Chapter 7

Methods and Data for Calculating Doses to People Resulting from Exposure Routes to Man Other Than the Ingestion of Cows' Milk

CONTENTS: Exposure routes to man other than the ingestion of cows' milk also contribute to the thyroid dose resulting from ^{131}I released into the atmosphere by nuclear weapons tests. The exposure routes considered in this report are the inhalation of ^{131}I-contaminated air and the ingestion of ^{131}I-contaminated goats' milk, cottage cheese, eggs, and leafy vegetables. The methods and data used to estimate thyroid doses to people resulting from these exposure routes are presented.

The ingestion of cows' milk is usually the most important human exposure route for ^{131}I in fallout from nuclear weapons testing. However, other exposure routes also need to be considered, particularly for those individuals who do not drink cows' milk. The purpose of this chapter is to indicate how the thyroid doses due to exposure routes other than the ingestion of fresh cows' milk have been estimated.

The exposure routes considered in this chapter include the inhalation of ^{131}I-contaminated air and the ingestion of ^{131}I-contaminated goats' milk, cottage cheese, eggs and leafy vegetables. The consumption of mothers' milk also is considered for infants under one year of age. The selection of these exposure routes is based on the experience acquired from measurements of ^{131}I carried out during the period of heavy fallout from nuclear weapons testing in the Pacific and in the USSR in 1961 and 1962, and also after reactor accidents, such as those that occurred at Windscale in 1957 and at Chernobyl in 1986.

In the first part of this chapter, the methodology used for calculating doses to people resulting from exposure routes to man other than the ingestion of cows' milk is described. It is applied to the same example scenarios as those used in **Chapter 4** to show the relative importance of the various environmental pathways leading to the contamination of cows' milk. On the basis of these example scenarios, it is shown that in most cases the ingestion of cows' milk results in thyroid doses that are much greater than those due to any other exposure route to man.

In the second part of this chapter, the calculation procedures used to apply the methodology for calculating doses to people resulting from exposure routes to man other than the ingestion of cows' milk for the populations of each county of the contiguous U.S. following each test are presented. Thyroid dose calculations have been carried out for each of the selected exposure routes following each test and for the populations of each county of the contiguous U.S., subdivided into the same 14 age and sex groups considered in the estimation of the thyroid doses due to consumption of cows' milk. However, in view of the relatively minor importance of these exposure routes, only total doses from these exposure routes have been estimated, and many simplifying assumptions have been made in the assessment of the doses from these sources.

7.1. METHODOLOGY AND EXAMPLE CALCULATIONS

For illustration purposes, the thyroid doses received via inhalation of ^{131}I-contaminated air, ingestion of ^{131}I-contaminated goats' milk, cottage cheese, eggs and leafy vegetables, and, for infants under 1 year of age, consumption of mothers' milk are compared with doses received via ingestion of cows' milk. Comparisons are made both when the cows are on pasture and when cows are off pasture, using the same scenarios and general assumptions as in **Section 4.2** of **Chapter 4**. For convenience, the description of those scenarios is provided again here.

Eight scenarios, denoted as sc, have been considered, representing a range of conditions at two hypothetical sites: (a) one situated far away from the NTS (3000 km), and (b) one close to the NTS (100 km). The factors considered are the presence or absence of rain during deposition, and the presence or absence of cows on pasture during deposition. The characteristics of the eight scenarios are as follows:

Scenario number, sc	Daily rainfall amount R (L m^{-2})	Distance from the NTS, X (km)	Presence of cowsonpasture
1	0 (no rain)	3000	yes
2	0 (no rain)	3000	no
3	1 (light rain)	3000	yes
4	1 (light rain)	3000	no
5	100 (heavy rain)	3000	yes
6	100 (heavy rain)	3000	no
7	0 (no rain)	100	yes
8	0 (no rain)	100	no

In each of the eight scenarios, it is assumed that a deposition, DG, of ^{131}I of 1 nCi m^{-2} has occurred at time t = 0.

The values selected for parameters used in the calculations include:

- T_r (radioactive half-life of ^{131}I) = 8.04 d, corresponding to a radioactive decay constant λ_r = 0.086 d^{-1}.
- T_w (environmental half-life of stable iodine on pasture) = 10 d, corresponding to a rate constant λ_w = 0.069 d^{-1}; the GSD assumed for the distribution of T_w is 1.8 (**Section 4.1.2**).
- T_e (effective half time of residence of ^{131}I on pasture) = 4.5 d, corresponding to an effective mean time of residence τ_e of 6.5 d and to a rate constant λ_e of 0.15 d^{-1}; the GSD assumed for the distributions of T_e and τ_e is 1.3 (**Section 4.1.2**).
- Y (standing crop biomass of pasture) = 0.3 kg (dry mass) m^{-2}, the GSD assumed for the distribution of Y is 1.8 (**Section 4.1.1.1.1**).
- AD (air density) = 1.2 kg m^{-3}.
- U_{sl} (soil density) = 1.5 x 10^3 kg (dry mass) m^{-3}.
- H_w (depth of farm pond) = 0.5 m.
- PR_{hay} (ratio of time-integrated concentration of ^{131}I in stored hay to that in pasture grass) = 0.04 (**Section 4.2.7**).
- F(sc) (fraction of deposited activity intercepted by pasture grass): ranges from 0.04 for dry deposition close to the NTS (100 km) to 0.72 for light rain far away from the NTS (3000 km). Values for each scenario from **Section 4.2.3** are given in the table below.
- F*(sc) (mass interception factor): ranges from 0.13 m^2 kg^{-1} for dry deposition close to the NTS (100 km) to 2.4 m^2 kg^{-1} for light rain far away from the NTS (3000 km). Values for each scenario from **Section 4.2.2** are given in the table below.
- H_{sl}(sc) (depth of soil over which the deposited activity is uniformly distributed): assumed to be equal to 0.001 m for dry deposition, 0.005 m for light rain, and 0.01 m for heavy rain. Values for each scenario from **Section 4.2.3** are given in the table below.
- v_g(sc) (deposition velocity): varies with distance from the NTS and is taken to be equal to 4000 m d^{-1} at 100 km from the NTS and to 1200 m d^{-1} at 3000 km from the NTS (see **Appendix 7**). Values for each scenario from **Section 4.2.5** are given in the table below.
- WR(sc) (washout ratio): varies with distance from the NTS and with daily rainfall amount. Values for WR at 3000 km from the NTS are 120 kg/kg for heavy rain and 3000 kg/kg for light rain (see **Appendix 7**). Values for each scenario from **Section 4.2.5** are given in the table on the next page.

