

## The public health implications of combined exposure to multiple sources of $^{131}\text{I}$ released during the Cold War Era: Extension of dose reconstruction to risk analysis and beyond

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**Abstract.** During the past 15 years, doses have been reconstructed to members of the public who were exposed to radiation released from Cold War Era government facilities that supported the development and testing of nuclear weapons. A major component of these exposures resulted from releases of  $^{131}\text{I}$  to the atmosphere. This paper addresses the public health implications of the combined exposures from the production of radioactive lanthanum at Oak Ridge which released  $^{131}\text{I}$ , and  $^{131}\text{I}$  deposited in the regions around Oak Ridge resulting from atmospheric weapons testing at the Nevada Test Site. Full application of uncertainty analysis is used to quantify estimates of thyroid dose, the excess lifetime risk of thyroid neoplasms, the risk of non-neoplastic disease at high exposures, and the probability that past exposure could be responsible for present thyroid disease. The results show that fallout  $^{131}\text{I}$  is a substantial contributing factor to the total exposure and excess risk of thyroid cancer for those exposed as children residing downwind of local government installations. For many persons exposed in childhood, the upper confidence limit of the estimate of PC may exceed 50%, regardless of the location where milk was produced.

### 1. INTRODUCTION

During the past 15 years, major efforts were undertaken in the U.S. to reconstruct exposures and doses to members of the public from the past operation of Cold War Era governmental facilities that supported the development and testing of nuclear weapons. At many of these facilities a major component of exposure resulted from releases of  $^{131}\text{I}$  to the atmosphere. Public exposures to  $^{131}\text{I}$  occurred during the 1940s through the early 1960s from the operation of fuel reprocessing and chemical separation activities at Oak Ridge, TN, Savannah River, GA, the Idaho National Engineering Laboratory, ID, and Hanford, WA. At about the same time,  $^{131}\text{I}$  was deposited throughout the Northern Hemisphere in fallout from atmospheric weapons testing at the Nevada Test Site (NTS), 1952 through 1957 [1], the Marshall Islands, 1952 through 1958, and the former Soviet Union from 1958 through 1962 [2].

In the U.S., dose reconstructions to assess public health risk, quantitative uncertainty analysis has been mandated to formally bound the limits of credibility in all estimated values [3]. Quantitative uncertainty analysis was first applied to the air-pasture-cow-milk exposure pathway for  $^{131}\text{I}$  to estimate thyroid dose [4,5]. Recently, uncertainty analysis has been extended to estimates of the excess lifetime risk of thyroid cancer and other neoplasms, as well as to the probability that disease was caused by past exposure [6]. As the result of legislation in the U.S., eligibility for compensation for potential radiation induced cancers will be based on uncertainty analysis of the probability of causation (PC). If there is as much as a 1% chance that PC exceeds 50%, a former radiation worker with a diagnosed cancer would be compensated for their claim and be given medical care for life [7].

### 2. METHODS

The reconstruction of historic exposures and doses from releases of  $^{131}\text{I}$  from the mid-1940s to the early 1960s requires extensive use of mathematical models because of the general absence of measurements. In dose reconstructions for both fallout  $^{131}\text{I}$  and for releases of  $^{131}\text{I}$  from local facilities, probability distributions are assigned to represent the state of knowledge for all uncertain variables. Monte Carlo calculations are used to propagate uncertainties through equations to produce probability distributions for exposure, dose, and health risk. From these probability distributions central estimates and a 95% subjective confidence interval are obtained. (The term "subjective" is used to emphasize the important role of investigator judgment in the specification of probability distributions for model inputs [8]) For dose reconstructions at Oak Ridge, Tennessee, the source term for emissions of  $^{131}\text{I}$  from radioactive

lanthanum operations was the inventory of  $^{131}\text{I}$  in the dissolver. Probability distributions were assigned to the dissolver inventory and to the efficiency of the caustic scrubber and other retention devices that would have prevented  $^{131}\text{I}$  from escaping to the atmosphere. Probability distributions were also assigned to the amount of iodine that escaped during off-normal releases. For the dose reconstruction for local fallout from the Nevada Test Site, the source term was the deposition of  $^{131}\text{I}$  in fallout obtained from interpolation of gross beta analysis of particulate fallout on a national network of gummed film stations [1].

