Reports

United States Population Dose Estimates for Iodine-131 in the Thyroid After the Chinese Atmospheric Nuclear Weapons Tests

Abstract. *Analysis of samples collected within the United States after the Chinese atmospheric nuclear weapons tests of 26 September and 17 November 1976 indicates that the radiation dose to the thyroid from iodine-131 in milk was predominant. A U.S. population dose to the thyroid of 68,000 man-rads was calculated for the iodine-131 fallout. The four excess thyroid cancers that are estimated to occur as a result of the September test during the next 45 years will be masked by the 380,000 cases of thyroid cancer which are expected to occur in the United States from all causes during the same interval.*

The People's Republic of China conducted atmospheric nuclear weapons tests on 26 September 1976 and 17 November 1976. The Office of Radiation Programs (ORP) within the Environmental Protection Agency operates the Environmental Radiation Ambient Monitoring System (ERAMS) (*1*) which consists of a nationwide network of sampling stations where measurements are made of ambient radiation levels in milk, air, and precipitation. After the September and the November weapons tests the EPA's Eastern Environmental Radiation Facility analyzed the milk, air, and precipitation samples that had been collected after both events. The increase in environmental levels of radioactivity measured after the second event was so low that meaningful dose (*2*) calculations could not be made. For the first event, individual doses were calculated for all radionuclides detected in milk (^{89}Sr, ^{90}Sr, ^{131}I, ^{137}Cs, ^{140}Ba) and air (^{95}Zr, ^{95}Nb, ^{106}Ru, ^{131}I, ^{140}Ba, ^{144}Ce) to give an indication of the relative significance of these nuclides for various pathways (*3*). The individual doses were calculated for the sampling stations showing the highest amounts of radioactivity. For the calculated individual doses, the dose from the ^{131}I-milk-thyroid pathway was a factor of 7.5 higher than the next highest dose which was for the ^{89}Sr-milk-bone pathway. Therefore, detailed short-term population dose calculations were performed only for the ^{131}I-milk-thyroid pathway (*4*). In this report we summarize the results of the calculations made after the September event.

To calculate the individual doses we used Eq. 1 for milk ingestion and air inhalation and Eq. 2 for air submersion (that is, external irradiation of individuals because of radionuclides in the air):

$$ID = (C_j)\,(IR)\,(\mathrm{DCF}) \qquad (1)$$

$$ID = 24\,(C_j)\,(\mathrm{DF}) \qquad (2)$$

where *ID* is the individual dose for the integration period expressed as millirems except for ^{131}I in milk which is expressed as millirads; C_j is the integrated radionuclide concentration in milk or air for the highest station, corrected to sample collection time (picocuries times days per liter or per cubic meter); *IR* is the individual intake rate of milk or air for the critical receptor (liters per day or cubic meters per day); *DCF* is the dose commitment factor for critical receptor (millirems per picocurie intake except for ^{131}I in milk which is millirads per picocurie intake); 24 is for the hours in 1 day; and *DF* is the skin or total body dose factor for the critical receptor (millirems per hour per picocurie per cubic meter). For the milk pathway, the infant is the critical receptor. An infant milk consumption rate of 1 liter per day (*5*) and an integration period from 1 October to 12 November 1976 (the period during which milk levels were elevated) is used. For the inhalation pathway, the child and adult are critical receptors with breathing rates of 10.4 m^3/day and 22 m^3/day, respectively (*6*). The integration period is 1 October to 10 October 1976, for inhalation and the submersion pathway.

Dose commitment factors for the milk ingestion and the air inhalation pathways are from *Regulatory Guide 1.109* (*7*) except for the ^{131}I in milk. Dose commitment factors for ^{131}I in milk are from Kereiakes *et al.* (*8*) and are based on more recent data on the uptake of ^{131}I by the thyroid than the data in (*7*). Dose factors for the submersion pathway are from the FESALAP report (*9*) since they are not given in *Regulatory Guide 1.109*. The individual doses are listed in Table 1. The highest individual dose calculated (18.4 mrad) is for ^{131}I in milk, and the next highest dose calculated (2.4 mrem) is for ^{89}Sr in milk. The inhalation doses are more than a factor of 10 below the dose for ^{131}I in milk. The calculated submersion doses for skin and total body are insignificant ($<10^{-2}$ mrem).

