	1.2E-3	7.2	1.6E-3	6.8	1.6E-4	5.7
ts02d2.res:	AL AUTAUGA	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0
ts03d2.res:	AL AUTAUGA	6.0E-2	7.1	6.2E-2	7.1	8.7E-2	6.7	8.4E-3	5.6
ts04d2.res:	AL AUTAUGA	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0
ts05d2.res:	AL AUTAUGA	6.7E-2	4.7	6.9E-2	4.7	9.1E-2	4.5	8.9E-3	3.6
ts06d2.res:	AL AUTAUGA	3.1E-2	5.4	3.3E-2	5.4	4.4E-2	5.3	4.2E-3	4.2
ts07d2.res:	AL AUTAUGA	4.2E-2	6.2	4.4E-2	6.2	5.8E-2	5.9	6.1E-3	4.8
ts08d2.res:	AL AUTAUGA	8.8E-3	3.8	9.0E-3	3.8	1.1E-2	3.8	1.2E-3	2.9
ue01d2.res:	AL AUTAUGA	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0
ue02d2.res:	AL AUTAUGA	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0
ue03d2.res:	AL AUTAUGA	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0
ue04d2.res:	AL AUTAUGA	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0
ue05d2.res:	AL AUTAUGA	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0
ue06d2.res:	AL AUTAUGA	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0
ue07d2.res:	AL AUTAUGA	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0
ue08d2.res:	AL AUTAUGA	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0
ue09d2.res:	AL AUTAUGA	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0
ue10d2.res:	AL AUTAUGA	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0
ue11d2.res:	AL AUTAUGA	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0
ue12d2.res:	AL AUTAUGA	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0
ue13d2.res:	AL AUTAUGA	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0
ue14d2.res:	AL AUTAUGA	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0
ue15d2.res:	AL AUTAUGA	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0
ue16d2.res:	AL AUTAUGA	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0
ue17d2.res:	AL AUTAUGA	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0
uk01d2.res:	AL AUTAUGA	9.8E-3	4.1	1.0E-2	4.1	1.4E-2	4.0	1.3E-3	3.2
uk02d2.res:	AL AUTAUGA	3.1E-2	4.6	3.4E-2	4.7	4.5E-2	4.5	4.4E-3	3.6
uk03d2.res:	AL AUTAUGA	9.8E-3	6.1	1.0E-2	6.1	1.3E-2	5.8	1.3E-3	4.8
uk04d2.res:	AL AUTAUGA	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0
uk05d2.res:	AL AUTAUGA	3.6E-3	7.2	3.6E-3	7.2	5.2E-3	6.8	5.0E-4	5.7
uk06d2.res:	AL AUTAUGA	7.5E-3	5.1	7.5E-3	5.1	9.8E-3	4.9	1.1E-3	3.9
uk07d2.res:	AL AUTAUGA	8.3E-2	4.0	8.6E-2	4.0	1.1E-1	3.9	1.2E-2	2.9
uk08d2.res:	AL AUTAUGA	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0	0.0E+0	0.0
uk09d2.res:	AL AUTAUGA	1.4E-1	3.9	1.5E-1	3.9	1.7E-1	3.8	2.1E-2	2.9
uk10d2.res:	AL AUTAUGA	5.8E-3	4.3	5.8E-3	4.3	7.1E-3	4.3	8.7E-4	3.2
uk11d2.res:	AL AUTAUGA	1.1E-3	7.2	1.1E-3	7.2	1.5E-3	6.8	1.4E-4	5.7

Figure 2. Layout of a sample dose input file

2.2   Reporting thyroid doses from NTS fallout

IRAD-NTS contains an underlying computational engine, which is responsible for estimation of doses and future lifetime risks of thyroid cancer, and which is programmed using Analytica® programming software (Analytica® 2003). The Analytica® code is stored in an internally documented file labeled "ELR_ver20.ana". The Internet-based user interface interacts with the Analytica® computer code by using Analytica® Decision Engine (ADE) ActiveX Automation Server, which is a specialized software part of the Analytica® programming software package (Section 5).

The Internet-based interface allows users to enter their personal information (date of birth, gender, the states and counties where they lived between 1951 and 1971, and the primary type of milk diet). The user can specify multiple locations of residence and different milk diets on a monthly basis.

Based on the personal information specified, IRAD-NTS extracts the relevant thyroid doses reported in the NCI database for each nuclear test. Since the residence history is specified on a monthly basis, IRAD-NTS extracts from the database the doses for the nuclear tests, which took place between the 15th of the month when the individual moved to a new location up to the 15th of the month when the individual moved away from that location, or between the date of birth and the 15th of the month when the individual moved away from the county in which he was born. The same method of extracting the doses from the original NTS database is applied if the milk consumption changed from one exposure period to the next. The relevant doses for each nuclear test are submitted to the Analytica® computer code (ELR_ver20.ana) for further manipulation and for estimation of future lifetime risk.

If the individual was breastfed during the period of fallout from NTS testing, or if the individual consumed goat milk, the thyroid doses extracted from the original NCI database are first corrected to account for the updates in the milk transfer coefficients (F_m; Section 2.3). Other specific considerations used in the process of extracting the doses from the database are discussed in detail in Section 2.4.

The doses for each nuclear test, corrected as needed, are first summed to create a dose for each year of exposure (e.g., the doses from all relevant nuclear tests in 1953 are summed to obtain a dose for 1953). The doses from all nuclear tests relevant for an individual are also summed (over all years) to obtain a total thyroid dose for that individual. The summation is performed using Monte-Carlo methods for error propagation (300 hundred random simulations obtained using midpoint Latin Hypercube Sampling). The future lifetime risk of thyroid cancer is calculated by using the annual doses, and by knowing the age of the individual during the year when the annual dose was delivered (Section 3).

The total thyroid dose, expressed in "rad"[3], is reported in the main dose-display web-page (i.e., "*results.asp*"; Section 5.4). The annual doses and the doses from each

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[3] The SI unit of absorbed dose is the joule per kilogram (J kg^{-1}), and its special name is "gray" (Gy). One "rad" is defined as 100 ergs per gram; 1 Gy = 100 rad.

relevant nuclear test can be displayed in tabular form by clicking the appropriate buttons, which call up secondary dose display pages. As requested by NCI, the 50th percentile of the probability distribution describing the uncertainty in the estimated dose is reported as the best estimate of the dose. The 90% confidence interval of the estimated doses is displayed in every case as the low and high end values. The dose-display pages also contain a summary of the personal information and of the residence and milk consumption history for that individual. The dose-display pages also contain explanatory text that put into perspective the reported NTS thyroid doses and provide the definition of a "rad".

2.3 Correcting the original NCI doses from ingestion of goat milk and from ingestion of mother's milk

Since the doses from exposure to ^{131}I from NTS fallout were first estimated by NCI, more data has become available regarding the transfer of ^{131}I from food products into the milk produced by lactating mothers (Simon et al. 2002). Also, the transfer of ^{131}I into goat milk was reanalyzed by other investigators (Apostoaei et al. 1999).

This section describes the methods applied to adjust the ^{131}I thyroid doses in the NCI database of doses from NTS fallout by accounting for updated values of the milk transfer coefficients (F_m) for goat milk and mother's milk.

2.3.1 Transfer of iodine into mother's milk

The thyroid doses from ingestion of mother's milk published by NCI (1997) are obtained using a transfer coefficient from intake to milk, based on fourteen measurements, mostly from women with health problems. The milk transfer coefficient was characterized by a lognormal distribution with geometric mean of 0.10 d L^{-1} and a geometric standard deviation of 2.9. More recently, Simon et al. (2002) derived values for this parameter by reviewing numerous studies reporting intake and mammary excretion data. They separated the measurements from women with normal iodine metabolism from the measurements from women with abnormal iodine metabolism (either because of health problems or administration of stable iodine or iodinated compounds). The study found that, for the "normal" group, the excretion of iodine into mother's milk is higher than previously assumed. The intake-to-mother's milk transfer coefficient (F_m) can be described by a lognormal distribution with a geometric mean of 0.37 d L^{-1} and a geometric standard deviation of 1.5. This distribution is used in IRAD-NTS (Table 1). For the breastfeeding child, it was assumed that the mother had an average milk diet (i.e., 0.8 liters of cow milk per day; L d^{-1})

2.3.2 Transfer of iodine into goat milk

The thyroid doses from ingestion of goat milk in the NCI database are based on 21 measurements for the goat milk transfer coefficient, summarized as a lognormal distribution with a geometric mean of 0.22 d L^{-1} and a geometric standard deviation of 2.5, which produces a 95% confidence interval of 0.037 d L^{-1} to 1.33 d L^{-1}. However, F_m

values greater than one are unrealistic (e.g., would require a goat to produce less than a liter of milk a day). A more recent analysis by Apostoaei et al. (1999) suggested the use of a log-triangular (instead of a lognormal) distribution to limit the upper bound of the distribution. The mode of the distribution was set to 0.22 d L^{-1}, with the minimum and maximum values of this distribution being 0.04 and 0.9 d L^{-1}, respectively (Table 1).

Table 1   Previous and updated values of the milk transfer coefficient (F_m)

F_m (d L^{-1}) **values used by NCI (1997)**	
Goat milk[1]	Lognormal (GM=0.22, GSD=2.5)
Mother's milk[2]	Lognormal (GM=0.10, GSD=2.9)
Updated F_m (d L^{-1}) values applied in NTS Thyroid Dose/Risk Calculator	
Goat milk[3]	Log-triangular (min=0.04, mode=0.22, max=0.9)
Mother's milk[4]	Lognormal (GM=0.37; GSD=1.5)

[1] NCI (1997); page 4.26, paragraph 4.1.4.2
[2] NCI (1997); page 4.26, paragraph 4.1.4.3
[3] Apostoaei et al. (1999); Volume 1; page 6-6
[4] Simon et al. (2002)

2.3.3   Method used to correct the original NCI doses

The approach for updating the original NCI goat milk and mother's milk doses from *a given nuclear test* is based on the following facts.

- The dose reported in the NCI dose file is <u>primarily</u> the result of a multiplicative chain of parameters, one of which is the milk transfer coefficient (F_m).

- The uncertainty in the dose reported in the original NCI dose files is obtained by analytical error propagation methods, assuming that all variables are described by lognormal distributions.

The generic equation for estimation of dose from *a given nuclear test* is as follows

$$D = F_m \cdot X \tag{1}$$

where D is the dose (in rad), F_m is the milk transfer coefficient (in d L^{-1}) and X is a composite parameter representing the combination of all other variables (rad L d^{-1}).

The updated (new) dose from *a given nuclear test* is given by Eq. 2.

$$D_{new} = F_{m,new} \cdot X \tag{2}$$

To obtain the updated dose, one has to determine the composite parameter X (and its associated uncertainty), and then multiply by the updated $F_{m, new}$.

By reversing the analytical error propagation formulas for multiplication of lognormal distributions, the geometric mean (GM) and the geometric standard deviation (GSD) of the composite parameter X are calculated as described in Eq. 3 and 4.

$$GM_X = \exp\left[\ln(GM_D) - \ln(GM_{F_m})\right] = \frac{GM_D}{GM_{F_m}} \tag{3}$$

$$GSD_X = \exp\left[\sqrt{(\ln(GSD_D))^2 - (\ln(GSD_{F_m}))^2}\right] \tag{4}$$

Using the calculated geometric mean and the geometric standard deviation, a lognormal distribution for the composite parameter X is sampled and then is multiplied by the sampled distribution for the $F_{m, new}$. The updated dose is calculated using standard Monte Carlo techniques.

Table 1 summarizes the values of the milk transfer coefficient (F_m) used by NCI (1997), and provides the updated F_m values obtained from recent studies.

2.4   Other considerations

2.4.1   Doses for persons living outside of the United States

Some individuals lived in Hawaii, Puerto Rico and Alaska (or in other countries) during the time of some of the tests. The doses from exposures at these locations are lower than the average dose for a person living in the contiguous United States, but they might not have been zero. The current methodology does not include quantitative estimates of exposures for these locations. An entry choice was added to the bottom of the pull-down menu listing of the states that reads "Outside Contiguous USA". If this option is selected in IRAD-NTS, the assigned dose for the specified period of time is assumed to be zero.