The reconstructed, time integrated concentrations of  $^{131}\text{I}$  in different sources of milk (commercial cow, backyard cow, and goats milk) were estimated using separate models (one for Oak Ridge releases, one for Nevada Test Site fallout). Time-integrated concentrations of  $^{131}\text{I}$  in milk were added then propagated from milk to the human diet, to the thyroid gland, and to estimates of excess lifetime risk of thyroid cancer.

For those with a diagnosed thyroid neoplasm, an estimate of the probability that the disease was caused by exposure was made using the equation  $PC = (RR - 1)/RR * 100$ , where  $PC$  = probability of causation, and  $RR$  = relative risk. Monte Carlo calculations were performed using 1,000 iterations with a mid-point Latin hypercube sampling [9].

### 3. RESULTS AND DISCUSSION

The importance of the Nevada Test Site Fallout throughout the U.S. is illustrated in Figures 1 and 2. Figure 1 shows that 830 counties in the U.S. received average doses per capita greater than 4 cGy (1 cGy = 1 rad). Figure 2 focuses on a birth cohort of January 1, 1952 with an average diet, but higher than average milk consumption. In this case, there are 2,148 counties in the U.S. that would have had individuals with average doses exceeding 10 cGy and 236 counties where the doses would exceed 30 cGy. The national average for children under the age of 1 at time of exposure to Nevada Test Site fallout range from 5 to 20 cGy. For doses in excess of 20 cGy, the risk of autoimmune thyroiditis may be increased for some individuals [10].

Table 1 presents thyroid doses from exposure to NTS fallout, the excess lifetime risk of thyroid cancer or other neoplasms, and the probability of causation that a diagnosed cancer was caused by exposure for representative individuals from selected locations in the continental U.S. who were born on January 1, 1952, who consumed an average diet composed of average amounts of fresh milk from commercial sources. The large overlap between the upper and lower confidence limits in dose from one location to the next indicates that for NTS fallout, place of residence was not a major determinant in estimating exposure, dose, and risk. The major factors that determine the risk of thyroid cancer are age at time of exposure,  $^{131}\text{I}$  concentration in milk, dietary source of milk, amount of milk consumed, and gender. The risk of developing thyroid cancer is highest for those who were exposed as children.

Table 2 presents the combined exposure to  $^{131}\text{I}$  released from the Oak Ridge facilities and Nevada Test Site fallout for an individual born in 1952 (consuming two 8-ounce glasses of milk produced from a local commercial dairy). The uncertainty in the reconstructed thyroid dose encompasses a range slightly greater than a factor of 10. The excess lifetime risk of thyroid cancer ranges from a few chances in 10,000, to slightly more than 1 chance in 100, depending on the location where the milk was produced. For individuals with a diagnosed neoplasm of the thyroid gland, the estimate of  $PC$  ranges from a few percent (meaning that the chances are very remote that exposure caused disease) to upper bounds that exceed 50%. In all but a few locations (which are located close in to the Oak Ridge Reservation), Nevada Test Site fallout was the predominant source of exposure.

With the exception of those who consumed goats' milk, the excess lifetime risk of thyroid cancer per individual is low. However, many individuals exposed as children in the 1950s, who consumed fresh milk from cows or goats and who have a diagnosed thyroid neoplasm, would qualify for medical care and compensation if the same rules for eligibility ( $PC_{99} > 50\%$ ) adopted for radiation workers were to be extended to members of the public.