sc	Desctiption of scenario sc			F(sc)[a]	F* (sc) (m^2kg^{-1})[b]	H_{sl} (sc) (m)[a]	v_g (sc) (m d^{-1})[c]	WR (sc) (kg kg^{-1})[c]
	Rain	Distance	Cows					
1	none	3000 km	on pasture	0.57	1.9	0.001	1200	0
2	none	3000 km	off pasture	0.57	1.9	0.001	1200	0
3	light	3000 km	on pasture	0.72	2.4	0.005	1200	3000
4	light	3000 km	off pasture	0.72	2.4	0.005	1200	3000
5	heavy	3000 km	on pasture	0.30	1.0	0.01	1200	120
6	heavy	3000 km	off pasture	0.30	1.0	0.01	1200	120
7	none	100 km	on pasture	0.04	0.13	0.001	4000	0
8	none	100 km	off pasture	0.04	0.13	0.001	4000	0

[a]From **Section 4.2.3.**
[b]From **Section 4.2.2.**
[c]From **Section 4.2.5.**

The thyroid doses are the products of: (a) the average time-integrated concentrations of ^{131}I in air or in the foodstuff considered, (b) the corresponding inhalation or consumption rates, and (c) the dose conversion factors. The three quantities are discussed in turn.

7.1.1. *Time-integrated Concentrations of ^{131}I in Foodstuffs and Air*

In view of the relatively minor importance of the exposure routes other than the ingestion of cows' milk, several important simplifying assumptions are made:

(a) All the foodstuffs were considered to be of local origin. It is recognized that, in most cases, these foodstuffs may have been produced far away from the county where they were subsequently consumed, resulting in time-integrated concentrations of ^{131}I that may have been higher than the time-integrated concentrations in local foodstuffs for some tests and lower for other tests. Because (a) there is no readily available information on the commercial distribution of these foodstuffs across the country during the 1950s and (b) the contribution to the total dose represented by the ingestion of these foodstuffs is in general of minor importance, it seems reasonable to make the simplifying assumption that the foodstuffs other than cows' milk that are consumed in a given county originate within the same county. When estimating the ^{131}I concentrations in mothers' milk, it is assumed that the mother consumes the volume-weighted mixed milk (**Section 6.1.1.5**) for the county of residence.

(b) The time of the year when goats and chickens are kept outdoors is assumed to correspond to the time of year when "backyard" cows are on pasture. Similarly, the time of the year when goats and chickens are under shelter and consume less ^{131}I-contaminated food than when they are kept outdoors is assumed to correspond to the time of year when "backyard" cows are off pasture. These times vary from state to state (see **Section 4.1.3.5**).

(c) Because the foodstuffs are assumed to be of local origin, it is also assumed that the delay times between production and consumption were short. The appropriate delay times are estimated to be at the lower ends of the ranges of published values (Quinault 1989): 0.5 day for goats' milk, 1 day for leafy vegetables, 2 days for cottage cheese, and 3 days for eggs.

7.1.1.1. *Cows' milk (reference conditions)*

The contamination of cows' milk by ^{131}I for the eight scenarios considered was estimated in **Chapter 4 (Section 4.2)** for five pathways: (a) ingestion by cows of ^{131}I-contaminated pasture; (b) ingestion by cows of ^{131}I-contaminated soil; (c) inhalation by cows of ^{131}I-contaminated air; (d) ingestion by cows of ^{131}I-contaminated water; and, (e) ingestion by cows of ^{131}I-contaminated hay. The results, already presented in **Chapter 4** *(Table 4.9)*, are presented again in *Table 7.1* and are discussed briefly on the following page.

Table 7.1. Median time-integrated ^{131}I concentrations in fresh cows' milk, in nCi dL^{-1}, resulting from various exposure routes for a unit deposition of ^{131}I of 1 nCi m^{-2} (from Section 4.2).

Route of intake by cow	Distance from the NTS: 3000 km						Distance from the NTS: 100 km	
	Dry conditions		Light rain		Heavy rain		Dry conditions	
	Cows on pasture	Cows off pasture	Cows on pasture	Cows off pasture	Cows on pasture	Cows off pasture	Cows on pasture	Cows off pasture
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8
Pasture consumption	0.40	0.005	0.50	0.006	0.21	0.003	0.03	0.0003
Ingestion of soil	0.01	0.005	0.002	0.0009	0.001	0.0006	0.02	0.008
Ingestion of water	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007
Ingestion of stored hay	0.0002	0.02	0.0002	0.02	0.0001	0.008	0.00001	0.001
Inhalation	0.0004	0.0004	0.0001	0.0001	0.00005	0.00005	0.0001	0.0001
All routes	0.42	0.035	0.52	0.036	0.22	0.021	0.057	0.019

When cows are on pasture, the most important pathway leading to the contamination of cows' milk with ^{131}I is pasture consumption. At 3000 km from the NTS, all pathways other than pasture consumption contribute only a few percent of the total time-integrated ^{131}I concentration in cows' milk. At 100 km from the NTS, the mass interception factor is much lower than at 3000 km from the NTS, and, consequently, pasture is much less contaminated at 100 km than at 3000 km from the NTS, for the same ^{131}I deposition on the ground. At 100 km from the NTS, all pathways other than pasture consumption contribute about as much as pasture consumption to the total contamination of cows' milk with ^{131}I.