2.4.2   Doses from *in-utero* exposures

For *in-utero* exposures, the NCI original dose files are organized by mother's diet. Since the milk diet of the mother while the person was *in utero* may not be known, an average diet of cow milk for the mother (i.e., 0.8 liters of cow milk per day L d^{-1}) is assumed as a default to identify the specific NCI dose file to be used as input to IRAD-NTS.

For estimating doses from *in-utero* exposures, it is important to know where the mother lived during her pregnancy. However, it is possible that the user will not have this information available. Thus, IRAD-NTS uses the default assumption that, during her pregnancy, the mother resided in the same location as location where the child was born.

2.4.3   Split counties

NCI reported thyroid doses for 3,071 separated geographical regions of the contiguous United States.   In most cases, the geographical regions are actual administrative counties.   In a few cases, the geographical region represents an area different from a county.   For instance, thyroid doses are reported for independent cities in Virginia.   Also, several counties changed names or boundaries with time.

Fourteen counties are large enough for the thyroid dose to have varied significantly from one area of the county to another.   These counties are: Coconino, AZ; Mohave, AZ; Inyo, CA; Clark, NV; Esmeralda, NV; Lander, NV; Lincoln, NV; Nye, NV; White Pine, NV; Box Elder, UT; Iron, UT; Kane, UT; Tooele, UT; and Washington, UT.   The NCI database contains doses for two or more areas in each of these counties (e.g., Clark County, Nevada is divided into three areas: Clark1, Clark2, Clark3).   If the exposed individual lived in one of these counties, the user selects the county from the pull-down menu and is directed to a map of the county showing the areas for which the dose is different.   The user can click on the part of the county where the person lived to select the correct residence (be it a county or an area) for that person.

2.4.4   Unknown name of the county of residence

Since the largest exposures occurred more than 30 years ago, a common problem for a user is remembering the name of the county in which he or she lived during the atmospheric testing (e.g., some exposed individuals were young children during 1950s and 1960s).   IRAD-NTS provides a link to the U.S. Census Bureau website (http://quickfacts.census.gov/cgi-bin/lookup) that allows the user to locate a county by entering a town, city, or zip code.   This link is embedded in the program and aids the user to query the U.S. Census Bureau website without leaving the IRAD-NTS session.

3.   FUTURE LIFETIME RISK OF THYROID CANCER INCIDENCE FROM NTS FALLOUT

In addition to providing an estimate of thyroid dose, the IRAD-NTS provides a future lifetime risk of thyroid cancer incidence. In 2003, the NCI published the Interactive RadioEpidemiological Program (IREP; Land et al. 2003). This program represents the current update of the 1985 RadioEpidemiological Tables published by NCI (NIH 1985). IREP, implemented using the Analytica® software (Analytica® 2003) is an Internet-based application that estimates the excess relative risk (ERR) from past exposure to radiation and, for those individuals with a diagnosed case of cancer, the probability that the cancer was caused by that exposure. IREP uses Monte Carlo simulation techniques to propagate the uncertainty in input assumptions (represented as probability distributions) and to produce an estimate of uncertainty in the final estimates of the excess relative risk (ERR) and the probability of causation (PC).

The IREP program includes the information required to quantify the ERR and PC from exposure of the thyroid gland to ^{131}I from Nevada Test Site fallout. This information includes the following: (1) the ERR per Gy from exposure to external gamma and X rays as an exponentially-decreasing function of age at time of exposure (with uncertainties), and (2) the dose and dose rate effectiveness factor (DDREF), which accounts for the potential departures from a linear dose response observed at high doses and high dose rates when actual exposures are chronic at low dose rates (with uncertainties). The ERR per Gy used by IREP is the same for both males and females.

In 2006, the National Research Council of the National Academies released its most recent analysis of health risks from exposure to low levels of ionizing radiation (BEIR VII report, NRC/NAS 2006). The BEIR VII committee reanalyzed the thyroid cancer epidemiologic data and developed a model for the ERR per Gy for thyroid cancer only slightly different than the one in IREP. That is, the ERR per Gy recommended by BEIR VII depends on age at time of exposure with exactly the same exponentially-decreasing function as that used in IREP, but the ERR per Gy values are sex-dependent, with the risk for females being twice the risk for males. Version 2.0 of IRAD-NTS, which operated from 2003 until 2006, was based on the ERR per Gy risk model used in IREP. The current version of IRAD-NTS (i.e., v.3.0) uses the ERR per Gy risk model recommended by the BEIR VII committee.

3.1   Methodology for risk estimation

For a given individual, the excess risk at age z from exposure to ^{131}I at age x is denoted *ER(x,z),* while the absorbed dose to the thyroid received at age x is labeled *D(x)*. The dose *D(x)* is obtained by summing all the thyroid doses received during the year when the individual was of age x (Section 2). Because the radiation types emitted by ^{131}I are considered to have a biological effectiveness equivalent to high-energy gamma rays,

the radiation effectiveness factor for ^{131}I is equal to 1.0. Thus, an absorbed dose of 1 Gy is equal to a thyroid equivalent dose of 1 Sv (see footnote [4]).

Using a relative risk model, the excess risk at age z from the exposure at age x is:

$$ER(x,z) = ERR(x,z) \cdot (B(z) \cdot \Delta z) \tag{5}$$

where $ERR(x,z)$ is the excess relative risk of thyroid cancer. Generally, ERR depends on the age at exposure (x) and the age at which the risk is calculated (z). The current relative risk model for thyroid cancer indicates that the risk depends on age at exposure only, and not on attained age or time since exposure [i.e., $ERR(x,z) = ERR(x)$]. The ERR depends on the thyroid dose received at age x. The dose-response function that defines the ERR is given in Section 3.1.1.

The annual baseline risk of cancer [$B(z)$] is given by the cancer incidence rate observed in the U.S. population (in cases per 100,000 per year). $B(z)\Delta z$ represents the probability of getting cancer at age z from causes other than the specific (individual) exposure to ^{131}I for which the risk is calculated (Δz is set to equal 1 year).

The <u>excess future lifetime risk</u> (*EFLR*) represents the excess risk from the present time up to the end of the expected lifetime of the individual assuming that the exposed individual is alive and presently free of thyroid cancer.

$$EFLR = ER(x) = \frac{ERR(x) \sum_{z=age\ today}^{\infty} S(z) \cdot (B(z) \cdot \Delta z)}{S(age\ today)} \tag{6}$$

$S(z)$ is the survival function (i.e. the probability of the individual living to age z). In other words, S is the fraction of live-born individuals in an unexposed population expected to survive to age z. S is equal to 1 for a newborn [$S(0)=1$], and it decreases monotonically for increasing values of z (Appendix A).

The total risk is defined here as the sum of the baseline and of the risk of cancer from exposure to NTS fallout. The total risk at age z from the exposure at age x is

$$TR(x,z) = Baseline + Excess\ Risk =$$
$$= (B(z) \cdot \Delta z) + \beta(x) \cdot D(x) \cdot (B(z) \cdot \Delta z) \tag{7}$$

For a person who is presently alive and free of thyroid cancer, the <u>total future lifetime risk</u> (*TFLR*) represents the total risk from today forward, up to the end of the expected lifetime, is given by the sum from today forward of the risks at each age (z) weighted by the survival function.

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[4] 1 Gy = 100 cGy = 100 rad; 1 Sv = 100 cSv = 100 rem.

$$TFLR = TR(x) =$$

$$= \frac{\sum\limits_{z=age\ today}^{\infty} S(z) \cdot (B(z) \cdot \Delta z)}{S(age\ today)} + \frac{ERR(x) \sum\limits_{z=age\ today}^{\infty} S(z) \cdot (B(z) \cdot \Delta z)}{S(age\ today)} = \tag{8}$$

$$= \frac{\sum\limits_{z=age\ today}^{\infty} S(z) \cdot (B(z) \cdot \Delta z)}{S(age\ today)} \cdot [1 + ERR(x)]$$

The first term in the above summation is the <u>baseline future lifetime risk</u> (*BFLR*) and it represents the risk of getting thyroid cancer from the present time up to the end of the expected lifetime of the individual from causes other than the individual's exposure to NTS fallout.

$$BFLR = \frac{\sum\limits_{z=age\ today}^{\infty} S(z) \cdot (B(z) \cdot \Delta z)}{S(age\ today)} \tag{9}$$

The annual baseline risk of thyroid cancer [*B(z)*] is calculated using the cancer incidence rates taken directly from the SEER[5] database, and it represents an average risk for the U.S. population as a whole. The global effect of the NTS fallout on the U.S. average incidence rates is eliminated by correcting the baseline downwards, as described in section 3.2.1.

Because nuclear weapons testing in Nevada took place over many years, an individual exposure history usually consists of multiple exposures (e.g., *h* exposures) occurring at various ages at exposure. The excess or the total risk from this exposure history (*h*) is obtained by summing the excess or the total risk from each exposure, respectively. The <u>total future lifetime risk from an exposure history (*h*)</u> is presented below.

$$TFLR(h) = TR(h)$$

$$= \frac{\sum\limits_{z=age\ today}^{\infty} S(z) \cdot (B(z) \cdot \Delta z)}{S(age\ today)} + \frac{\sum\limits_{x}^{h} ERR(x) \sum\limits_{z=age\ today}^{\infty} S(z) \cdot (B(z) \cdot \Delta z)}{S(age\ today)} =$$

$$= \frac{\sum\limits_{z=age\ today}^{\infty} S(z) \cdot (B(z) \cdot \Delta z)}{S(age\ today)} \cdot \left[1 + \sum\limits_{x}^{h} ERR(x)\right] \tag{10}$$

$$\frac{\sum\limits_{z=age\ today}^{\infty} S(z) \cdot (B(z) \cdot \Delta z)}{S(age\ today)} \cdot [1 + ERR(h)]$$

---

[5] SEER is the Surveillance, Epidemiology and End Results program of NCI.

As before, the first term in the above summation is the baseline future lifetime risk (*BFLR*).

Propagation of uncertainties for the equations presented in Section 3.1 was done using Monte Carlo methods (300 random simulations obtained using mid-point Latin Hypercube Sampling for each exposure). Complete correlation was assumed to exist between the risk coefficients assigned to each exposure. The incidence rates for each attained age are also fully correlated, but they are independent from the risk coefficients.

3.1.1   The dose-response function thyroid cancer

The dose-response for thyroid cancer was derived from studies of patients exposed to medical X rays and studies of the A-bomb survivors. The large majority of these subjects were exposed to doses less than 1200 cSv. The risk of thyroid cancer in these studies was found to increase linearly with increasing thyroid dose up to at least 500 rad (Ron et al. 1995, Land et al. 2003, NRC/NAS 2006).

At higher doses, other effects are observed (e.g., killing of thyroid cells), while the risk of thyroid cancer no longer increases. The rather limited data on populations with higher-dose exposures suggests that the slope of the dose-response decreases at higher dose levels and eventually reaches a plateau or declines (Tucker et al. 1991, Hall and Wuu 2003). In addition, the thyroid cancer risk in exposed populations has never reached levels consistent with lifetime risk far above 50% (and of course the lifetime risk cannot exceed 100%).

In IRAD-NTS, the dose-response for a single exposure at a given age at exposure (*x*) was considered to be linear in dose (Eq. 11).

$$ERR(x) = \left(\beta(x) / DDREF\right) \cdot D(x) \tag{11}$$

The factor $\beta(x)$ is the excess relative risk per unit dose *ERR/Sv* for an exposure at age *x*, as derived from the medical X rays and the A-bomb survivor studies (Table 2). These risk coefficients are those recommended by BEIR VII committee (NAS/NRC 2006). Before they are applied to a person exposed to ^{131}I from NTS fallout, the risk coefficients are reduced by the dose and dose rate effectiveness factor (DDREF), which accounts for the difference in effectiveness between the acute exposure to X rays and gamma rays and the chronic exposures to ^{131}I. The DDREF was defined using a discrete probability distribution function. The possible DDREF values are 0.5, 0.7, 1, 1.5, 2, 3, and 4. They occur with the following respective probabilities: 1%, 4%, 35%, 23%, 23%, 10% and 4% (Land et al. 2003).