The equation used to calculate the thyroid population dose is:

$$PD = \frac{10^6}{43\rho} \sum_{j=1}^{51} \sum_{i=1}^{4} \sum_{m=1}^{2} (C_j)(MC_j)(f_m)(f_i)(DCF_i)\exp^{(-\lambda_r t_m)} \quad (3)$$

where PD is the U.S. population dose (man-rads) to the thyroid from ^{131}I in milk during the period 1 October to 12 November 1976; 10^6 is the conversion factor (pounds to million pounds); j is the summation index for state (51 states; including all states and the District of Columbia); i is the summation index for age group (four age groups); m is the summation index for food group (two food groups); C_j is the integrated net milk concentration for a state corrected to sample collection date (picocuries times days per liter); MC_j is the total fluid milk and fluid milk products consumption for a state (million pounds); f_m is the fraction of milk used for food group m (dimensionless); f_i is the fraction of total milk consumption used by age group i (dimensionless); DCF_i is the ingestion dose commitment factor for age group i (manrads committed per picocuries of ^{131}I ingested); λ_r is the ^{131}I radioactive decay constant (day^{-1}); t_m is the time between sample collection and consumption (days); 43 is for the days in the period of integration; and ρ is the milk density (pounds per liter).

The portion of the ERAMS network responsible for sampling pasteurized milk includes 63 stations in the United States with at least one sampling station in each state and the District of Columbia. Net (*10*) ^{131}I concentrations in milk for the period 1 October through 12 November are plotted and integrated to obtain the integrated milk concentrations (C_j). For states with only one sampling station, the integrated milk concentration for that location is used as the value of C_j for the entire state. For states with more than one sampling station, an average of the data for each location is used for C_j.

Total U.S. milk production of 13,434 million pounds for the integration period is estimated by extending the data from the U.S. Department of Agriculture (USDA) on milk production for October 1976 (*11*) through November 12. It is assumed that all of this milk produced domestically would be consumed within the United States, and milk consumption in each state is estimated from U.S. Census Bureau statistical data on state populations (*12*).

The fraction of the total milk consumption going into different dairy products is estimated from USDA milk utilization data for 1975 (*13*). After consultation with USDA dairy personnel two food groups were established:

Food group 1. This group includes butter, ice cream, cheese, canned and condensed milk, dry milk, and other manufactured products. The fraction of total U.S. milk consumption (f_m) equals 0.52. Marketing-to-consumption time (t_m) equals 30 days.

Food group 2. This group includes fluid milk products, cottage cheese, and residual milk. The fraction of total U.S.