For a given ^{131}I deposition on the ground, the time-integrated concentrations in cows' milk are much smaller when cows are off pasture than when they are on pasture. When cows are off pasture, ingestion of stored hay is estimated to be the most important pathway at 3000 km from the NTS. However, at 100 km from the NTS, incidental ingestion of soil leads to a greater contamination of cows' milk than the ingestion of stored hay. The relative importance of the ingestion of soil and of stored hay is linked to the variation of the mass interception factor with distance from the NTS. At short distances from the NTS (e.g., 100 km), the mass interception factor is small, so that soil is more contaminated than vegetation per unit area of ground. At large distances from the NTS (e.g., 3000 km), the mass intersception factor is high, so that vegetation (pasture or stored hay) is more heavily contaminated than soil per unit area of ground.

Whether cows are on pasture or off pasture, the inhalation of ^{131}I-contaminated air contributes very little to the time-integrated ^{131}I concentration in cows' milk.

7.1.1.2. Goats' milk

The contamination of goats' milk by ^{131}I results from the same pathways that cause the contamination of cows' milk. The equations used to estimate the ^{131}I concentration in fresh goats' milk are therefore similar to those used to calculate the ^{131}I concentration in fresh cows' milk presented in **Chapter 4 (Section 4.2)**. The only modifications made in those equations consisted in denoting the time-integrated concentrations of ^{131}I in fresh goats' milk as IMG (instead of IMC for fresh cows' milk), in adding the subscript gt (for goats) to parameter symbols where appropriate, and in adding a term accounting for the activity loss due to delay between production and consumption. Five pathways from ^{131}I deposition to milk contamination are considered: (a) ingestion by goats of ^{131}I-contaminated pasture; (b) ingestion by goats of ^{131}I-contaminated soil; (c) inhalation by goats of ^{131}I-contaminated air; (d) ingestion by goats of ^{131}I-contaminated water; and (e) ingestion by goats of ^{131}I-contaminated hay.

As noted in **Section 7.1**, a unit deposition, DG, of 1 nCi m^{-2} is assumed for all scenarios. The reference values of parameters common to many scenarios are listed in **Section 7.1**. Parameters used or derived in **Chapter 4 (Section 4.2)** for specific scenarios are also listed for convenience in **Section 7.1.**

7.1.1.2.1. ^{131}I concentrations in goats' milk due to the ingestion of pasture

The time-integrated concentration of ^{131}I in goats' milk due to pasture consumption, for a scenario, sc, $IMG_p(sc)$, in nCi d L^{-1}, is estimated in the same way as for cows' milk. The relevant *equation (4.33)* is modified to read:

$$IMG_p\,(sc) = DG \times F^*\,(sc) \times \tau_e \times PI^{*gt}\,(sc) \times f_{m,gt} \times e^{-\lambda_r \times TD_{gt}} \qquad (7.1)$$

Table 7.2. Median time-integrated ^{131}I concentrations in fresh goats' milk, in nCi dL^{-1}, resulting from various exposure routes for a unit deposition of ^{131}I of 1 nCi m^{-2} (from Section 4.2).

Route of intake by cow	Distance from the NTS: 3000 km						Distance from the NTS: 100 km	
	Dry conditions		Light rain		Heavy rain		Dry conditions	
	Goat on pasture	Goat off pasture	Goat on pasture	Goat off pasture	Goat on pasture	Goat off pasture	Goat on pasture	Goat off pasture
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8
Pasture consumption	3.6	0	4.6	0	1.9	0	0.26	0
Ingestion of soil	0.23	0	0.039	0	0.029	0	0.30	0
Ingestion of water	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017
Ingestion of stored hay	0	0.13	0	0.16	0	0.073	0	0.0093
Inhalation	0.001	0.001	0.0005	0.0005	0.0004	0.0002	0.0004	0.0004
All routes	3.8	0.15	4.7	0.18	2.0	0.095	0.57	0.027

where:

$PI^*_{gt}(sc)$ is the rate of pasture intake equivalent for goats, which is numerically equal to the rate of pasture consumption for goats. Whicker and Kirchner (1987) estimated as 1.5 kg d^{-1} the rate of pasture consumption for sheep; the same value is used in this report for the median pasture consumption by goats on pasture throughout the country, i.e., for scenarios 1, 3, 5, and 7. The GSD of the distribution of PI^*_{gt} is taken to be 1.4, corresponding to 95% of the values being in the range from 0.8 to 3 kg d^{-1}. During the off-pasture season, PI^*_{gt} is assumed to be negligible.

$f_{m,gt}$ is the intake-to-milk transfer coefficient for goats taken to have a median value of 0.2 d L^{-1} and a GSD of 2.5 (**Section 4.1.4.2**).

TD_{gt} is the time delay between milking and consumption of goats' milk, assumed to be 0.5 day.

Other common and scenario specific parameters were given in **Section 7.1.** Estimates of the time-integrated concentrations of ^{131}I in goats' milk due to the ingestion of pasture were computed using *equation 7.1.* The results are presented in the first row of *Table 7.2.*

7.1.1.2.2. ^{131}I concentrations in goats' milk due to the ingestion of soil

The time-integrated concentration of ^{131}I in goats' milk due to soil consumption for scenario sc, IMG_{sl} (sc), in nCi d L-1, is estimated in the same way as for cows. The relevant *equation (4.52)* is modified to read:

$$IMG_{sl}\,(sc) = DG \times \frac{e^{-\lambda_r \times TD_{gt}}}{\lambda_r \times H_{sl}\,(sc) \times U_{sl}} \times \left(1 - F(sc) \times \frac{\lambda_r}{\lambda_e}\right) \times CR_{sl,gt}\,(sc) \times f_{m,gt} \tag{7.2}$$

where:

$CR_{sl,gt}$ is the ingestion rate of soil by goats. The soil intake by sheep can make up to 14% of the dry matter intake (Healy 1967; Zach and Mayoh 1984). It is assumed in this report that this figure also applies to goats on pasture. It is estimated in this report that the average soil intake is 14% of the dry matter intake, or 0.2 kg d-1, when goats are on pasture, and to be negligible when goats are under shelter.