The dose-response presented above is used to calculate the total future lifetime risk (*TFLR*) from a single exposure. The total future lifetime risk [*TFLR(h)*] from all combined exposures in an exposure history (*h*) is calculated as a summation of the risks for each exposure (i.e., *TFLR*).

To account for the reduction in the slope and the existence of a plateau in the dose-response, a risk limit (*L*) was imposed on the calculated *TFLR(h)*. The risk limit *(L)*

is expressed by a lognormal distribution with a 90% confidence interval of 0.4 – 0.8 (i.e., 40%-80% risk) was used. This distribution has a geometric mean of 0.57 (or a 57% risk) and a geometric standard deviation of 1.23.

The estimated risk *TFLR(h)* is first calculated as presented in the previous section, but before reporting, *TFLR(h)* is adjusted by using the risk limit (*L*). If *TFLR(h)* is greater than $100 \times Q\%$ of the risk limit (*L*), the adjusted risk approaches the limit (*L*) asymptotically.

The parameter Q is the percentage of the risk limit at which the risk starts deviating from the risk obtained from the linear dose-response.

$$TFLR(h)_{adj} = \begin{cases} TFLR(h) & if \ TFLF(h) \leq Q \cdot L \\ L \cdot \left(Q + (1-Q) \cdot \left[1 - \exp\left\{ -\frac{(TFLR(h) - Q \cdot L)}{(1-Q) \cdot L} \right\} \right] \right) & if \ TFLR(h) > Q \cdot L \end{cases} \tag{12}$$

Parameter Q is represented as a triangular uncertainty distribution with a minimum value of 0.4, a mode of 0.6, and a maximum value of 0.8.

Table 2   The excess relative risk per unit dose [$\beta(x)$=ERR/Gy] for thyroid cancer as a function of age at exposure (x), and gender.

| Age at exposure[a] | FEMALES | | | MALES | | |
| | | 95 % C.I. | | | 95 % C.I. | |
	GM	Lower	Upper	GM	Lower	Upper
0	12.7	2.7	58.5	6.4	1.4	29.5
5	8.4	2.3	30.2	4.2	1.2	15.2
10	5.5	1.5	21.0	2.8	0.7	10.6
15	3.6	0.81	16.5	1.8	0.41	8.3
20	2.4	0.47	12.3	1.2	0.24	6.2
25	1.6	0.29	8.6	0.80	0.15	4.3
30	1.1	0.19	5.7	0.53	0.10	2.9
35	0.69	0.13	3.8	0.35	0.06	1.9
40	0.46	0.064	3.3	0.23	0.032	1.7
45	0.30	0.032	2.8	0.15	0.016	1.4
50	0.20	0.016	2.5	0.10	0.0081	1.2

[a] ERR/Gy decrease exponentially with age at exposure. The geometric mean ERR/Gy = $1.05 \times \exp[-0.083 \times (x\text{-}30)]$ for females, and ERR/Gy = $0.53 \times \exp[-0.083 \times (x\text{-}30)]$ for males; where x is the age at exposure (NRC/NAS 2006). Uncertainties are described as lognormal probability distributions with the geometric means described above and with the geometric standard deviations provided by Land et al. (2003).

3.2   Baseline future lifetime risk of thyroid cancer

The baseline (or background) future lifetime risk of thyroid cancer is based on the thyroid cancer incidence rates reported by SEER for the standard 18 five-year age groups (from age 0 to age 85; SEER 2000).

To obtain a smooth transition from one age to another, the logarithms of the incidence rates (for both males and females) were fitted by polynomial functions (Fig. 3). For the purpose of applying the fitting procedure, the rate for a given age group was assigned to the mid age in that age group (e.g., the rate for age-group 0-4 was assigned to age 2, the rate for age group 5-9 was assigned to age 7 and so on). For ages 85 and older the incidence rates at any age were assumed to be constant and equal to the incidence rates estimated for age-group +85. The uncertainty in each incidence rate was described as a lognormal distribution, with the arithmetic mean equal to the rate obtained by using the fitted polynomials and the arithmetic standard deviation equal to the standard error reported by SEER.
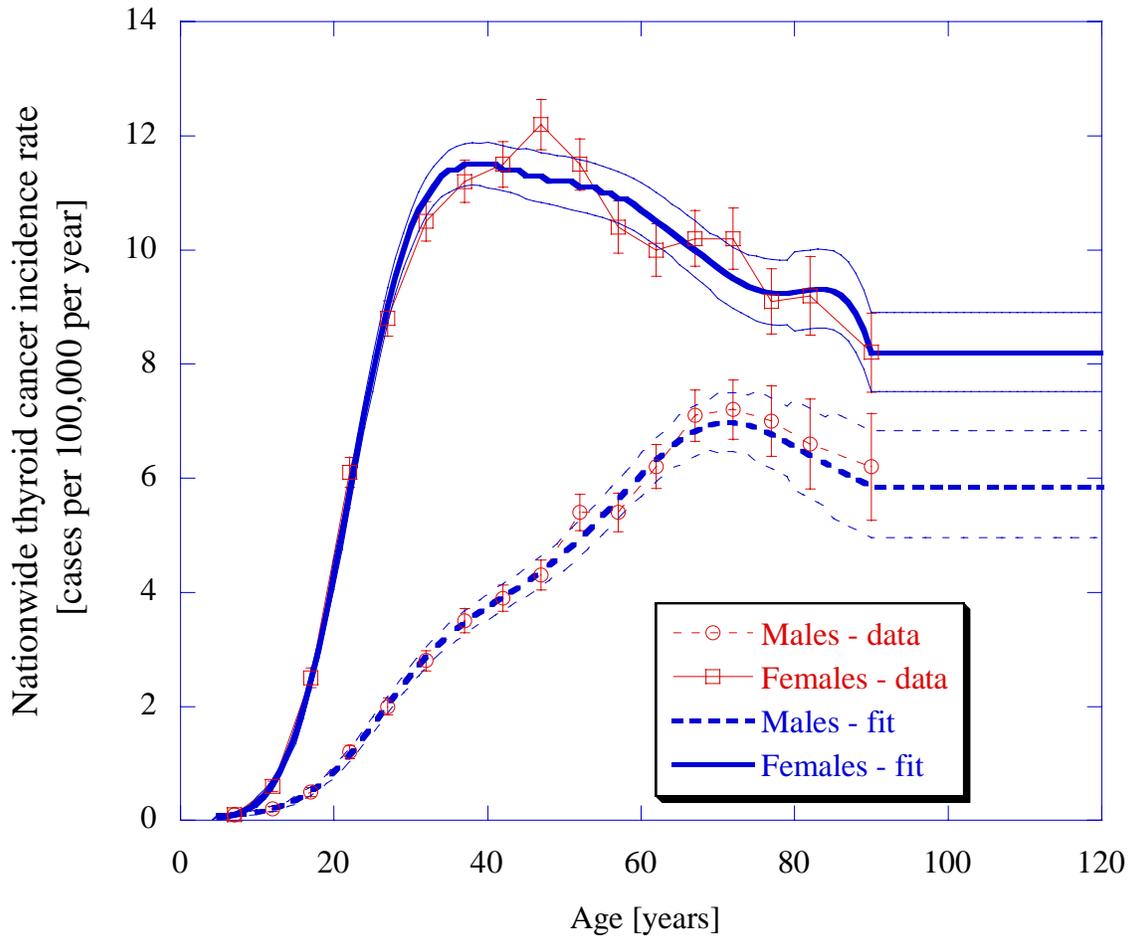
Figure 3.   Nationwide thyroid cancer incidence rates reported by SEER and the curves obtained using polynomial functions to fit the data. The vertical lines on the data points and the upper and lower curves of the fitted polynomial represent a 90% confidence interval for the rate at a given age.

3.2.1   Adjustments of the baseline future lifetime risk of thyroid cancer to correct for ^{131}I exposure from NTS fallout

The baseline future lifetime risk of thyroid cancer is first calculated using the cancer incidence rates for persons now living in the SEER registry areas, and it represents an average risk for the U.S. population as a whole. Because the thyroid cancer incidence rates reflect the historical exposures to NTS fallout, the SEER baseline future lifetime risk is biased upward by a factor depending on the average exposure history to NTS fallout.

If *h** is the average exposure history, the SEER baseline future lifetime risk of thyroid cancer [*BFLR_{SEER} = TFLR (h*)*] is about *1+ERR(h*)* times higher than it would have been in the absence of exposure to NTS fallout (Eq. 10). To obtain a baseline for those who were never exposed to ^{131}I, the global effect of exposure to NTS fallout was eliminated by dividing the SEER baseline future lifetime risk [*BFLR_{SEER} = TFLR (h*)*] by *1+ERR(h*)*.

$$BFLR = BFLR_{adj} = \frac{BLFR_{SEER}}{1 + ERR(h^*)} \qquad (13)$$

The average exposure history (*h**) is defined as the average thyroid dose for the entire United States population of a given year of birth. For example, the average dose for all people born in 1920 is different from the average dose for all people born in 1950, because of different ages at the time of exposure to NTS fallout. These doses are presented in Appendix B, and they apply for both males and females.

Using the doses for the average exposure history presented in Appendix B, and thyroid cancer risk coefficients *β(x)*, the correction factor was calculated as (1 + ERR(*h**)) for each birth year from 1930 to 1963 (Fig. 4). For people born before 1930, the correction for 1930 is used. For people born after 1963, no correction is necessary. The doses for the average exposure (Appendix B) are low enough so that the linear portion of the dose response applies for all birth years.

When applying Eq. 13, we assumed that the correlation between the uncertainty in the total estimated future lifetime risk and the uncertainty in the exposure correction factor is negligible, because the exposure history for any individual (*h*) and the average exposure history for the entire United States (*h**) are independent. Also, the uncertainties in the risk coefficients (ERR/Sv) used to estimate the individual total future lifetime risk are independent from the uncertainties in the risk coefficients (ERR/Sv) used to estimate the NTS exposure correction factor. In other words, a given individual can have a lower or a larger risk, which is independent from the baseline risk assigned to the U.S. population. The effect of the correction on the baseline risk for males and females is shown in Table 3.