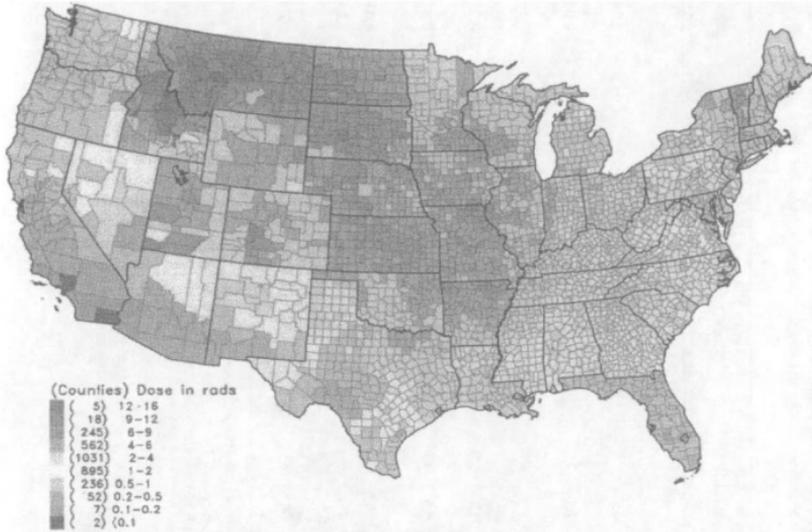


Figure 1. Average per capita thyroid doses from  $^{131}\text{I}$  in NTS fallout per county from Nevada Test Site fallout from exposure to  $^{131}\text{I}$  [1].

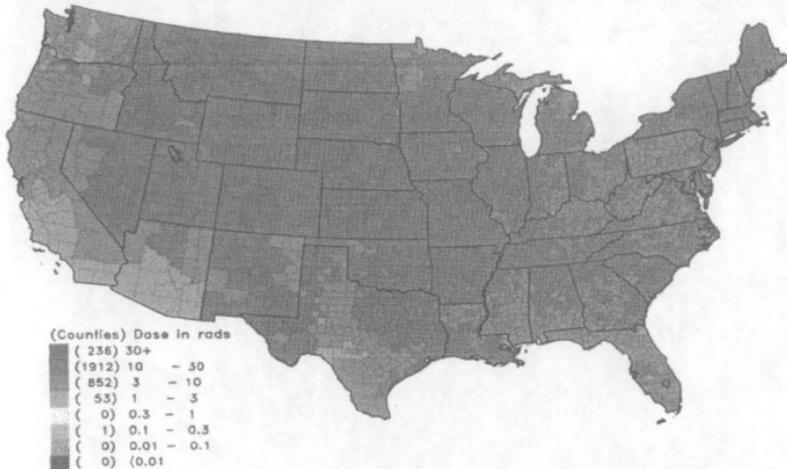


Figure 2. Per capita thyroid dose from  $^{131}\text{I}$  in NTS fallout per county for persons born on January 1, 1952 with an average diet but higher than average milk consumption [1].

**Table 1.** Thyroid doses and probabilities of causation for representative individuals from selected locations in the continental United States who were exposed to  $^{131}\text{I}$  from NTS fallout, who were born on January 1, 1952, and who consumed an average diet composed of average amounts of fresh milk from commercial sources.

Percentiles	Alameda, CA (95% C.I.)			Denver, CO (95% C.I.)			St. Louis, MO (95% C.I.)			Washington, D.C. (95% C.I.)			Albany, NY (95% C.I.)		
	2.5	50	97.5	2.5	50	97.5	2.5	50	97.5	2.5	50	97.5	2.5	50	97.5
<b>Main NTS Test Series</b>															
Tumbler-Snapper (4/52 - 6/52)	0.11	0.83	6.2	0.94	4.8	24	0.44	4.8	52	0.27	1.6	9.6	0.36	3.9	43
Upshot-Knothole (3/53 - 6/53)	0.01	0.11	1.0	0.24	1.3	7.2	0.17	1.7	17	0.20	0.92	4.3	0.08	1.8	38
Teapot (2/55 - 5/55)	0.01	0.13	3.1	0.26	1.3	6.6	0.12	0.84	5.8	0.12	0.56	2.6	0.12	0.97	7.8
Plumbbob (5/57 - 10/57)	0.002	0.02	0.26	0.49	2.1	8.9	0.34	2.5	19	0.04	0.67	11	0.08	1.1	16
<b>Total Dose (cGy)<sup>b</sup></b>	<b>0.13</b>	<b>1.1</b>	<b>11</b>	<b>1.9</b>	<b>9.5</b>	<b>47</b>	<b>1.1</b>	<b>9.8</b>	<b>94</b>	<b>0.63</b>	<b>3.8</b>	<b>27</b>	<b>0.64</b>	<b>7.8</b>	<b>104</b>
<b>Excess Lifetime Risk<sup>c</sup></b>															
<b>Females</b>	<b>0.15</b>	<b>3.7</b>	<b>85</b>	<b>2.0</b>	<b>30</b>	<b>460</b>	<b>1.3</b>	<b>33</b>	<b>740</b>	<b>0.63</b>	<b>12</b>	<b>240</b>	<b>0.83</b>	<b>26</b>	<b>740</b>
<b>Males</b>	<b>0.049</b>	<b>1.3</b>	<b>35</b>	<b>0.73</b>	<b>12</b>	<b>180</b>	<b>0.46</b>	<b>12</b>	<b>300</b>	<b>0.23</b>	<b>4.6</b>	<b>87</b>	<b>0.29</b>	<b>10</b>	<b>300</b>
<b>Probability of Causation (%)<sup>d</sup></b>	<b>1</b>	<b>8</b>	<b>51</b>	<b>8</b>	<b>39</b>	<b>83</b>	<b>8</b>	<b>43</b>	<b>87</b>	<b>3</b>	<b>22</b>	<b>67</b>	<b>7</b>	<b>41</b>	<b>90</b>