All other parameters in *equation 7.2* have previously been defined in this chapter. Estimates of the time-integrated concentrations of ^{131}I in goats' milk due to the ingestion of soil were computed using *equation 7.2*. The results are presented in the second row of *Table 7.2.*

7.1.1.2.3. ^{131}I concentrations in goats' milk due to inhalation of air

The time-integrated concentration of ^{131}I in goats' milk due to inhalation of air for scenario sc, IMG_{inh} (sc), in nCi d L^{-1}, is estimated in the same way as for cows. The relevant *equation (4.66)* is modified to read:

$$IMG_{inh}\,(sc) = \frac{DG \times e^{-\lambda_r \times TD_{gt}}}{v_g\,(sc) + \dfrac{R\,(sc) \times WR\,(sc)}{AD}} \times BR_{gt} \times f_{m,gt} \tag{7.3}$$

where:

BR_{gt} is the breathing rate (m^3 d^{-1}) of goats. Comar (1966) estimated the breathing rate for sheep to be 9 m3 d^{-1}; the same value is used in this report for goats. All other parameters in *equation 7.3* have previously been defined in this chapter. Estimates of the time-integrated concentrations of ^{131}I in goats' milk due to the inhalation of air were computed using *equation 7.3.* The results are presented in the last row of *Table 7.2.*

7.1.1.2.4. ^{131}I concentrations in goats' milk due to the ingestion of water

The time-integrated concentration of ^{131}I in goats' milk due to the ingestion of water for scenario sc, IMG_w(sc), in nCi d L^{-1} is estimated in the same way as for cows. The relevant *equation (4.70)* is modified to read:

$$IMG_w\,(sc) = DG \times \frac{k_1}{H_w \times \lambda_r} \times CR_{w,gt} \times f_{m,gt} \times e^{-\lambda_r \times TD_{gt}} \qquad (7.4)$$

where:

$k_1 = 10^{-3}$ m^3 L^{-1} is a unit conversion factor and $CR_{w,gt}$ is the rate of water consumption (L d^{-1}) by goats. Comar (1966) estimated the rate of water consumption by sheep to be 3.5 L d^{-1}. Although goats are among the most efficient animals in the use of water (Perry 1984), the value reported for sheep has also been used for goats in this report. All other parameters in *equation 7.4* have previously been defined in this chapter. Estimates of the time-integrated concentrations of ^{131}I in goats' milk due to the ingestion of water were calculated using *equation 7.4.* The results are presented in the third row of *Table 7.2.*

7.1.1.2.5. ^{131}I concentrations in goats' milk due to the ingestion of stored hay

The time-integrated concentration of ^{131}I in goats' milk due to consumption of stored hay for scenario sc, IMG_{hay} (sc), in nCi dL^{-1}, is estimated in the same way as for cows. The relevant *equation (4.73)* is modified to read:

$$IMG_{hay}\,(sc) = DG \times F^*\,(sc) \times \tau_e \times PR_{hay,\,gt} \times CR_{hay,\,gt} \times f_{m,\,gt} \times e^{-\lambda_r \times TD_{gt}} \qquad (7.5)$$

where:

$CR_{hay,gt}$ is the rate of hay consumption by goats, estimated to be 1.5 kg d^{-1} when goats are under shelter, and to be negligible when goats are on pasture. All other parameters in *equation 7.5* have previously been defined in this chapter. Estimates of the time-integrated concentrations of ^{131}I in goats' milk due to the ingestion of stored hay were calculated using *equation 7.5.* The results are presented in the fourth row of *Table 7.2.*

7.1.1.2.6. Time-integrated concentrations of ^{131}I in goats' milk: Summary

Table 7.2 summarizes the time-integrated concentrations of ^{131}I that are due to each of the exposure routes considered. At long distances from the NTS, the exposure routes that result in the highest time-integrated concentrations of ^{131}I in goats' milk are the consumption of pasture when goats are on pasture and the ingestion of stored hay when goats are under shelter. Other exposure routes are much less important.

At short distances from the NTS, the fraction of fallout ^{131}I that is intercepted by vegetation is much less than at large distances. Consequently, the time-integrated concentrations of ^{131}I in pasture and in stored hay are much lower. The most important exposure routes of exposure at short distances from the NTS are the intake of soil when goats are on pasture and the consumption of water when goats are under shelter.

The contamination of goats' milk by ^{131}I by all mechanisms discussed above has been evaluated in this report for each county, i, of the contiguous United States and for each day, j, for which deposition of ^{131}I on the ground was estimated following each test. *Equations 7.1* to *7.5* were modified only to change the variable indices (i and j replacing sc in most cases) and to replace F with its equivalent (F* x Y) *in equation 7.2.*

For contamination of goats' milk by ^{131}I due to pasture consumption, *equation 7.1* becomes:

$$IMG_p\,(i,j) = DG\,(i,j) \times F^*\,(i,j) \times \tau_e \times PI^*_{gt} \times f_{m,\,gt} \times e^{-\lambda_r \times TD_{gt}} \qquad (7.6)$$

For contamination of goats' milk by ^{131}I resulting from the ingestion of soil, *equation 7.2* becomes:

$$IMG_{sl}\,(i,j) = DG\,(i,j) \times \frac{e^{-\lambda_r \times TD_{gt}}}{\lambda_r \times H_{sl}\,(i,j) \times U_{sl}} \times \left(1 - \frac{F^*\,(i,j) \times Y \times \lambda_r}{\lambda_e}\right) \times CR_{sl,\,gt} \times f_{m,\,gt} \qquad (7.7)$$

For the contamination of goats' milk by ^{131}I resulting from inhalation, *equation 7.3* becomes:

$$IMG_{inh}\,(i,j) = \frac{DG\,(i,j)\, e^{-\lambda_r \times TD_{gt}}}{v_g\,(i) + \dfrac{R\,(i,j) \times WR\,(i,j)}{AD}} \times BR_{gt} \times f_{m,\,gt} \qquad (7.8)$$

For the contamination of goats' milk by ^{131}I resulting from the ingestion of water, *equation 7.4* becomes:

$$IMG_w\,(i,j) = DG\,(i,j) \times \frac{1}{H_w \times \lambda_r} \times CR_{w,\,gt} \times f_{m,gt} \times e^{-\lambda_r \times TD_{gt}} \qquad (7.9)$$