Because of population mobility, the average exposure history of a person born, for example, in 1950 and living in the SEER registry areas during 1973-1998 is different from that of the average person born in 1950 and living in the SEER areas during 1950-1962. Average exposures for the SEER area could be up to 30% less than those for the U.S. as a whole, and presumably could be greater than those of immigrants from other countries. Thus, the above correction for exposure to ^{131}I in NTS fallout is only an approximation. In principle, better approaches can be found but they would require extensive effort with little gain. For present purposes, the correction for exposure to ^{131}I in NTS fallout was applied for exposure histories of people who were living in the SEER areas, and who had average diets.
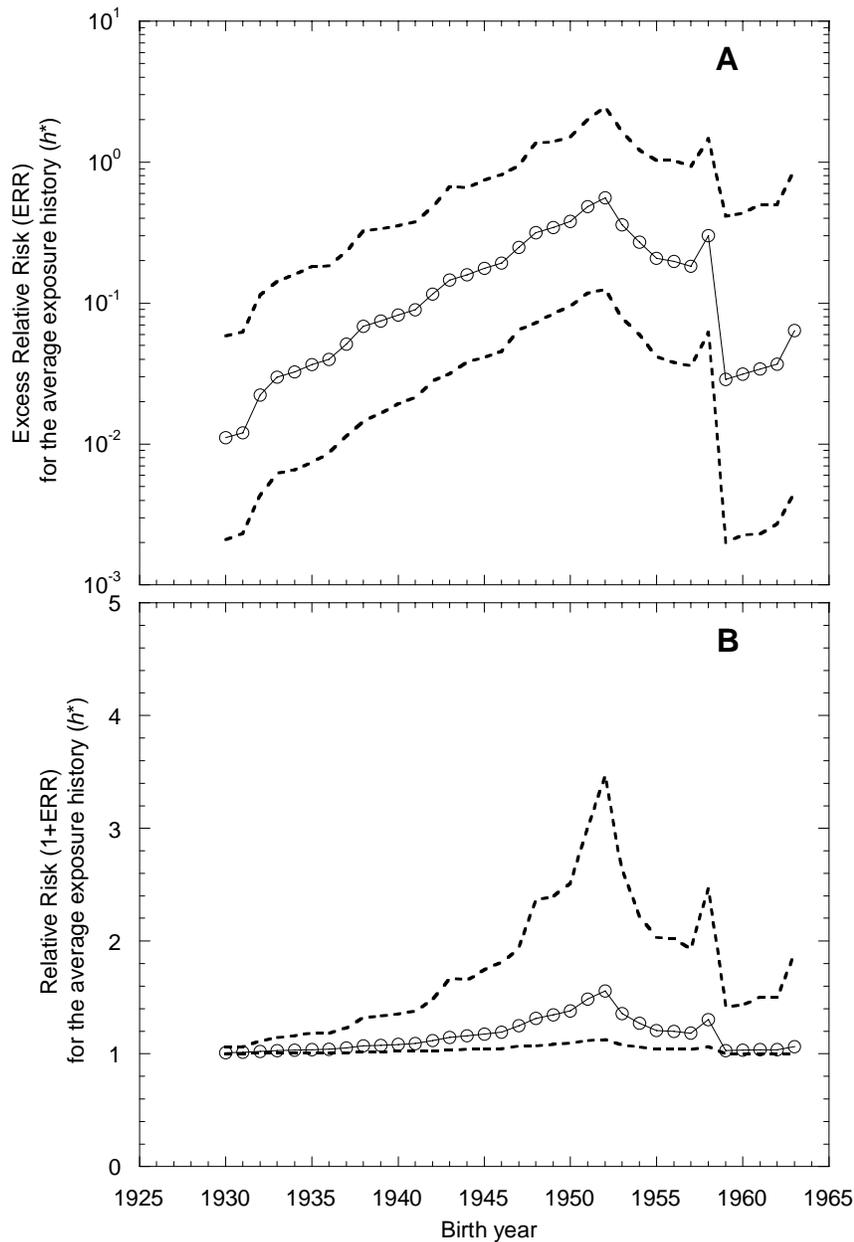
Figure 4.   Components used to correct the data reported by SEER to obtain a baseline future lifetime risk of thyroid cancer that excludes the effect of exposure to NTS fallout [131]I. Panel A is the excess relative risk [ERR($h*$)] as a function of the year of birth. Panel B shows the correction factor [1+ERR($h*$)] that is used as a divisor. The dotted lines represent the 90% confidence interval obtained by propagating uncertainties in the doses for the average exposure at a given age in the U.S. population and the uncertainties in the age-specific risk coefficients for thyroid cancer.

Table 3   Correction of the baseline future lifetime risk for males and females to
               eliminate the global effect of exposure to ^{131}I in NTS fallout.

SEER Baseline Future Lifetime Risk[a]

Birth	MALE Chances in 1000[b]			FEMALE Chances in 1000[b]		
Year	lower limit[c]	average	upper limit[c]	lower limit[c]	average	upper limit[c]
1910	0.18	0.23	0.29	0.31	0.38	0.47
1930	0.60	0.76	0.95	1.07	1.34	1.64
1940	0.93	1.18	1.47	1.68	2.10	2.58
1950	1.25	1.59	1.97	2.43	3.04	3.72
1952	1.31	1.66	2.07	2.59	3.24	3.98
1955	1.39	1.77	2.20	2.84	3.55	4.35
1958	1.48	1.87	2.33	3.10	3.87	4.75
1961	1.55	1.97	2.45	3.36	4.20	5.14

Adjusted Baseline Future Lifetime Risk[a]

Birth	MALE Chances in 1000[b]			FEMALE Chances in 1000[b]		
Year	lower limit[c]	average	upper limit[c]	lower limit[c]	average	upper limit[c]
1910	0.18	0.23	0.29	0.30	0.38	0.46
1930	0.58	0.75	0.93	1.04	1.32	1.62
1940	0.80	1.07	1.37	1.45	1.89	2.41
1950	0.62	1.11	1.55	1.21	2.12	2.94
1952	0.47	1.04	1.62	0.92	2.02	3.14
1955	0.80	1.40	1.88	1.62	2.81	3.74
1958	0.73	1.37	1.94	1.51	2.84	3.97
1961	1.23	1.81	2.33	2.65	3.86	4.91

[a] The baseline represents the risk of getting thyroid cancer from April, 2003 forward, up to the end of the expected lifetime. The SEER baseline is calculated from the SEER database incidence rates and it contains the average effect of the ^{131}I in NTS fallout on the SEER population. The "adjusted" baseline is obtained by applying the exposure correction factor discussed in the text (Eq. 13).

[b] Two digits after the decimal point are reported, so that small changes in the estimated baseline can be observed.

[c] The lower and the upper limits are the 5%-ile and the 95%-ile of probability distribution describing the uncertainty in the estimated baseline.

3.3   Risk from *in-utero* exposures

In the absence of any specific risk coefficients, the risk for individuals exposed *in utero* is estimated by applying the risk coefficients for newborns (age at exposure = 0). The entire dose assigned to the fetus is combined with the risk coefficient for newborns to estimate future lifetime risk.

3.4   Reporting the future lifetime risk of thyroid cancer

The risk-display page (i.e., *risk.asp*; Section 5) reports the total future lifetime risk [TFLR(h)] from the entire exposure history (*h*) and the baseline future lifetime risk (BFLR) of thyroid cancer as "chances in 1000". As requested by NCI, the mean of the probability distribution describing the uncertainty in the estimated risk is reported as the best estimate of the risk. The 90% confidence interval for the estimated risks is given in all cases, with the few exceptions noted below. An explanation of the meaning of the displayed risk quantities is provided in a separate window.

The risk-display page contains a "smart" number rounder, which is described in detail in the *risk.asp* file. In general, the estimated risk (expressed in "chances per 1000") is rounded to an integer. If the risk is low (around or below 1 chance in 1000), it is rounded to one significant digit after the decimal point. The significant digit is kept so that the displayed best estimate is different from the displayed lower or the upper bounds. If the difference between total and the baseline future lifetime risks is less than 10% of the baseline risk (measured by comparing the central values), then the 90% confidence intervals of the estimated risks are not displayed, and a message is posted explaining that the risk for the exposed person is not distinguishable from the risk in the absence of exposure.

If the estimated central value of the total future lifetime risk is greater than 10% (100 chances in 1000) a message is displayed informing the user that the thyroid dose and the risk of cancer are high, and encourages the user to consider screening for thyroid disease. At these levels of dose and risk, the chance of thyroid diseases other than cancer increases. The user is directed towards the published NCI information materials (e.g., NCI free booklets of thyroid disease), which contain useful thyroid screening.

The risk-display pages contain a summary of the personal information entered including the residence and milk consumption history for that individual. The risk-display pages also put the risk into perspective by comparing with risk of other cancers. Links to the other relevant parts of the NCI's iodine web site are provided on the risk-display pages.

4.   QUALITY ASSURANCE/QUALITY CONTROL

A series of quality assurance/quality control (QA/QC) calculations have been carried out and are presented in this section as part of a formal procedure to ensure that IRAD-NTS performs as intended. The methods used for and the results obtained from the QA/QC calculations are discussed below.

Four levels of QA/QC have been performed for IRAD-NTS v.2.0, which was released to the public in July 2003.

1. Test runs were completed by the code's developers to ensure that results conformed to expectations. Many of the findings of these initial runs led to discussions with NCI and to the eventual modifications of the code's underlying algorithms and assumptions.

2. Numerous individuals, who had no involvement in the development of IRAD-NTS used the program to estimate doses and risks for over 100 random scenarios. The purpose of this level of checking was two-fold: (a) to identify errors that might occur from the everyday use of the code, and (b) to identify portions of the code that might lead to confusion for members of the public.

3. Independent calculations were performed by users at NCI.

4. Independent calculations were performed by *SENES* Oak Ridge, Inc., using a separate programming platform (Microsoft Excel/ Decisioneering Crystal Ball[®]).

The first three levels of the QA/QC process are qualitative in nature. The last QA/QC level is quantitative because it involves numerical comparisons of estimated doses and risks. This type of quantitative checking is discussed in detail in Section 4.1.

IRAD-NTS v.3.0 is identical to IRAD-NTS v.2.0 with one difference having to do with the gender dependency of the ERR per Gy introduced by the new risk model (see Section 3).   When the gender dependency modifications were implemented in IRAD-NTS, the code was tested to ensure that it uses the correct ERR per Gy for males and females. No modifications were made in other portions of the code.

4.1   Quantitative QA/QC

IRAD-NTS has been created using a combination of programming tools and languages to estimate doses and risks from all NTS shots, while allowing users the flexibility of entering their residence history on a monthly basis.

Although many "face validity" checks have been performed, an independent computer code was created using Microsoft Excel and Decisioneering's Crystal Ball[®] (2000). This Microsoft Excel computer code (referred to as QA/QC code from this point forward) estimates doses and risks for 20 specific scenarios (Table 4). The scenarios were designed to ensure that IRAD-NTS properly estimated doses and risks for a variety of assumptions.

Table 4   Description of scenarios used in QA/QC calculations

#[a]	Birthdate	Sex	Exposure year	Residence during exposure year [b]	Milk consumption [c]	Test series of concern
1	01/01/1948	M	1953	Washington, UT	cow: average	Upshot-Knothole
2	01/01/1948	M	1953	Alameda, CA	cow: high	Upshot-Knothole
3	01/01/1948	M	1953	Denver, CO	goat: average	Upshot-Knothole
4	01/01/1948	F	1953	Fulton, GA	goat: high	Upshot-Knothole
5	01/01/1948	F	1953	Nantucket, MA	backyard cow	Upshot-Knothole
6	01/01/1948	F	1953	Anderson, TN	no milk	Upshot-Knothole
7	01/01/1953	F	1953	Clark1, NV	breastfed	Upshot-Knothole
8	01/01/1947	M	1957	Dade, MO	cow: average	Plumb Bob
9	01/01/1940	F	1955	Scott, IA	cow: high	Teapot
10	01/01/1932	M	1952	Citrus FL	backyard cow	Tumbler-Snapper
11	01/01/1953	F	1953	Gunnison CO	goat: high	Upshot-Knothole
12	01/01/1947	M	1957	Washington, DC	cow: average	Plumb Bob
13	01/01/1947	F	1957	Berkshire, MA	cow: high	Plumb Bob
14	01/01/1948	M	1953	Penobscott, ME	backyard cow	Upshot-Knothole
15	01/01/1932	F	1952	Spokane, WA	cow: average	Tumbler-Snapper
16	01/01/1932	M	1952	Salt Lake, UT	cow: average	Tumbler-Snapper
17	01/01/1940	F	1955	Santa Fe, NM	cow: high	Teapot
18	01/01/1940	M	1955	Dallas, TX	backyard cow	Teapot
19	01/01/1947	F	1957	Boise, ID	cow: average	Plumb Bob
20	01/01/1947	M	1952	Lincoln, SD	cow: high	Tumbler-Snapper

[a] The number assigned to each scenario.

[b] The residence prior to and after the exposure year was assumed to be outside the contiguous USA

[c] This column gives the type of milk consumed and the amount ingested. An "average amount" of milk is 1 to 3 glasses per day. A "high amount" of milk is 4 or more glasses per day. A person with a "backyard" cow is assumed to have consumed high amounts milk ($\geq$4 glasses per day), because of the easy accessibility to a milk source.