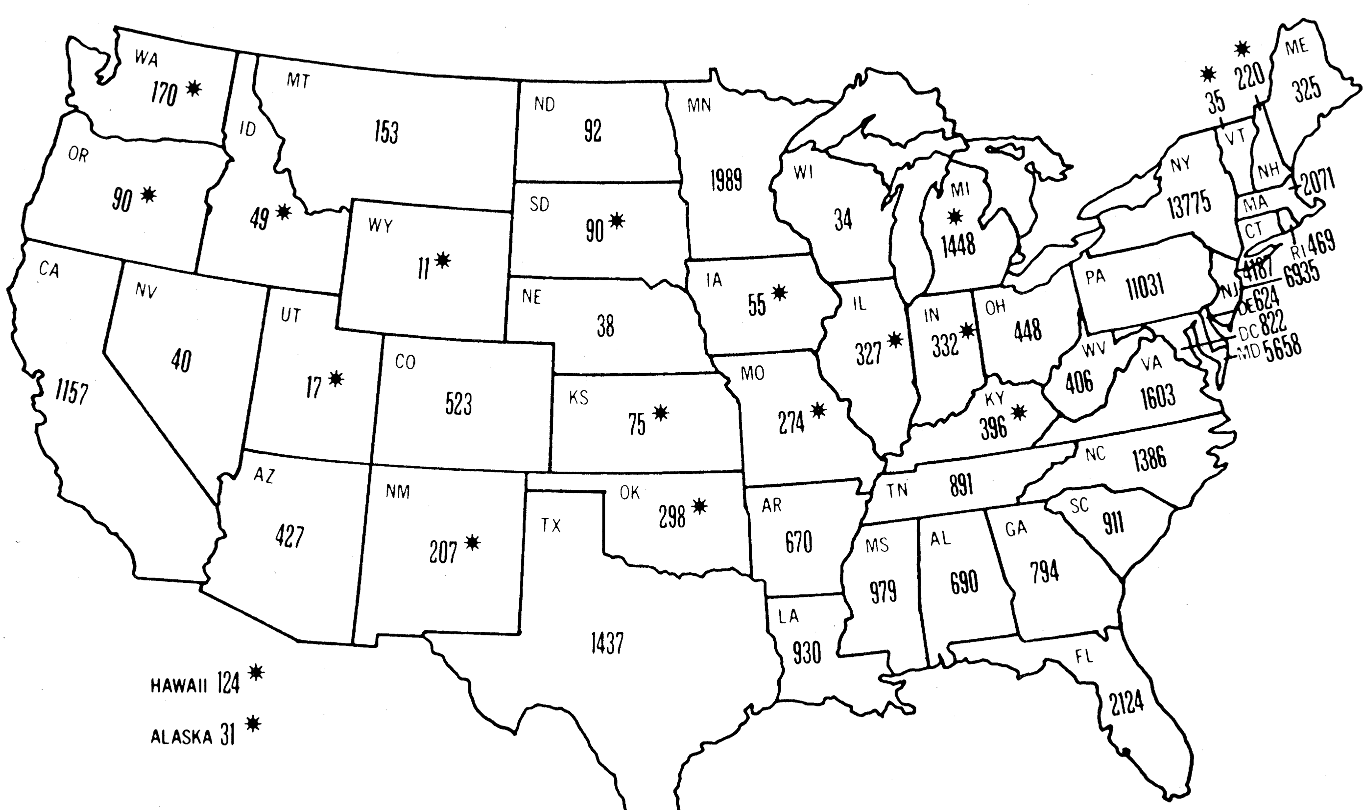

Fig. 1. Population thyroid dose (man-rad) by state for the period 1 October to 12 November 1976. Asterisks indicate best estimates based on laboratory measurements of ^{131}I levels below the minimum detectable level at the 95 percent confidence limit.

Table 1. Maximum doses for various radionuclides to individuals in the United States. All doses are given in millirems, except for ^{131}I from milk which is given in millirads.

Radionuclide	Location	Individual dose	Tissue
		Milk pathway	
^{89}Sr	Hartford, Connecticut	2.4	Infant bone
^{90}Sr	Norfolk, Virginia	1.1	Infant bone
^{131}I	Baltimore, Maryland	1.84×10^{1}	Infant thyroid
^{137}Cs	Jackson, Mississippi	2.0×10^{-1}	Infant liver
^{140}Ba	Hartford, Connecticut	1.0×10^{-1}	Infant bone
^{140}La*	Hartford, Connecticut	7.0×10^{-2}	Infant gastrointestinal tract
		Air inhalation pathway†	
^{95}Zr, ^{95}Nb	Miami, Florida	1.5×10^{-2}	Child lung
^{103}Ru, ^{106}Ru	Miami, Florida	7.0×10^{-1}	Child lung
^{131}I	Miami, Florida	1.0×10^{-1}	Child thyroid
^{140}Ba	Miami, Florida	4.0×10^{-2}	Child lung
^{140}La*	Miami, Florida	1.9×10^{-2}	Adult gastrointestinal tract
^{141}Ce, ^{144}Ce	Miami, Florida	1.0	Child lung
		Air submersion pathway†‡	
All nuclides listed under inhalation	Miami, Florida	2.1×10^{-3}	Skin
		6.8×10^{-4}	Total body