For the contamination of goats' milk by ^{131}I resulting from the ingestion of stored hay, *equation 7.5* becomes:

$$IMG_{hay}\,(i,j) = DG\,(i,j) \times F^*\,(i,j) \times \tau_e \times PR_{hay} \times CR_{hay,\,gt} \times f_{m,\,gt} \times e^{-\lambda_r \times TD_{gt}} \qquad (7.10)$$

The time-integrated concentration in goats' milk resulting from all exposure routes was estimated by adding the separate contributions:

$$MG\,(i,j) = IMG\,(i,j) + IMG_{sl}\,(i,j) + IMG_{inh}\,(i,j) + IMG_w\,(i,j) + IMG_{hay}\,(i,j) = DG\,(i,j) \times f_{m,\,gt} \times TF_{gt}\,(i,j) \times e^{-\lambda_r \times TD_{gt}} \qquad (7.11)$$

with

$$TF_{gt}(i,j) = F^*(i,j) \times \tau_e \times PI^*_{gt} + \left(\frac{CR_{sl,gt}}{\lambda_r \times H_{sl}(i,j) \times U_{sl}} \times \left(1 - \frac{F^*(i,j) \times Y \times \lambda_r}{\lambda_e} \right) \right) + \left(\frac{BR_{gt}}{v_g(i) + \frac{R(i,j) \times WR(i,j)}{AD}} \right) + \left(\frac{k_1}{H_w \times \lambda_r} \times CR_{w,gt} \right) + \left(F^*(i,j) \times \tau_e \times PR_{hay} \times CR_{hay,gt} \right) \quad (7.12)$$

The parameter $TF_{gt}(i,j)$ represents the transfer of ^{131}I from the deposition on the ground on day, j, and county, i, to the activity intake by the goat. It is expressed in nCi per nCi m^{-2}.

The uncertainty attached to the values of $TF_{gt}(i,j)$ is admittedly large and extremely difficult to quantify as some of the parameter values vary over a wide range and are site specific. In addition some of the mechanisms underlying the environmental transfers are poorly understood. The values of $TF_{gt}(i,j)$ derived from *equation 7.12* were assumed to represent the geometric means of log-normal distributions with GSDs of 4.

7.1.1.3. Cottage cheese

Since it is assumed that both fresh cows' milk and cottage cheese are of local origin, the time-integrated concentrations of ^{131}I in cottage cheese for scenario sc, ICC(sc), in nCi d kg^{-1}, are proportional to the time-integrated concentrations of ^{131}I in fresh cows' milk, in nCi d kg-1, from all routes of intake, IMC(sc), according to:

$$ICC(sc) = IMC(sc) \times FCC \times e^{-\lambda_r \times TD_{cc}} \quad (7.13)$$

where:

- FCC is the quotient of the ^{131}I concentrations in cottage cheese and in cows' milk at the time of cottage cheese production, expressed in nCi kg^{-1} per nCi L^{-1}. Information on values of FFC derived from measurements is very scarce: Kirchmann et al. (1966) obtained an average value of 2.3. From data published by Reavey et al. (1966) on ^{131}I concentrations in milk and dairy products of the same origin contaminated by global fallout, an average value of 0.33 can be inferred. In this report, the median value of FCC is taken to be 0.9, which is the geometric mean of 2.3 and 0.33. Because the data are sparse and the spread of values is large, the distribution of FCC is assumed to be log-normal with a geometric standard deviation of two.

- TD_{cc} is the time delay between production and consumption of cottage cheese; Quinault (1989) reported a range from 2 to 7 days for TD_{cc}. A value of 2 days has been assumed in this report because production is assumed to occur locally in all cases.

The estimates of time-integrated concentrations of ^{131}I in cottage cheese were calculated using *equation 7.13* and the cows' milk concentrations in *Table 7.1* (which are also shown in *Table 7.3*). The results are presented in *Table 7.3*.

7.1.1.4. Eggs

The ^{131}I concentrations in eggs resulting from ^{131}I deposition are very sensitive to the feeding practices for the chickens that produce them. Within the same area, chickens kept confined indoors and fed commercial grain mixes that have undergone considerable storage since harvesting would lay eggs containing much less ^{131}I than those produced by chickens allowed to range freely. The practice of keeping chickens in feed lots was already widespread in the 1950s (Okonski et al. 1961).

Very few measurements of ^{131}I in eggs resulting from ground contamination are available. However, low concentrations of ^{131}I in eggs were found after the nuclear reactor accident at Windscale (Russell 1966), which occurred in 1957. Measurements after that accident indicated that the ^{131}I activity in one whole egg was up to 5% that in one liter of milk. Since one egg weighs about 50 g (Pond and Kilpatrick 1956), this implies that the ^{131}I concentration in eggs, expressed in nCi kg^{-1}, is at most the same as the ^{131}I concentration in cows' milk, expressed in nCi L^{-1}. Barth et al. (1969), following the shot Pin Stripe conducted at the NTS in 1966, measured ^{131}I concentrations in eggs laid by chickens that were observed eating contaminated forage near a dairy farm. The time-integrated concentrations of ^{131}I in eggs derived from those measurements are about twice the time-integrated ^{131}I concentrations in fresh cows' milk produced at the same farm. However, Eisenbud and Wrenn (1963) found that the ^{131}I concentrations in eggs in the New York City area were much lower than those in cows' milk after the nuclear tests conducted by the Soviet Union in 1961.

In this report, the time-integrated ^{131}I concentrations in eggs, expressed in nCi d kg^{-1} and the time-integrated ^{131}I concentrations in cows' milk, expressed in nCi d L^{-1}, are assumed to be equal at the time of production. A delay of 3 days is assumed between production and consumption. For scenario sc, the time-integrated concentrations of ^{131}I in eggs at the time of consumption, IGG(sc), in nCi d kg^{-1}, are calculated using:

$$IGG(sc) = IMC(sc) \times FGG \times e^{-\lambda_r \times TD_{gg}} \quad (7.14)$$

where:

- FGG is the quotient of the ^{131}I time-integrated concentrations in eggs and in cows' milk at the time of production, expressed in µCi d kg^{-1} per µCi d L^{-1}. The distribution of FGG is assumed to be log-normal with a median of 1 and a geometric standard deviation of 1.4;

- TD_{gg} is the time delay between production and consumption of eggs. Quinault (1989) reported a range from three to 18 days for TD_{gg}. A value of 3 days has been used in this report because all eggs are assumed to be produced in the county where they are consumed.