Table 5   Results of QA/QC calculations

	Thyroid dose (rad)			Future risk [a] (chances in 1,000)		
	5th %-ile	50th %-ile [b]	95th %-ile	5th %-ile	Average [b]	95th %-ile
Scenario 1						
NCI calculator [c]	2.1	14	115	0.88	1.7	7.8
QA/QC [c]	2.2	14	114	1.1	1.8	8.7
Scenario 2						
NCI calculator	0.050	0.19	1.1	0.62	1.1	1.4
QA/QC	0.050	0.19	1.0	0.89	1.1	1.4
Scenario 3						
NCI calculator	1.8	5.1	20	0.74	1.4	2.7
QA/QC	2.0	5.2	16	1.0	1.4	2.5
Scenario 4						
NCI calculator	3.2	8.9	31	1.5	2.9	6.5
QA/QC	2.1	8.3	36	2.0	2.9	7.4
Scenario 5						
NCI calculator	0.36	1.3	7.1	1.2	2.2	3.2
QA/QC	0.35	1.3	6.9	1.8	2.2	3.2
Scenario 6						
NCI calculator	0.035	0.088	0.29	1.2	2.1	2.6
QA/QC	0.034	0.088	0.29	1.7	2.1	2.6
Scenario 7						
NCI calculator	0.87	4.4	34	1.6	3.1	11
QA/QC	0.75	4.32	36.9	2.18	3.16	11.2
Scenario 8						
NCI calculator	0.80	2.3	9.9	0.78	1.2	1.7
QA/QC	0.79	2.4	10	0.99	1.2	1.7
Scenario 9						
NCI calculator	0.080	0.30	1.7	1.5	1.9	2.1
QA/QC	0.080	0.30	1.7	1.7	1.9	2.1
Scenario 10						
NCI calculator	0.087	0.36	2.3	0.68	0.78	0.88
QA/QC	0.081	0.36	2.3	0.69	0.77	0.88

Table is continued on the next page

Table 5   continued

	Thyroid dose (rad)			Future risk [a] (chances in 1,000)		
	5th %-ile	50th %-ile [b]	95th %-ile	5th %-ile	Average [b]	95th %-ile
Scenario 11						
NCI calculator [c]	70	650	11700	7.8	97	602
QA/QC [c]	58	668	11100	7.8	106	667
Scenario 12						
NCI calculator	0.28	0.82	4.1	0.77	1.2	1.5
QA/QC	0.29	0.83	4.2	0.96	1.2	1.5
Scenario 13						
NCI calculator	0.70	2.4	13	1.5	2.3	3.5
QA/QC	0.71	2.3	13	1.9	2.3	3.4
Scenario 14						
NCI calculator	0.33	1.5	11	0.67	1.2	2.0
QA/QC	0.32	1.4	12	0.94	1.2	2.0
Scenario 15						
NCI calculator	0.033	0.12	0.56	1.2	1.4	1.5
QA/QC	0.031	0.11	0.56	1.3	1.4	1.5
Scenario 16						
NCI calculator	0.10	0.49	3.3	0.69	0.78	0.89
QA/QC	0.11	0.49	3.5	0.69	0.78	0.89
Scenario 17						
NCI calculator	0.23	0.77	4.0	1.5	1.9	2.1
QA/QC	0.23	0.81	3.9	1.7	1.9	2.2
Scenario 18						
NCI calculator	0.48	1.8	8.9	0.87	1.1	1.4
QA/QC	0.52	1.8	8.7	0.95	1.1	1.4
Scenario 19						
NCI calculator	0.37	1.6	10	1.5	2.3	3.0
QA/QC	0.41	1.6	10	1.9	2.2	3.1
Scenario 20						
NCI calculator	0.91	4.5	37	0.86	1.4	3.8
QA/QC	0.87	4.4	40	1.0	1.4	3.8

[a] Total future lifetime risk [TFLR(h)] from the entire exposure history (i.e., from all nuclear tests in the year of exposure specified in Table 4)

[b] As requested by NCI, the 50th percentile of the estimated dose and the average of the estimated risk are reported as best estimates of the dose and risk.

[c] For all scenarios, the number of Monte-Carlo iterations used is 1,000 for the NCI calculator (IRAD-NTS) and 10,000 for the QA/QC calculations.

The doses and risks estimated using the QA/QC code are presented in Table 5, along with estimates from IRAD-NTS v.2.0. The slight variance that exists between the two computer codes is due to differences in the techniques for random sampling employed by Analytica® (software used by IRAD-NTS to propagate uncertainty) and by Crystal Ball® (software used by the QA/QC code to propagate uncertainty).

The sampling technique used by IRAD-NTS is referred to as "median Latin Hypercube Sampling (LHS)." The advantage of median LHS over simple random sampling is that median LHS samples uniformly over the distribution, reducing the noise from random sampling. Crystal Ball® does not offer the option to sample distributions using median LHS. The sampling technique used by Crystal Ball® is referred to as "random LHS". Random LHS produces results that are intermediate between simple random sampling and median LHS. Using the QA/QC code (Crystal Ball®), 10,000 iterations were required to produce results that were as stable at the lower and upper bounds as were 1,000 iterations performed by IRAD-NTS (Analytica®).

4.2 Summary of the QA/QC process

All the comments received during the QA/QC process were addressed and most of them led to modifications to IRAD-NTS. The current version of IRAD-NTS can be easily used by individuals with various technical backgrounds. IRAD-NTS works properly when accessed using Internet connections with different speeds, and when using all recent versions of Internet browsers.

The quantitative checks performed as a part of the formal QA/QC process (Table 5) indicate that IRAD-NTS uses the appropriate dose input files based on age, location, and milk consumption patterns, properly sums the doses per shot, and calculates an individual's risk of obtaining thyroid cancer from the date of the calculation (assuming that they do not already have thyroid cancer).

5.   DESCRIPTION OF THE WEB-BASED PROGRAMMING FILES

5.1   Site Overview

The "Iodine-131 Thyroid Dose/Risk Calculator for NTS Fallout" website estimates the radiation dose from ^{131}I absorbed by the thyroid gland from nuclear tests conducted at the Nevada Test Site (NTS). The calculator also estimates the future lifetime risk of thyroid cancer from this exposure. Dose estimates for each county in the contiguous USA for each of the nuclear tests are contained in text files, organized by age group of the exposed individual. The user supplies information on birth date, gender, residence, and milk consumption history, which is used to identify the appropriate dose files to be retrieved. The dose estimates are then sent to the calculator, where total dose, dose by year, and dose by shot are calculated and displayed for the user. Risk of thyroid cancer as a result of the calculated doses is also estimated.

Web page construction on the site is based on Microsoft's Active Server Pages (ASP), included with Internet Information Services (IIS). ASP provides an array of objects and components that manage the interaction between the browser and the web server. Scripting languages such as VBScript and JavaScript are used to manipulate these objects. For this site, most scripting is done server-side with VBScript. In a few specific cases where client-side scripting is desired, JavaScript is employed.

The text files containing dose estimates have a specific naming convention and internal structure (see Figs. 1 and 2) that allows user-supplied information to be used to construct the directory path and name of the files to be retrieved, and to access the specific columns and rows within the file containing the needed information. Files are organized in two directories: one for cow milk consumption, the other for goat milk consumption. Each directory has 13 files for each county in the contiguous USA, corresponding to the 13 age groups defined for individuals. Each of these files contains dose estimates for each of the 83 nuclear tests.

Dose and risk calculations are performed by a model constructed with Analytica® modeling software from Lumina Decision Systems, Inc. Data are sent to the Analytica® model where calculations are performed and then sent back to the web pages. The interaction between web pages and the Analytica® model is conducted using Lumina's Analytica® Decision Engine (ADE) ActiveX Automation Server.

A Microsoft Access database is also used to house the list of all U.S. counties needed for user selection of residence history, via dynamic drop-down menus.

5.2   Directory Structure

All *.asp* web page files are contained under the *ntsi131* directory (Fig. 5).   Text files for cow milk dose estimates are in the "dose" directory.   Text files for goat milk dose estimates are in the *doseg* directory.   Image files used on the site are in the *Images* directory.
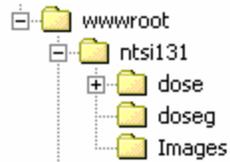
Figure 5.   File Directory Structure

5.3   Site Flow/Navigation

Figure 6 shows the general navigation routes through the site.   All users enter the site at the *default.asp* page and proceed eventually to the *results.asp* and *risk.asp* pages for dose and risk results.   Note that, for diagram simplicity, navigation arrows describing the capability to back up one page or to start over at the default page are not shown.

Table 6 lists all of the access points into and out of each of the pages on the site. Table 7 lists code segments that are used multiple times.   These are filed in separate files and included in appropriate pages via the "Include" command.

Primary Path

Information Pages

default → Summary_info

default → birthdate

birthdate → exposure

exposure → More_date

exposure → More_res

exposure → More_milk

changestate

MS Access → county

county ↔ exposure

changestate → county

County_map

exposure → results

results → credint

results → risk

ADE/Analytica ↔ results

risk → Future_mean

risk → Range_mean

Range_mean → Credint1

Note: Arrows for Start Over and Back One Page not shown

Figure 6.   Site Navigation

Table 6   List of access points to and from each page.

Page	Page Function	Can be accessed from these pages	Can go to these pages
default	Primary	*exposure, results*	*birthdate, summary_info, http://channels.netscape.com/ns/browsers/download.jsp, http://www.microsoft.com/windows/ie/default.asp*
birthdate	Primary	*default, exposure*	*exposure*
exposure	Primary	*birthdate, exposure, county, results*	*results, exposure, changestate, county, more_date, more_res, more_milk, default*
results	Primary	*exposure, results*	*risk, results, exposure, default, credint*
risk	Primary	*results*	*default, results, future_mean, range_mean, http://i131.nci.nih.gov/, http://i131.nci.nih.gov/decision.html*
changestate	Primary	*exposure*	*county*
county	Primary	*changestate, exposure*	*exposure, http://quickfacts.census.gov/cgi-bin/lookup*
county_map	Primary	*exposure*	*exposure*
credint	Information	*results*	
credint1	Information	*range_mean*	
more_date	Information	*exposure*	
more_milk	Information	*exposure*	
more_res	Information	*exposure*	
summary_info	Information	*default*	
future_mean	Information	*risk*	
range_mean	Information	*risk*	*credint1*
average_mean	Not used		

Table 7   Code filed in separate files, inserted into pages via "Include"

File name	Included in these pages	Description
banner	All site pages	Main NCI banner at the top of all pages
errmsg	*birthdate, exposure, changestate, county, county_map*	Code for creating error messages.
exp_nav_banner	*exposure*	Navigation banner to: *Start Over, Go Back One Page, Clear All Entries, or Clear Last Entry*
force_default	All site pages other than *default*	Code for forcing the user to the default page if they try to enter the site at any other page.
results_nav_banner	*results*	Navigation banner to: *Start Over, Go Back One Page*
risk_nav_banner	*risk*	Navigation banner to: *Start Over, Go Back One Page*

5.4   Page Descriptions

This section provides a brief description of each of the pages on the site, along with an overview of the functions performed by the VBScript and HTML portions of the code.

MAIN PAGES

Default.asp

Description: This is the default page of the site. All users must start here in order for variables to be set at their default settings.

VBScript: Default values for variables are set. Arrays holding shot and series information are defined.

HTML: Provides basic description of the site and a brief set of operating instructions to the user. Users hit the "Start Calculator" button to proceed to the *birthdate.asp* page.   Links are also provided, to more detailed information regarding nuclear testing and cancer risks (*Summary_info.asp*), and to download sites for Netscape (http://channels.netscape.com/ns/browsers/download.jsp) and Microsoft (http://www.microsoft.com/windows/ie/default.asp) browsers.

Birthdate.asp

Description: Input page for user's birth date and gender.

VBScript: Checks for return from exposure page and resets entry data to default values if true.

HTML: Provides form for user input of birth month, birth day, birth year, and gender. Users hit the "Next" button to proceed to the *exposure.asp* page.

Exposure.asp

Description: Main input page for user's location and milk drinking habits for 1951 to 1971. This page has multiple entry and exit points to allow user to continue adding new entries or to modify already entered ones. When finished with data entry, the user can submit data to *results.asp* for calculations.

VBScript: Checks for user request on this page to clear all entries or to clear last entry and sets submitReq to "Clear" or "ClearLast". Checks for user request to change an already entered state or an entered county, then requests needed information from form data, and redirects user either to *changestate.asp* (for state change) or *county.asp* (for county change).

Checks the value of submitReq to determine origination of entry to page.