*^{140}La is assumed to be in equilibrium with ^{140}Ba. †The doses for air inhalation and submersion are gross doses (no background subtracted); background levels for specific nuclides are not available. ‡We assumed that the submersion doses would be the same for all age groups.

milk consumption (f_m) equals 0.48. Marketing-to-consumption time (t_m) equals 1 day.

Using the four age groups described in *Regulatory Guide 1.109* (*7*), U.S. Census Bureau age-dependent population data (*14*), and age-dependent milk consumption data from ICRP Report No. 23 (*5*), we calculated the fractional milk consumption, f_i, for each age group in the U.S. population.

The age-dependent dose commitment factors (DCF_i) given by Kereiakes *et al.* (*8*), a radiological half-life for ^{131}I of 8.05 days, and a milk density of 2.3 pounds per liter are applied in the calculations. Using the methods, equation, and data discussed, we calculated a U.S. thyroid population dose of 68,000 man-rads for the September event. The population dose estimates for each state are listed in Fig. 1. For many of the parameters used in these calculations, a range of values are reported in the literature. Realistic values for parameters from within the range of reported numbers are chosen instead of the values which would lead to the highest dose estimate. The averaging and extrapolation procedures used in the analysis also lead to the calculation of realistic rather than highly conservative dose. A more complete discussion of the uncertainty in these calculated doses is given in (*1*).

It appears that the risk of thyroid cancers resulting from radiation exposure of the thyroid is age-dependent (*15*). For this reason, dose-to-risk conversion factors must be age-weighted before multiplying by population dose. Using a risk estimate for thyroid cancers of 63 excess thyroid cancer cases per 10^2 man-rads, age-weighted on the basis of the 1967 U.S. population (*15, 16*), we calculated that an excess of 4.3 thyroid cancer cases could occur in the United States as a result of the ^{131}I in milk after the September event. A comparison of these projected thyroid cancers with the occurrence of thyroid cancer from all causes lends perspective to this problem. It is estimated that during the next 45 years, on the order of 380,000 cases of thyroid cancer will occur in the United States from all causes (*17*). For this reason, confirmation of these predicted excess thyroid cancers is not possible because of the masking of the effects of thyroid cancers from all causes.

On the basis of this analysis, we conclude that the thyroid cancers that could develop in the U.S. population as a result of the weapons test of 26 September 1976 will be indistinguishable from the thyroid cancers likely to occur from other causes, and that the potential health effects of the 17 November 1976 test will be insignificant.

J. MICHAEL SMITH
JON A. BROADWAY
ANN B. STRONG

Eastern Environmental Radiation Facility, U.S. Environmental Protection Agency, Montgomery, Alabama 36109