The estimates of time-integrated concentrations of ^{131}I in eggs were calculated using *equation 7.14* and the cows' milk concentrations in *Table 7.1* (also shown in *Table 7.3*). The results are presented in *Table 7.3*.

Table 7.3. Median time-integrated ^{131}I concentrations in various foodstuffs and in air following a unit deposition density of 1 nCi m^{-2}.

	Distance from the NTS: 3000 km						Distance from the NTS: 100 km	
	Dry conditions		Light rain		Heavy rain		Dry conditions	
	Cows on pasture	Cows off pasture	Cows on pasture	Cows off pasture	Cows on pasture	Cows off pasture	Cows on pasture	Cows off pasture
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8
Foodstuffs (nCi d L^{-1} per nCi m^{-2}) or (nCi d kg^{-1} per nCi m^{-2})								
cows' milk	0.42	0.035	0.52	0.036	0.22	0.021	0.057	0.019
goats' milk	3.8	0.15	4.7	0.18	2.0	0.095	0.57	0.027
cottage cheese	0.32	0.028	0.39	0.026	0.17	0.014	0.043	0.012
eggs	0.32	0.028	0.39	0.026	0.17	0.015	0.044	0.012
leafy vegetables	0.23	0.0	0.29	0.0	0.12	0.0	0.015	0.0
mothers' milk	0.034	0.0030	0.041	0.0027	0.018	0.0015	0.0046	0.00013
Air (nCi d m^{-3} per nCi m^{-2}):								
	0.00037	0.00037	0.00010	0.00010	0.000033	0.000033	0.00011	0.00011

7.1.1.5. Leafy vegetables

The growing season of leafy vegetables varies according to climatological conditions and is generally limited to a few months during the year. In this report, the growing and harvesting season of leafy vegetables is assumed to coincide with the pasture season of backyard cows. The leafy vegetables that are most frequently consumed include broccoli, cabbage, cauliflower, celery, lettuce, and spinach. To estimate the time-integrated concentrations of ^{131}I in leafy vegetables for scenario sc, ILV(sc), it is further assumed that:

- the ^{131}I deposition is intercepted and retained by the leafy vegetables in the same way as was estimated for pasture grass (**Sections 4.1.1** and **4.1.2**);
- the yield of leafy vegetables is 3 kg (fresh weight) per m^2, or 0.3 kg (dry weight) per m^2— the corresponding dry to fresh weight ratio, DFW, is 0.1;
- there is a delay, TD_{lv}, of 1 day between production and consumption of leafy vegetables;
- culinary practices (washing, removal of outer leaves, etc.) removes 80% of the activity (F_{wr} = 0.2). This average figure is based on the results of Thompson and Howe (1973) who found that 75 to 90% (and, in one case, 34%) of the ^{131}I activity deposited on lettuce was removed by removing the outer leaves and by washing. In more recent experiments, Wilkins et al. (1987) found that 59 to 93% of the ^{131}I activity deposited on lettuce was removed during culinary practices. The distribution of F_{wr} is assumed to be lognormal with a geometric standard deviation of 1.5.

The time-integrated concentrations (fresh weight) of ^{131}I in leafy vegetables for scenario sc, ILV(sc), in nCi d kg^{-1}, are calculated as:

$$ILV\,(sc) = DG \times F^*\,(sc) \times \tau_e \times F_{wr} \times e^{-\lambda_r \times TD_{lv}} \times DFW \qquad (7.15)$$

The parameters F_{wr} and DFW are discussed above. Other common and scenario-specific parameters were given in **Section 7.1.** During the non-growing season, the contamination of leafy vegetables is taken to be equal to zero.

The estimates of time-integrated concentrations of ^{131}I in leafy vegetables were calculated using *equation 7.15*. The results are presented in *Table 7.3*.

7.1.1.6. Inhalation

The time-integrated concentration of ^{131}I in ground-level air, IC_{air}(sc), that corresponds to a deposition of 1 μCi m^{-2} depends, among other factors, upon the physical and chemical form of ^{131}I, and upon environmental conditions (in particular, upon the presence or absence of precipitation). It is assumed in this report that the ^{131}I present in the radioactive cloud is associated with particles, and it is shown in **Appendix 7** that this assumption does not substantially affect the dose estimates. The equations used to relate the time-integrated concentrations of ^{131}I in outdoor ground-level air and the depositions per unit area of ground also are presented in **Appendix 7**, along with the selection of the parameter values.

For scenario sc, the time-integrated concentration of ^{131}I in outdoor ground-level air, IC_{air}(sc), corresponding to deposition via dry and wet processes, is estimated using *equation 4.64*, repeated here:

$$IC_{air}(sc) = \frac{DG}{\left[V_g(sc) + \frac{R(sc) \times WR(sc)}{AD}\right]} \quad (7.16)$$

Values for the common and scenario specific parameters in the equation are given in **Section 7.1**.

In general, people spend most of their time indoors, where the ^{131}I concentrations are lower than those outdoors. The average (indoor and outdoor) time-integrated concentrations of ^{131}I in air, in nCi d m^{-3}, ICR(sc), to which people are exposed are calculated using:

$$ICR(sc) = IC_{air}(sc) \times OF_{out} + IC_{air}(sc) \times RIO \times OF_{in} \quad (7.17)$$

where:

OF_{out} is the average fraction of time spent outdoors, taken to be 0.2 (Roy and Courtay 1991; UNSCEAR 1988),

OF_{in} (= 1 - OF_{out} = 0.8) is the average fraction of time spent indoors,

RIO is the average ratio of the indoor and outdoor time-integrated concentrations of ^{131}I, assumed to be 0.3 (Alzona et al. 1979; Cohen and Cohen 1980; Megaw 1962; Yocom et al. 1976).