- If origin is *birthdate.asp*, it requests form data and does error checking of data.

- If origin is *exposure.asp*/"Insert Additional Information", it requests form data and increments the variable named *numentries* by one to provide new row for user data entry.

- If origin is *county.asp*, requests county name, it checks to see if an image map is required, and sends to *county_map.asp* if true.

- If origin is *exposure.asp*/"Calculate Dose", it requests form data, calculates age, location and milk at each shot, performs error checks of data, and sends to *results.asp* for calculations.

- If origin is *exposure.asp*/"Clear", resets all data to default values and sets "numentries" to one.

- If origin is *exposure.asp*/"ClearLast", it resets most recent entry to default values and decrements "numentries" by one.

HTML: Provides form for user input of start date, state, county, and milk type/amount for up to 30 entries. Includes capability to change previously entered data.   Users hit the "Calculate Dose" button to proceed to the *results.asp* page

Results.asp

Description: Main calculation and dose display page. User inputs are retrieved from *exposure.asp*, then used to access and retrieve data from the appropriate dose text files. Dose and user information are sent to ADE/ Analytica® to calculate does exposure and risk of thyroid cancer.   Dose results are then

displayed as total dose, dose by year, or dose by shot. Total future lifetime risk can be viewed by pressing the "Calculate Risk" button.

VBScript: User-entered data are used to determine dose text file and position within that file for retrieving dose. File is opened and dose data are retrieved for shots. Dose and user data are configured for calculations, then an ADE session is initiated, data are sent to Analytica$^{®}$ and calculated dose and risk data are retrieved.

HTML: Presents dose results and user-entered data in tabular form. The user can select to view dose data by Total, by Year, or by Shot.   Users hit the "Calculate Risk" button to proceed to the *risk.asp* page

Risk.asp

Description: Risk display page. Calculated risk is retrieved from *results.asp*, then displayed.

VBScript: Data to display are retrieved (note that risk calculations were done during Analytica$^{®}$ call in *results.asp*).

HTML: Presents risk results in text form.

Changestate.asp

Description: Page for selecting a state in cases where a state has already been selected and the user wishes to change the entry.

VBScript: Entry data are retrieved.

HTML: Provides drop-down list for user to change the state. User then hits "Select County" to go to *county.asp*.

County.asp

Description: Page for selecting the county where user lived.

VBScript: Detects whether entry is from *exposure.asp* or *changestate.asp*, retrieves state entry, then gets proper county list from Microsoft Access database of U.S. counties.

HTML: Provides drop-down list for users to select the county where they lived. User hits "Continue" to go to back to *exposure.asp*. User can also access U.S. Census Bureau site for help in finding the name of the county (http://quickfacts.census.gov/cgi-bin/lookup).

County_map.asp

Description: Page to select the portion of the county where the user lived, for the 14 cases where large counties are divided into parts.

VBScript: Detects the county name, and creates a holder variable to select the correct image and image map.

HTML: Shows the image of the county, from which the users click where they lived, sending them to the *exposure.asp* page.

INFORMATIONAL PAGES

Summary_info.asp

  Information page giving brief overview of nuclear testing in Nevada, fallout of ^{131}I, dose exposure and risk.

More_date.asp

  Information and help page explaining date entries on the *exposure.asp* page.

More_res.asp

  Information and help page explaining residence location entries on the *exposure.asp* page.

More_milk.asp

  Information and help page explaining milk entries on the *exposure.asp* page.

Future_mean.asp

  Information page explaining what future risk means. This page is dynamic – it pulls the user's actual calculated risks and displays them within the text of the message.

Range_mean.asp

  Information page explaining what displayed ranges of risk mean. This page is dynamic – it pulls the user's actual calculated risks and displays them within the text of the message.

Credint.asp

  Information page explaining the 90 percent confidence interval on the *results.asp* page.

Credint1.asp

  Information page explaining the 90 percent confidence interval on the *range_mean.asp* page.

5.5 Description of Variables

  Table 8 lists all VBScript variables used in the site, along with their page locations and a brief description of their function within those pages.

Table 8   List of VBScript variables and functions used in site.

Variable Name	Page Locations	Description/Function
addone	*results*	Conditional variable to increment *colskip* value by one if *agegroup* is greater than 9.
ade, session("ade")	*results*	Variable to hold the active ADE session object.
agegroup(83), session("agegroup")	*default, exposure, shot_loc*	Defines the age group a person is in during each of the 83 shots.
baseline_future, session("baseline_future")	*results, risk, future_mean, range_mean*	Calculated baseline future lifetime risk (without dose exposure), calculated in Analytica®.
baseline_lifetime, session("baseline_lifetime")	*results, risk, future_mean, range_mean*	Calculated baseline lifetime risk (without dose exposure), calculated in Analytica®.
bdate, session("bdate")	*default, exposure, results, risk*	Date of birth in mm/dd/yyyy format.
bda, session("bda")	*default, birthdate, exposure, results, risk*	Day of month of birthday of the subject.
bmo, session("bmo")	*default, birthdate, exposure, results, risk*	Month of birthday of the subject.
byr, session("byr")	*default, birthdate, exposure, results, risk*	Year of birthday of the subject.
county	*exposure, county_map*	Name of the county selected by the user on one of the county image maps or in drop-down lists on *county.asp*.
cnty	*exposure*	Shortened name for county to use in long if-then-else statement
colskip(83)	*results*	Number of columns to skip to retrieve correct milk type dose during dose text file retrieval.

Table is continued on the next page

Table 8   continued

Variable Name	Page Locations	Description/Function
county_redirect	*exposure*	Variable to detect if the user has selected to change a previously entered county
daysalive(83)	*exposure*	Calculated number of days person has been alive at each shot date
entry_data(5,30), session("entry_data")	*default, birthdate, exposure, results, risk, changestate, county, county_map*	Array to hold user-entered data for residence location and milk habits for up to 30 entries. In order, data are: month-year-state-county-milk
entry_day	*exposure*	Placeholder for assumed day of the month for a user entered month. Since days are not entered, assume the 15th except where the birth date applies, then use that day.
entrynum, session("entrynum")	*exposure, changestate, county, county_map*	Variable to indicate which entry is being modified.
err_msg(x), session("error")	*default, birthdate, exposure, changestate, county, county_map*	Array to hold error messages for later display back to user
error_flag(30)	*exposure*	Array of on-off (1/0) checks for detected errors. Needed to avoid repeating same error message more than once.
gender, session("gender")	*default, birthdate, exposure, results, risk*	Gender of the subject.
geomean(83)	*results*	Array to hold the geometric mean dose for each shot retrieved from dose text files.
getfile(83)	*results*	The constructed directory path and file name used to retrieve the appropriate dose text file for each shot.

Table 8   continued

Variable Name	Page Locations	Description/Function
goatflag1	*results*	Conditional variable to adjust *getfile* name to account for goat milk usage.
goatflag2	*results*	Conditional variable to adjust *getfile* name to account for goat milk usage.
gsd(83)	*results*	Array to hold the geometric standard deviation for dose for each shot retrieved from dose text files.
mapname	*county_map*	Variable to hold name of coordinate map for selected county image map boundaries.
milk(83)	*results*	Array of milk types for each shot to send to Analytica®. Equivalent to values in *shot_loc(3,i).*
milk1, milk2,… milk29, milk30	*exposure*	User entered value for milk type consumed for up to 30 data entries
model	*results*	Variable to hold the currently open Analytica® model object.
month1, month2,… month29, month30	*exposure*	User entered value for start month for up to 30 data entries
numentries, session("numentries")	*default, birthdate, exposure, results, risk*	Variable to keep track of the number of location/milk entries the user has defined.
pgsource	*birthdate, exposure, results*	Conditional variable used to check for page entry from another specific page.
session("randomseed")	*default, results*	Random number seed for Monte Carlo simulations in Analytica®

Table is continued on the next page

Table 8   continued

Variable Name	Page Locations	Description/Function
session("sample_size")	*default, results*	Number of samples to run n Monte Carlo simulations in Analytica®
series_dates(3,8), *session("series_dates")*	*default, results*	Array to hold information for each of the 8 shot series. In order, data are: *series-start date-end date.*
session("sessionactive")	*results*	On-off (1/0) to indicate whether an ADE session is already open.
shot_dates(4,83), *session("shot_dates")*	*default, exposure, results*	Array to hold shot information for each of the 83 shots. In order, data are: *annex-test-series-date.*
shot_info(4,83), *session("shot_info")*	*results*	Shot information retrieved from Analytica® for each shot. Ordered by number-shot name-series name-date.
shot_loc(3,83), *session("shot_loc")*	*exposure, results, risk*	Array to hold user information for each of the 83 shots. In order, data are: state-county-milk.
shot_percentiles(3,83), *session("shot_percentiles")*	*results*	Calculated low-mid-high dose percentiles by shot, calculated in Analytica®.
shotusedflag(83)	*results*	Array to flag whether a shot is applicable. Set during loop to retrieve data in dose text files.
st	*exposure*	Shortened name for state to use in long if-then-else statement.
startmonth(30)	*results, risk*	Text names of entry data months – converted from numeric for display purposes.
state	*county, county_map*	Full name of states, converted from two letter abbreviations for display purposes.

Table is continued on the next page

Table 8   continued

Variable Name	Page Locations	Description/Function
state1, state2,… state29, state30	*exposure*	User-entered value for the state for up to 30 data entries.
submitreq	*exposure, results, county*	Holds value passed by the type=submit of a form. Often used to discriminate origin of submittal when accessing a new page.
submitreq1, submitreq2, ... submitreq29, submitreq30	*exposure*	Holds the value passed by the *type=submit* of a form. Numbered versions are used for requests to change a selected state or county.
textbmo	*exposure*	Text names of birth month – converted from numeric for display purposes.
total_future, session("total_future")	*results, risk, future_mean, range_mean*	Calculated total future risk from dose exposure, calculated in Analytica®.
total_lifetime, session("total_lifetime")	*results, risk, future_mean, range_mean*	Calculated total lifetime risk from dose exposure, calculated in Analytica®.
total_percentiles(3), session("total_percentiles")	*results*	Calculated total low-mid-high dose percentiles, calculated in Analytica®.
session("user")	*default, birthdate, exposure, results, risk, changestate, county, county_map*	User name is set in default page, then its definition is checked in other pages to ensure user only enters through default page.
year1, year2,… year29, year30	*exposure*	User entered value for start year for up to 30 data entries
yearly_percentiles(3,21), session("yearly_percentiles")	*results*	Calculated low-mid-high dose percentiles by year, calculated in Analytica®.

6.   SUMMARY

To support NCI's efforts in disseminating quantitative information about the thyroid dose and future lifetime risk of thyroid cancer from exposure to ^{131}I in fallout following atmospheric nuclear bomb tests at the Nevada test site, a new Internet-based computer code has been developed. This computer code allows an individual to enter personal information (i.e., birth date, gender, milk diet and location in the contiguous United States during the time of weapons testing in Nevada) and to obtain estimates of the thyroid dose and of the future lifetime risk of thyroid cancer. The new dose and risk calculator is referred to as IRAD-NTS, and is available through the National Cancer Institute's website.

IRAD-NTS reports individual thyroid doses obtained from the NCI database of pre-calculated thyroid dose files. The NCI database of thyroid dose files consists of estimated individual doses for representative individuals residing in each of the 3,071 counties of the contiguous United States, organized by nuclear test for 13 different age-at-exposure categories, by type of milk diet used, and by gender. The doses from each nuclear test are extracted from the NCI database for the location, age, and type of milk diet of the individual at the time of the test. For individuals exposed over the age of 20, the data are differentiated by gender. IRAD-NTS allows for changes in location, and in milk diet from one test to another on a monthly basis. Monte-Carlo methods are used within IRAD-NTS for propagation of uncertainties to report a 90% credibility interval for the total dose to the thyroid gland and the future risk of thyroid cancer.