References and Notes

1. A. B. Strong, J. M. Smith, R. H. Johnson, "EPA assessment of fallout in the United States from atmospheric nuclear testing on September 26 and November 17, 1976, by the People's Republic of China," *EPA-520/5-77-002* (Office of Radiation Programs, U.S. Environmental Protection Agency, Washington, D.C., 1977).
2. The term "dose" is used broadly in this report in referring to radiation absorbed dose (rad) or dose equivalent (radiation-equivalent-man; rem) and in referring to either internal or external exposures. The rem is the product of the absorbed dose (rad), an assigned quality factor, and other necessary modifying factors specific for the radiation considered. The absorbed dose has units of energy absorption per unit mass, and the quality factor is a measure of the biological effect of the radiation compared to gamma radiation. Population dose is computed by summing the individual doses for all members of a population. In this report, population dose is calculated in man-rads and the health-effects data are expressed as health effects per man-rad which is consistent with the population dose. However, in comparing individual doses for different pathways, a quality factor of one has been used and it has been assumed that 1 rad is equal to 1 rem. The term dose, as used in this report, applies only to radiation protection. Dose commitment is the dose which will be delivered during the 50-year period following radionuclide intake. The curie (Ci) is a measure of radionuclide transformation rate; 1 Ci equals 3.7×10^{10} transformations per second.
3. The term pathway refers to the movement of radionuclides through the environment; for example, the ^{131}I-milk-thyroid pathway indicates that airborne ^{131}I was deposited on pasture grass that was consumed by dairy cows whose milk was consumed by humans who retained the ^{131}I in their thyroid glands.
4. Most of the fallout will eventually be deposited over the earth, contributing to a slight increase in background levels. This long-term impact is not assessed herein.
5. W. S. Snyder, M. J. Cook, L. R. Karhausen, E. S. Nasset, G. P. Howells, I. H. Tipton, *Report of the Task Group on Reference Man, ICRP Publ. No. 23, International Commission on Radiological Protection* (Pergamon, New York, ed. 1, 1975), pp. 355–357.
6. Based on data in Snyder *et al.* (*5*, p. 346).
7. "Calculation of annual doses to man from routine releases of reactor effluents for the purpose of evaluating compliance with 10 CFR Part 50, Appendix I," *Regulatory Guide 1.109* (U.S. Nuclear Regulatory Commission, Washington, D.C., 1976).
8. J. G. Kereiakes, P. A. Feller, F. A. Ascoli, S. R. Thomas, M. J. Gelfarad, E. L. Saenger, "Pediatric radiopharmaceutical dosimetry," proceedings of the Radiopharmaceutical Dosimetry Symposium at Oak Ridge, Tenn., *HEW Publ. (FDA) 76-8044* (Food and Drug Administration, Washington, D.C., 1976).
9. "Final environmental statement concerning proposed rule making action: Numerical guides for design objectives and limiting conditions for operation to meet the criteria 'as low as practicable' for radioactive material in light-water-cooled nuclear power reactor effluents," *Analytical Models and Calculations, WASH-1258* (Directorate of Regulatory Standards, U.S. Atomic Energy Commission, July 1973), vol. 2.
10. Background ^{131}I levels, based on July and August 1976 data from ERAMS, are used to estimate net ^{131}I concentrations.
11. "Federal milk order market statistic," *FMOS-186* (Dairy Division, Agricultural Marketing Service, U.S. Department of Agriculture, Washington, D.C., November 1976).
12. *Statistical Abstract of the United States: 1973* (U.S. Bureau of the Census, Washington, D.C., ed. 94, 1973).
13. "Milk production, disposition, income 1973–1975," *Da 1-2(76)* (Crop Reporting Board, Statistical Reporting Service, U.S. Department of Agriculture, Washington, D.C., May 1976), corrected copy.
14. *Statistical Abstract of the United States: 1970* (U.S. Bureau of the Census, Washington, D.C., ed. 91, 1970).
15. "Environmental analysis of the uranium fuel cycle, part II—Nuclear power reactors," *EPA-520/9-73-003-C* (Office of Radiation Programs, U.S. Environmental Protection Agency, Washington, D.C., November 1973).
16. Memorandum to F. Galpin from N. S. Nelson, "^{131}I risk from Chinese bomb fallout—September 26, 1976" (Criteria and Standards Division, Office of Radiation Programs, U.S. Environmental Protection Agency, 6 December 1976).
17. "Interim report of EPA's assessment following the September 26, 1976, nuclear detonation by the People's Republic of China" (Office of Radiation Programs, U.S. Environmental Protection Agency, Washington, D.C., December 1976); "Preliminary report: Third national cancer survey—1969 incidence," *DHEW Publ. (NIH)72-128* (National Cancer Institute, Bethesda, Md., 1971).

25 November 1977