Replacing IC_{air}(sc) by its value in *equation 7.17* yields:

$$ICR(sc) = DG \times \frac{OF_{out} + RIO \times OF_{in}}{V_g(sc) + \frac{R(sc) \times WR(sc)}{AD}} \quad (7.18)$$

The estimates of time-integrated concentrations of ^{131}I in air, ICR(sc), computed using *equation 7.18* are presented in *Table 7.3.*

7.1.1.7. Mothers' milk

For scenario sc, the time-integrated concentrations of ^{131}I in mothers' milk, IMM(sc), in nCi d L^{-1}, are the products of the daily ^{131}I activity intakes (in nCi) by lactating mothers, AI_{mt}(sc), and of the diet-to-milk transfer coefficient for ^{131}I in lactating women, $f_{m,mt,}$ in d L^{-1}. The data on the maternal milk transfer coefficients are discussed in **Chapter 4**. The relationship is shown in *equation 7.12*.

$$IMM(sc) = AI_{mt}(sc) \times f_{m,\,mt} \quad (7.19)$$

The median value of $f_{m,mt}$ is estimated in **Section 4.1.4.3** to be 0.1 d L^{-1} and the distribution of $f_{m,mt}$ is assumed to be lognormal with a geometric standard deviation of 2.9. The value of $f_{m,mt}$ is higher than the corresponding estimate for cows (f_m = 4 x 10^{-3} d L^{-1}) and only two times lower than the value for goats ($f_{m,gt}$ = 0.2 d L^{-1}). However, for a given deposition of ^{131}I on the ground, the daily activity intake of ^{131}I by lactating women is much lower than those of grazing animals. Consequently, human milk is usually much less contaminated than cows' or goats' milk.

For the scenarios discussed in this section, the values of AI_{mt}(sc) are approximated as the products of the time-integrated concentrations of ^{131}I in fresh cows' milk, IMC(sc), presented in *Table 7.1*, and the daily intake of fresh cows' milk by lactating women, taken to be 0.8 L d^{-1} (see **Section 6.2.2**). However, for the estimation of the thyroid doses due to each test conducted at the Nevada Test Site, the daily intakes of ^{131}I by lactating mothers, AI_{mt}, are calculated more exactly taking into account the ^{131}I time-integrated concentrations in each component of the diet.

The estimates of time-integrated concentrations of ^{131}I in mothers' milk, IMM(sc), computed using *equation 7.19* are presented in *Table 7.3.*

7.1.1.8. Time-integrated concentrations of ^{131}I in air and in foodstuffs: Summary

The time-integrated concentrations of ^{131}I in air or in the foodstuffs of interest corresponding to a unit deposition of 1 nCi m^{-2}, obtained in these example calculations, are summarized in *Table 7.3.* The values of the time-integrated concentrations for cows' milk, cottage cheese, eggs, and leafy vegetables are fairly similar. The time-integrated concentrations of ^{131}I in goats' milk are about 10 times greater than those for cows' milk when goats are on pasture and about five times greater when goats are under shelter. The time-integrated concentrations of ^{131}I in mothers' milk are about 10 times less than those in cows' milk.

Estimates of median time-integrated concentrations of ^{131}I in ground-level air and in the foodstuffs of interest were calculated for each test and each county of the contiguous United States; they are presented in the Annexes.

7.1.2. Consumption Rates of the Foodstuffs of Interest and Breathing Rates

With the exception of cows' milk, information on the variation with age and sex of the consumption rates of the foodstuffs of interest and on the fractions of the population that actually consume those foodstuffs is relatively scarce. The estimates used in this report have been obtained as follows.

7.1.2.1. Cows' milk (reference conditions)

Estimates of median consumption rates of cows' milk for milk drinkers in the contiguous U.S. and the associated GSDs were presented for the 10 post-natal age groups considered in *Table 6.2* of **Chapter 6**.The fractions of the persons in each of the groups that drank milk were also given in *Table 6.2.* The product of the two quantities yields the estimates of consumption rates given in *Table 7.4.*

Table 7.4. Median consumption rates of selected foodstuffs (Ld^{-1} or kg d^{-1}) and average breathing rates (m^3 d^{-1}) as a function of age and sex.

	Age								Adult male	Adult female	Per capita
	0-2 mo	3-5 mo	6-8 mo	9-11 mo	1-4 y	5-9 y	10-14 y	15-19 y			
Consumption rates (L d^{-1} or kg d^{-1})											
Cows' milk	0.13	0.46	0.70	0.70	0.49	0.66	0.64	0.57	0.20	0.14	0.37
Goats' milk	0.00003	0.0001	0.0002	0.0002	0.0001	0.0002	0.0002	0.0002	0.00007	0.00005	0.0001
Cottage cheese	0.00003	0.0005	0.003	0.003	0.004	0.005	0.005	0.005	0.005	0.005	0.005
Eggs	0	0.005	0.01	0.02	0.04	0.04	0.04	0.06	0.07	0.04	0.06
Leafy vegetables	0	0.002	0.004	0.006	0.009	0.02	0.03	0.03	0.05	0.05	0.04
Mothers' milk	0.16	0.07	0.02	----	----	----	----	----	----	----	----
Breathing rates (m^3 d^{-1})											
Air	2	3	4	5	7	12	17	19	23	18	15

7.1.2.2. Goats' milk

Goats' milk may be consumed as a substitute for cows' milk by people who are allergic to cows' milk. The per capita consumption of goats' milk over the population of the U.S. has been estimated from information on the number of milk goats and an assumed average production rate of milk by goats. Data compiled from the 1974 Census of Agriculture (Shor et al. 1982) show that there were 11,009 milk goats in the country in 1974 (to be compared with about 11 million milk cows). Assuming that the number of milk goats in the 1950s was the same as in 1974 and that the daily production of milk by goats is 1.5 L (*Table 4.7* in **Chapter 4**), the production rate of goats' milk in the U.S. in the 1950s was 16.5 kL d^{-1}. Dividing by the 1954 U.S. population of 163 million (*Table 5.6* in **Chapter 5**) yields a per capita consumption rate of goats' milk by the U.S. population of about 0.0001 L d^{-1} (to be compared with a per capita consumption rate of cows' milk of about 0.4 L d^{-1}).