The current version of IRAD-NTS (v.3.0) estimates the future risk of thyroid cancer using epidemiological and radiobiological information about thyroid cancer from the most recent analysis of the health risks from low levels of ionizing radiation performed by the BEIR VII committee (NRC/NAS 2006) and from the Interactive RadioEpidemiological Program (IREP) (IREP; Land et al. 2003). The risk model for thyroid cancer in IRAD-NTS is based on the linear dose response obtained from the analysis of epidemiologic studies of children and adults exposed to external gamma and X rays performed by the BEIR VII committee. However, IRAD-NTS uses the same dose and dose rate effectiveness factor (DDREF) as IREP. DDREF accounts for the potential departures from a linear dose response observed at high doses and high dose rates when actual exposures are chronic at low dose rates.

IRAD-NTS is programmed using Analytica®, a software allowing Monte Carlo procedures for propagating errors for complex calculations, and it is driven remotely by an Internet-based user interface interacting with Analytica® Decision Engine. Thus, IRAD-NTS performs on-line (or "live") calculations of doses and risk using Monte Carlo uncertainty propagation (300 random simulations are made using midpoint Latin Hypercube Sampling). IRAD-NTS can be accessed by anyone with access to the Internet. IRAD-NTS resides at a central location and can be updated without the need for re-distributing the software or the documentation. IRAD-NTS has a user-friendly input screen, presents the dose and risk estimates in an easy-to-read manner, and provides information to help users put their future risk from exposure to NTS fallout into perspective using comparisons with the risk of thyroid cancer from natural causes.

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APPENDIX A

The survival function

The survival function represents the probability of an individual surviving up to a given age. The survival function used in this work originates from probability of death data tabulated in the U.S. Decennial Life Table for 1989-1991 (NCHA 1997). These data were transformed into survival functions for males, females, and both genders combined, and summarized by Federal Guidance Report No. 13 (EPA 1999).

The survival functions [$S(a)$] published by EPA (1999) represent the probability of survival to age a (Eq. A.1)

$$S(a) = [1 - q(a-1)] \cdot S(a-1) = \prod_{i=0}^{a-1} [1 - q(i)] \cdot S(0) = \prod_{i=0}^{a-1} [1 - q(i)] \qquad (A.1)$$

where $q(a)$ is the probability of death at age a, and $S(0)=1$.

For an individual who is alive today, at age a_0, the probability of survival is unity [$S(a_0)=1$]. In this case, the surviving function for an age $a > a_0$ is the probability of surviving to age a, given that the person was alive at age a_0.

$$S_{a_0}(a) = [1 - q(a-1)] \cdot S(a-1) = \prod_{i=a_0}^{a-1} [1 - q(i)] \cdot S(a_0) = \prod_{i=a_0}^{a-1} [1 - q(i)] \qquad (A.2)$$

Combining Equations A.1 and A.2, one obtains, for $a > a_0$,

$$S(a) = S(a_0) \cdot S_{a_0}(a) \qquad (A.3)$$

or

$$S_{a_0}(a) = \frac{S(a)}{S(a_0)} \qquad (A.4)$$

The survival functions reported by EPA (1999) are presented in Table A.1. Equation A.4 is used in IRAD-NTS to calculate the probability of survival for an individual who is alive at the present time. As an example, the survival function for a 60-year-old individual is presented in Table A-2

Table A.1   Gender- and age-specific values for the survival function, *S(a)* (EPA
              1999).

Age	Survival function, $S(a)$		
(years)	combined	male	female
0	1.000	1.000	1.000
1	9.9064×10^{-1}	9.8961×10^{-1}	9.9173×10^{-1}
2	9.8992×10^{-1}	9.8884×10^{-1}	9.9106×10^{-1}
3	9.8944×10^{-1}	9.8830×10^{-1}	9.9064×10^{-1}
4	9.8908×10^{-1}	9.8789×10^{-1}	9.9033×10^{-1}
5	9.8878×10^{-1}	9.8754×10^{-1}	9.9008×10^{-1}
6	9.8851×10^{-1}	9.8723×10^{-1}	9.8984×10^{-1}
7	9.8826×10^{-1}	9.8696×10^{-1}	9.8963×10^{-1}
8	9.8804×10^{-1}	9.8670×10^{-1}	9.8944×10^{-1}
9	9.8784×10^{-1}	9.8647×10^{-1}	9.8928×10^{-1}
10	9.8766×10^{-1}	9.8628×10^{-1}	9.8912×10^{-1}
11	9.8750×10^{-1}	9.8611×10^{-1}	9.8897×10^{-1}
12	9.8735×10^{-1}	9.8594×10^{-1}	9.8882×10^{-1}
13	9.8713×10^{-1}	9.8570×10^{-1}	9.8864×10^{-1}
14	9.8682×10^{-1}	9.8528×10^{-1}	9.8843×10^{-1}
15	9.8636×10^{-1}	9.8465×10^{-1}	9.8815×10^{-1}
16	9.8574×10^{-1}	9.8377×10^{-1}	9.8780×10^{-1}
17	9.8498×10^{-1}	9.8267×10^{-1}	9.8740×10^{-1}
18	9.8410×10^{-1}	9.8140×10^{-1}	9.8694×10^{-1}
19	9.8315×10^{-1}	9.8000×10^{-1}	9.8646×10^{-1}
20	9.8217×10^{-1}	9.7855×10^{-1}	9.8597×10^{-1}
21	9.8114×10^{-1}	9.7703×10^{-1}	9.8545×10^{-1}
22	9.8008×10^{-1}	9.7546×10^{-1}	9.8492×10^{-1}
23	9.7897×10^{-1}	9.7383×10^{-1}	9.8437×10^{-1}
24	9.7785×10^{-1}	9.7218×10^{-1}	9.8381×10^{-1}
25	9.7671×10^{-1}	9.7050×10^{-1}	9.8324×10^{-1}
26	9.7556×10^{-1}	9.6881×10^{-1}	9.8266×10^{-1}
27	9.7440×10^{-1}	9.6710×10^{-1}	9.8207×10^{-1}
28	9.7321×10^{-1}	9.6536×10^{-1}	9.8146×10^{-1}
29	9.7197×10^{-1}	9.6356×10^{-1}	9.8081×10^{-1}
30	9.7067×10^{-1}	9.6167×10^{-1}	9.8013×10^{-1}
31	9.6930×10^{-1}	9.5970×10^{-1}	9.7939×10^{-1}
32	9.6786×10^{-1}	9.5763×10^{-1}	9.7861×10^{-1}

Table is continued on the next page

Table A.1   continued

Age	Survival function, $S(a)$		
(years)	combined	male	female
33	9.6636×10^{-1}	9.5549×10^{-1}	9.7778×10^{-1}
34	9.6479×10^{-1}	9.5325×10^{-1}	9.7690×10^{-1}
35	9.6314×10^{-1}	9.5092×10^{-1}	9.7597×10^{-1}
36	9.6140×10^{-1}	9.4847×10^{-1}	9.7498×10^{-1}
37	9.5958×10^{-1}	9.4591×10^{-1}	9.7394×10^{-1}
38	9.5767×10^{-1}	9.4324×10^{-1}	9.7282×10^{-1}
39	9.5567×10^{-1}	9.4048×10^{-1}	9.7162×10^{-1}
40	9.5358×10^{-1}	9.3762×10^{-1}	9.7034×10^{-1}
41	9.5140×10^{-1}	9.3467×10^{-1}	9.6896×10^{-1}
42	9.4910×10^{-1}	9.3160×10^{-1}	9.6748×10^{-1}
43	9.4668×10^{-1}	9.2840×10^{-1}	9.6587×10^{-1}
44	9.4409×10^{-1}	9.2501×10^{-1}	9.6413×10^{-1}
45	9.4132×10^{-1}	9.2140×10^{-1}	9.6223×10^{-1}
46	9.3831×10^{-1}	9.1752×10^{-1}	9.6013×10^{-1}
47	9.3502×10^{-1}	9.1333×10^{-1}	9.5780×10^{-1}
48	9.3145×10^{-1}	9.0880×10^{-1}	9.5524×10^{-1}
49	9.2758×10^{-1}	9.0392×10^{-1}	9.5242×10^{-1}
50	9.2339×10^{-1}	8.9868×10^{-1}	9.4933×10^{-1}
51	9.1884×10^{-1}	8.9301×10^{-1}	9.4595×10^{-1}
52	9.1387×10^{-1}	8.8686×10^{-1}	9.4223×10^{-1}
53	9.0844×10^{-1}	8.8017×10^{-1}	9.3814×10^{-1}
54	9.0253×10^{-1}	8.7288×10^{-1}	9.3367×10^{-1}
55	8.9610×10^{-1}	8.6494×10^{-1}	9.2882×10^{-1}
56	8.8913×10^{-1}	8.5634×10^{-1}	9.2356×10^{-1}
57	8.8157×10^{-1}	8.4701×10^{-1}	9.1785×10^{-1}
58	8.7334×10^{-1}	8.3687×10^{-1}	9.1164×10^{-1}
59	8.6437×10^{-1}	8.2583×10^{-1}	9.0485×10^{-1}
60	8.5460×10^{-1}	8.1381×10^{-1}	8.9744×10^{-1}
61	8.4405×10^{-1}	8.0086×10^{-1}	8.8940×10^{-1}
62	8.3274×10^{-1}	7.8701×10^{-1}	8.8076×10^{-1}
63	8.2064×10^{-1}	7.7224×10^{-1}	8.7147×10^{-1}
64	8.0770×10^{-1}	7.5649×10^{-1}	8.6148×10^{-1}
65	7.9390×10^{-1}	7.3974×10^{-1}	8.5076×10^{-1}

Table A.1   continued

Age	Survival function, $S(a)$		
(years)	combined	male	female
66	7.7922×10^{-1}	7.2201×10^{-1}	8.3930×10^{-1}
67	7.6370×10^{-1}	7.0334×10^{-1}	8.2708×10^{-1}
68	7.4729×10^{-1}	6.8369×10^{-1}	8.1406×10^{-1}
69	7.2989×10^{-1}	6.6298×10^{-1}	8.0014×10^{-1}
70	7.1140×10^{-1}	6.4109×10^{-1}	7.8522×10^{-1}
71	6.9173×10^{-1}	6.1797×10^{-1}	7.6919×10^{-1}
72	6.7085×10^{-1}	5.9359×10^{-1}	7.5197×10^{-1}
73	6.4873×10^{-1}	5.6801×10^{-1}	7.3349×10^{-1}
74	6.2547×10^{-1}	5.4137×10^{-1}	7.1377×10^{-1}
75	6.0118×10^{-1}	5.1387×10^{-1}	6.9286×10^{-1}
76	5.7598×10^{-1}	4.8565×10^{-1}	6.7082×10^{-1}
77	5.4988×10^{-1}	4.5679×10^{-1}	6.4764×10^{-1}
78	5.2292×10^{-1}	4.2742×10^{-1}	6.2321×10^{-1}
79	4.9505×10^{-1}	3.9763×10^{-1}	5.9734×10^{-1}
80	4.6622×10^{-1}	3.6750×10^{-1}	5.6987×10^{-1}
81	4.3643×10^{-1}	3.3706×10^{-1}	5.4077×10^{-1}
82	4.0583×10^{-1}	3.0647×10^{-1}	5.1017×10^{-1}
83	3.7468×10^{-1}	2.7609×10^{-1}	4.7821×10^{-1}
84	3.4339×10^{-1}	2.4650×10^{-1}	4.4512×10^{-1}
85	3.1230×10^{-1}	2.1816×10^{-1}	4.1115×10^{-1}
86	2.8153×10^{-1}	1.9116×10^{-1}	3.7643×10^{-1}
87	2.5117×10^{-1}	1.6550×10^{-1}	3.4113×10^{-1}
88	2.2156×10^{-1}	1.4140×10^{-1}	3.0573×10^{-1}
89	1.9307×10^{-1}	1.1910×10^{-1}	2.7074×10^{-1}
90	1.6604×10^{-1}	9.8784×10^{-2}	2.3666×10^{-1}
91	1.4063×10^{-1}	8.0549×10^{-2}	2.0372×10^{-1}
92	1.1706×10^{-1}	6.4441×10^{-2}	1.7231×10^{-1}
93	9.5685×10^{-2}	5.0524×10^{-2}	1.4310×10^{-1}
94	7.6820×10^{-2}	3.8824×10^{-2}	1.1672×10^{-1}
95	6.0582×10^{-2}	2.9266×10^{-2}	9.3463×10^{-2}
96	4.6893×10^{-2}	2.1656×10^{-2}	7.3392×10^{-2}
97	3.5553×10^{-2}	1.5693×10^{-2}	5.6407×10^{-2}
98	2.6410×10^{-2}	1.1151×10^{-2}	4.2432×10^{-2}