<sup>a</sup> Thyroid doses were estimated using the NCI individual dose calculator ([http://rex.nci.nih.gov/NTRCE\\_GIFS/WHITNEW\\_INTR\\_DOC.htm](http://rex.nci.nih.gov/NTRCE_GIFS/WHITNEW_INTR_DOC.htm))

<sup>b</sup> The total doses reported in this table are different from doses seen in Table 1. The doses in Table 1 are produced assuming that the total dose is a log-normal distribution, while the doses in this table were summed with a Monte Carlo simulation (1,000 iterations using midpoint LHS) to total across individual test series.

<sup>c</sup> Excess Lifetime Risk expressed as chances in 10,000.

<sup>d</sup> Probabilities of Causation were estimated using the Interactive RadioEpidemiological Program (IREP) which is an update to the 1985 Radioepidemiological Tables [1], and are applicable only to those with a diagnosed thyroid cancer or non-cancerous thyroid neoplasm.

**Table 2.** The thyroid dose, risk and probability of causation from combined exposure to I-131 in releases from the X-10 facility near Oak Ridge, TN, (1944 to 1956) and I-131 in Nevada Test Site fallout (1952 to 1957).

Exposure scenario: A female born on January 1, 1952, consuming 2 eight-oz. glasses of milk produced from a local commercial dairy.

Location	Thyroid dose (cGy) (95% uncertainty range)	Excess lifetime risk of thyroid cancer (95% uncertainty range)	Probability of causation for a diagnosed neoplasm (95% uncertainty range)	Relative importance to total dose and risk
Bradbury, TN	2.9 to 41 <sup>(b)</sup>	$4.9 \times 10^{-4}$ to $1.8 \times 10^{-26}$	11 to 81% <sup>(d)</sup>	NTS (34%) X-10 (66%)
Solway, TN	1.6 to 25	$2.7 \times 10^{-4}$ to $1.1 \times 10^{-2}$	7.2 to 71%	NTS (39%) X-10 (61%)
Farragut, TN	1.4 to 19	$2.1 \times 10^{-4}$ to $8.1 \times 10^{-3}$	5.8 to 64%	NTS (51%) X-10 (49%)
Oak Ridge, TN <sup>(a)</sup>	1.1 to 17	$1.8 \times 10^{-4}$ to $6.4 \times 10^{-3}$	4.8 to 60%	NTS (75%) X-10 (25%)
Knoxville, TN <sup>(a)</sup>	1.0 to 13	$1.5 \times 10^{-4}$ to $4.9 \times 10^{-3}$	3.9 to 55%	NTS (70%) X-10 (30%)
Maryville, TN	1.0 to 15	$1.3 \times 10^{-4}$ to $5.7 \times 10^{-3}$	3.6 to 57%	NTS (85%) X-10 (15%)
Sweetwater, TN	1.0 to 16	$1.6 \times 10^{-4}$ to $5.9 \times 10^{-3}$	3.9 to 60%	NTS (83%) X-10 (17%)
Warburg, TN	0.7 to 16	$1.1 \times 10^{-4}$ to $6.2 \times 10^{-3}$	3.2 to 59%	NTS (92%) X-10 (8%)

(a) Residents of the cities of Oak Ridge and Knoxville, Tennessee, obtained mostly commercial milk from regional dairies.