Table A.1   continued

Age (years)	Survival function, $S(a)$		
	combined	male	Female
99	1.9215×10^{-2}	7.7620×10^{-3}	3.1241×10^{-2}
100	1.3686×10^{-2}	5.2851×10^{-3}	2.2507×10^{-2}
101	9.5253×10^{-3}	3.5144×10^{-3}	1.5837×10^{-2}
102	6.4653×10^{-3}	2.2780×10^{-3}	1.0862×10^{-2}
103	4.2700×10^{-3}	1.4365×10^{-3}	7.2452×10^{-3}
104	2.7372×10^{-3}	8.7932×10^{-4}	4.6879×10^{-3}
105	1.6982×10^{-3}	5.2121×10^{-4}	2.9340×10^{-3}
106	1.0164×10^{-3}	2.9833×10^{-4}	1.7705×10^{-3}
107	5.8477×10^{-4}	1.6438×10^{-4}	1.0262×10^{-3}
108	3.2202×10^{-4}	8.6882×10^{-5}	5.6892×10^{-4}
109	1.6891×10^{-4}	4.3873×10^{-5}	3.0020×10^{-4}
110	8.3912×10^{-5}	2.1069×10^{-5}	1.4990×10^{-4}
111	3.9216×10^{-5}	9.5701×10^{-6}	7.0343×10^{-5}
112	1.7103×10^{-5}	4.0859×10^{-6}	3.0771×10^{-5}
113	6.8928×10^{-6}	1.6274×10^{-6}	1.2422×10^{-5}
114	2.5380×10^{-6}	5.9920×10^{-7}	4.5737×10^{-6}
115	8.5432×10^{-7}	2.0170×10^{-7}	1.5396×10^{-6}
116	2.5924×10^{-7}	6.1205×10^{-8}	4.6717×10^{-7}
117	6.9636×10^{-8}	1.6441×10^{-8}	1.2549×10^{-7}
118	1.6159×10^{-8}	3.8150×10^{-9}	2.9120×10^{-8}
119	3.1292×10^{-9}	7.3878×10^{-10}	5.6391×10^{-9}
120	4.7981×10^{-10}	1.1328×10^{-10}	8.6466×10^{-10}

Table A.2   The survival function for an individual alive at age 60, *S(a)/S(60)*

Age [years]	Survival function, *S(a)/S(50)* Male	Female	Age [years]	Survival function, *S(a)* Male	Female
60	1.000	1.000	90	1.2138×10^{-1}	2.6371×10^{-1}
61	9.8409×10^{-1}	9.9104×10^{-1}	91	9.8978×10^{-2}	2.2700×10^{-1}
62	9.6707×10^{-1}	9.8141×10^{-1}	92	7.9184×10^{-2}	1.9200×10^{-1}
63	9.4892×10^{-1}	9.7106×10^{-1}	93	6.2083×10^{-2}	1.5945×10^{-1}
64	9.2957×10^{-1}	9.5993×10^{-1}	94	4.7706×10^{-2}	1.3006×10^{-1}
65	9.0898×10^{-1}	9.4799×10^{-1}	95	3.5962×10^{-2}	1.0414×10^{-1}
66	8.8720×10^{-1}	9.3522×10^{-1}	96	2.6611×10^{-2}	8.1779×10^{-2}
67	8.6426×10^{-1}	9.2160×10^{-1}	97	1.9283×10^{-2}	6.2853×10^{-2}
68	8.4011×10^{-1}	9.0709×10^{-1}	98	1.3702×10^{-2}	4.7281×10^{-2}
69	8.1466×10^{-1}	8.9158×10^{-1}	99	9.5379×10^{-3}	3.4811×10^{-2}
70	7.8776×10^{-1}	8.7496×10^{-1}	100	6.4943×10^{-3}	2.5079×10^{-2}
71	7.5935×10^{-1}	8.5709×10^{-1}	101	4.3185×10^{-3}	1.7647×10^{-2}
72	7.2940×10^{-1}	8.3791×10^{-1}	102	2.7992×10^{-3}	1.2103×10^{-2}
73	6.9796×10^{-1}	8.1731×10^{-1}	103	1.7652×10^{-3}	8.0732×10^{-3}
74	6.6523×10^{-1}	7.9534×10^{-1}	104	1.0805×10^{-3}	5.2236×10^{-3}
75	6.3144×10^{-1}	7.7204×10^{-1}	105	6.4046×10^{-4}	3.2693×10^{-3}
76	5.9676×10^{-1}	7.4748×10^{-1}	106	3.6658×10^{-4}	1.9728×10^{-3}
77	5.6130×10^{-1}	7.2165×10^{-1}	107	2.0199×10^{-4}	1.1435×10^{-3}
78	5.2521×10^{-1}	6.9443×10^{-1}	108	1.0676×10^{-4}	6.3394×10^{-4}
79	4.8860×10^{-1}	6.6560×10^{-1}	109	5.3911×10^{-5}	3.3451×10^{-4}
80	4.5158×10^{-1}	6.3500×10^{-1}	110	2.5889×10^{-5}	1.6703×10^{-4}
81	4.1418×10^{-1}	6.0257×10^{-1}	111	1.1760×10^{-5}	7.8382×10^{-5}
82	3.7659×10^{-1}	5.6847×10^{-1}	112	5.0207×10^{-6}	3.4288×10^{-5}
83	3.3926×10^{-1}	5.3286×10^{-1}	113	1.9997×10^{-6}	1.3842×10^{-5}
84	3.0290×10^{-1}	4.9599×10^{-1}	114	7.3629×10^{-7}	5.0964×10^{-6}
85	2.6807×10^{-1}	4.5814×10^{-1}	115	2.4785×10^{-7}	1.7155×10^{-6}
86	2.3490×10^{-1}	4.1945×10^{-1}	116	7.5208×10^{-8}	5.2056×10^{-7}
87	2.0336×10^{-1}	3.8011×10^{-1}	117	2.0203×10^{-8}	1.3983×10^{-7}
88	1.7375×10^{-1}	3.4067×10^{-1}	118	4.6878×10^{-9}	3.2448×10^{-8}
89	1.4635×10^{-1}	3.0168×10^{-1}	119	9.0780×10^{-10}	6.2835×10^{-9}
			120	1.3920×10^{-10}	9.6347×10^{-10}

APPENDIX B

The average exposure to NTS fallout

Table B.1   Per capita thyroid doses (cGy) by year of birth in SEER regions assuming an average milk diet. Doses are described by a lognormal distribution defined using the reported geometric mean (GM) and geometric standard deviation (GSD).

Birth year	1930 GM	GSD	1931 GM	GSD	1932 GM	GSD	1933 GM	GSD	1934 GM	GSD
1951	0.013	3.4	0.013	3.4	0.028	3.5	0.028	3.5	0.028	3.5
1952	0.4	1.5	0.4	1.5	1.1	1.5	1.1	1.5	1.1	1.5
1953	0.26	1.5	0.26	1.5	0.26	1.5	0.69	1.4	0.69	1.4
1954	0.065	2.7	0.065	2.7	0.065	2.7	0.065	2.7	0.065	2.7
1955	0.31	1.6	0.31	1.6	0.31	1.6	0.31	1.6	0.31	1.6
1956	0	0	0	0	0	0	0	0	0	0
1957	0.073	4	0.073	4	0.073	4	0.073	4	0.073	4

Birth year	1935 GM	GSD	1936 GM	GSD	1937 GM	GSD	1938 GM	GSD	1939 GM	GSD
1951	0.028	3.5	0.028	3.5	0.037	3.5	0.037	3.5	0.037	3.5
1952	1.1	1.5	1.1	1.5	1.5	1.5	1.5	1.5	1.5	1.5
1953	0.69	1.4	0.69	1.4	0.69	1.4	0.94	1.5	0.94	1.5
1954	0.14	3	0.14	3	0.14	3	0.14	3	0.14	3
1955	0.31	1.6	0.31	1.6	0.31	1.6	0.84	1.6	0.84	1.6
1956	0	0	0	0	0	0	0	0	0	0
1957	0.073	4	0.073	4	0.073	4	0.073	4	0.073	4

Birth year	1940 GM	GSD	1941 GM	GSD	1942 GM	GSD	1943 GM	GSD	1944 GM	GSD
1951	0.037	3.5	0.037	3.5	0.052	3.5	0.052	3.5	0.052	3.5
1952	1.5	1.5	1.5	1.5	2.1	1.5	2.1	1.5	2.1	1.5
1953	0.94	1.5	0.94	1.5	0.94	1.5	1.3	1.4	1.3	1.4
1954	0.19	3	0.19	3	0.19	3	0.19	3	0.19	3
1955	0.84	1.6	0.84	1.6	0.84	1.6	1.1	1.6	1.1	1.6
1956	0	0	0	0	0	0	0	0	0	0
1957	0.073	4	0.073	4	0.073	4	0.21	4	0.21	4

Birth year	1945 GM	GSD	1946 GM	GSD	1947 GM	GSD	1948 GM	GSD	1949 GM	GSD
1951	0.052	3.5	0.052	3.5	0.071	3.5	0.071	3.5	0.071	3.5
1952	2.1	1.5	2.1	1.5	3	1.5	3	1.5	3	1.5
1953	1.3	1.4	1.3	1.4	1.3	1.4	1.9	1.4	1.9	1.4
1954	0.27	3	0.27	3	0.27	3	0.27	3	0.27	3
1955	1.1	1.6	1.1	1.6	1.1	1.6	1.6	1.5	1.6	1.5
1956	0	0	0	0	0	0	0	0	0	0
1957	0.21	4	0.21	4	0.21	4	0.28	4	0.28	4

Table B.1   continued

| Birth year | 1950 | | 1951 | | 1952 | | 1953 | | 1954 | |
	GM	GSD	GM	GSD	GM	GSD	GM	GSD	GM	GSD
1951	0.071	3.5	0.12	3.6	0.023	3.7	0	0	0	0
1952	3	1.5	4.1	1.4	4.8	1.4	0.84	1.5	0	0
1953	1.9	1.4	1.9	1.4	1.9	1.4	2.6	1.4	1.3	1.5
1954	0.37	3	0.37	3	0.37	3	0.37	3	0.37	3
1955	1.6	1.5	1.6	1.5	1.6	1.5	1.6	1.5	2.3	1.5
1956	0	0	0	0	0	0	0	0	0	0
1957	0.28	4	0.28	4	0.28	4	0.28	4	0.41	3.9

| Birth year | 1955 | | 1956 | | 1957 | | 1958 | | 1959 | |
	GM	GSD	GM	GSD	GM	GSD	GM	GSD	GM	GSD
1951	0	0	0	0	0	0	0	0	0	0
1952	0	0	0	0	0	0	0	0	0	0
1953	0	0	0	0	0	0	0	0	0	0
1954	0.56	2.7	0.28	3	0	0	0	0	0	0
1955	2.3	1.5	2.3	1.5	2.3	1.5	4.1	1.5	0	0
1956	0	0	0	0	0	0	0	0	0	0
1957	0.41	3.9	0.41	3.9	0.41	3.9	0.41	3.9	0.58	3.9

| Birth year | 1960 | | 1961 | | 1962 | | 1963 | | | |
	GM	GSD	GM	GSD	GM	GSD	GM	GSD		
1951	0	0	0	0	0	0	0	0		
1952	0	0	0	0	0	0	0	0		
1953	0	0	0	0	0	0	0	0		
1954	0	0	0	0	0	0	0	0		
1955	0	0	0	0	0	0	0	0		
1956	0	0	0	0	0	0	0	0		
1957	0.58	3.9	0.58	3.9	0.58	3.9	1	3.8		