(b) An increased risk of autoimmune thyroiditis may be induced by doses exceeding 20 cGy [10].

(c) Values are in excess of baseline; the baseline risk of thyroid cancer incidence is  $2.3 \times 10^{-5}$  for males and  $6.0 \times 10^{-5}$  for females in the USA [12]; mortality of thyroid cancer is 10 to 20 times lower than incidence.

(d) Applicable only for those with a diagnosed thyroid cancer or non-cancer neoplasm.

## References

- [1] NCI (National Cancer Institute). 1997. Estimated Exposures and Thyroid Doses Received by the American People from Iodine-131 in Fallout Following Nevada Atmospheric Nuclear Bomb Tests. A Report from the National Cancer Institute. U.S. Department of Health and Human Services, Bethesda, MD.
- [2] UNSCEAR (United National Scientific Committee on the Effects of Atomic Radiation). 2000. Sources and Effects of Ionizing Radiation. UNSCEAR 2000 Report to the General Assembly, with Scientific Annexes. Volume I: Sources. United Nations, New York
- [3] Hoffman, F.O. 1999. Environmental Dose Reconstruction: How Large can Uncertainty be When Models Take the Place of Measurements? In: Uncertainties in Radiation Dosimetry and Their Impact on Dose-Response Analysis (Ron, E., and Hoffman, F.O. eds.). National Cancer Institute/National Institutes of Health Publication No. 99-4541.
- [4] Hoffman, F.O., and Baes III, C.F. (eds.). 1979. A statistical analysis of selected parameters for predicting food chain transport and internal dose of radionuclides. ORNL/NUREG/TM-282.
- [5] Schwarz, G., and Hoffman, F.O. 1981. Imprecision of dose predictions for radionuclides released to the environment: An application of a Monte Carlo simulation technique. *Environment International* 4:289-297.
- [6] Apostoaei, A.I., Burns, R.E., Hoffman, F.O., Ijaz, T., Lewis, C.J., Nair, S.K., Widner, T.E. 1999. Iodine-131 Releases from Radioactive Lanthanum Processing at the X-10 Site in Oak Ridge, Tennessee (1944-1956)--An Assessment of Quantities Released, Off-site Radiation Doses, and Potential Excess Risks of Thyroid Cancer. Tennessee Department of Health, Reports of the Oak Ridge Dose Reconstruction, Vols. 1 and 1A, The Report of Project Task 1.
- [7] White House. 2000. Executive Order. Providing Compensation to America's Nuclear Weapons Workers. Office of the Press Secretary, For Immediate Release, December 7, 2000.
- [8] NCRP (National Council on Radiation Protection and Measurements). 1996. A Guide for Uncertainty Analysis in Dose and Risk Assessments Related to Environmental Contamination. Chairman of Scientific Committee 64-17. NCRP Commentary No. 14. NCRP, Bethesda, MD.
- [9] Lumina (Lumina Decision Systems, Inc.). 1999. *Analytica User Guide, Version 2.0*. Lumina Decision Systems, Inc., Los Gatos, CA.
- [10] IOM (Institute of Medicine) and NRC (National Research Council). 1999. Exposure of the American People to Iodine-131 from Nevada Nuclear-Bomb Tests. Review of the National Cancer Institute Report and Public Health Implications. National Academy Press, Washington, DC.
- [11] Land, C., Gilbert, E., Smith, J., Hoffman, F.O., Apostoaei, I.A., Thomas, B.A. 2000. *Draft Report of the NCI-CDC Working Group to Revise the 1985 NIH Radioepidemiological Tables*.
- [12] NCI (National Cancer Institute). 1999. SEER (Surveillance, Epidemiology, and End Results) Cancer Incidence Public-Use Database, 1973-1996, August 1998 Submission. SEER\*Stat 2.0. U.S. Dept. of Health and Human Services, Bethesda, MD.