In a survey of dietary information for Nevada and Utah children in the 1950s (Stevens et al. 1992), it was found that 2.9% of the subjects drank goats' milk at least part of the time from birth through 14 years of age, that the consumption of cows' milk and goats' milk was not mutually exclusive, and that the average consumption rate of milk by goats' milk drinkers and by cows' milk drinkers was very similar (about 0.8 L d^{-1}).

The per capita consumption rates of goats' milk for the populations of the 10 post-natal age groups considered in this report were estimated from the figure of 0.0001 L d^{-1}, using the same relative distribution as a function of age as that of cows' milk (*Table 7.4*). Since only a small fraction of people consumed goats' milk at any age, the median consumption rates of goats' milk for the 10 post-natal age groups considered should be equal to zero. In this report, however, nominal values, equal to the per capita consumption rates of goats' milk, have been adopted (*Table 7.4*). The use of those nominal values does not change the estimates of total thyroid doses, as other components of the dose, in particular the ingestion of cows' milk, are much greater than the ingestion of goats' milk. It should be kept in mind, however, that the individuals with consumption of goats' milk similar to those of cows' milk drinkers are likely to have received greater doses than the cows' milk drinkers because the ^{131}I contamination of goats' milk per unit deposition of ^{131}I generally was about five to 10 times higher than that of cows' milk (*Table 7.3*).

7.1.2.3. Cottage cheese

The per capita consumption rates of cottage cheese for the entire U.S. population have been reported by the USDA (1960) to be 4.6 pounds per year, or 0.006 kg d^{-1}, in 1955 and by Judkins and Keener (1960) to be 4.5 pounds per year, or 0.006 kg d^{-1}, in 1956. Production rates of cottage cheese yield a similar value: there were 1654 manufacturing plants in the U.S. in 1957, each producing on average 420 thousand pounds of cottage cheese per year, leading to a per capita value of 0.005 kg d^{-1}. A per capita consumption rate of 0.005 kg d^{-1} has been adopted in this report.

No information has been found in the literature on the fraction of the population that consumes cottage cheese at any age or on the variation of the consumption rate with age. The small per capita consumption rate for the entire U.S. population seems to indicate that less than 50% of the population consumed cottage cheese, and, consequently, that the median consumption rate was probably zero.

In this report, as was done for goats' milk, nominal values, equal to the per capita consumption rates in each age group, have been used for the median consumption rates of cottage cheese. The variation of the consumption rate as a function of age was estimated from the per capita value of 0.005 kg d^{-1} for the entire U.S. population using the relative variation of the consumption rate of butter and cheese reported by Schwarz and Kersting (1984) for German children under 10 years of age, and the relative variation of the consumption rate of dairy products other than fresh cows' milk reported by Yang and Nelson (1984) for children over 10 years old and for adults. The resulting estimates are presented in *Table 7.4*.

7.1.2.4. Eggs

The per capita civilian consumption of eggs in the U.S. in 1955 was 46.9 pounds per year, or 0.06 kg d^{-1} (Taylor 1987). This represents about one egg per day. The relative variation of the mean consumption rates with age, taken from Yang and Nelson (1984), was used to make estimates for each age group. It is assumed that the medians of the distributions of the consumption rates of eggs for the various age groups have the same values as the estimated means. The results are presented in *Table 7.4*.

7.1.2.5. Leafy vegetables

The values of the per capita consumption rates of leafy vegetables for the 10 post-natal age groups considered are taken from Yang and Nelson (1984). Their values are presented in *Table 7.4*. For a given age group, it is assumed that the median and per capita values are the same.

7.1.2.6. Mothers' milk

As shown in *Table 5.2* in **Chapter 5**, mothers' milk is consumed primarily by infants under 9 months of age. The fraction of infants consuming mothers' milk is less than 50% in each age group, so that the median consumption rates should be taken equal to zero. In this report, however, as was the case for the consumption rates of goats' milk and of cottage cheese, the median consumption rates of mothers' milk are assumed to be equal to the means. Estimates of mean consumption rates were obtained from the monthly data of the fractions of infants consuming mothers' milk (*Table 5.2*) and of the per capita consumption rates of milk from all types (*Table 5.3*). The results are presented in *Table 7.4*.

7.1.2.7. Breathing rates

The mean breathing rates as a function of age and sex were derived from Roy and Courtay (1991), who compiled the information on: (1) ventilation rates of children of several ages (newborn, 1-, 5-, 10-, and 15-year old) and of adults of both sexes for various types of activity (sleep, school, recreation, work, etc.), and (2) the time budgeted for those activities. The mean breathing rates corresponding to the 10 post-natal ages considered have been interpolated from the results of Roy and Courtay (1991). The medians are assumed to be equal to the means. The results are presented in *Table 7.4*.

7.1.2.8. Uncertainties

For the purposes of the uncertainty analysis, the distributions of the consumption rates of the foodstuffs of interest are assumed to be log-normal with geometric standard deviations equal to those estimated for the consumption rates of cows' milk, which are presented in *Table 6.2*. This assumption is reasonable for the consumption of eggs and leafy vegetables, which are, like cows' milk, consumed regularly by most people. On the other hand, it is recognized that this assumption is clearly not valid for the consumption rates of goats' milk, mothers' milk, and cottage cheese, which are consumed by less than 50% of the population of the age groups considered. However, the average doses resulting from the consumption of those foodstuffs are small when compared to those due to the consumption of cows' milk, so that the estimates of median and per capita thyroid doses are not substantially distorted.

With respect to inhalation, the ratio of the maximum and minimum values of the breathing rates varies by a factor of 2 to 4, depending on the age group considered (Roy and Courtay 1991). Assuming that the minimum and maximum values represent the 5th and 95th percentiles of the distribution, respectively, the corresponding geometric standard deviations are between 1.2 and 1.4. A GSD of 1.3 is assumed in this report for all age groups.

7.1.3. Dose Conversion Factors

The dose conversion factors for ingestion were previously presented in **Section 6.3** of **Chapter 6**. The dose conversion factors for inhalation are taken to be the same as those for ingestion (**Appendix 6**).

7.1.4. Thyroid Doses Corresponding to the Eight Scenarios

Combining the time-integrated concentrations presented in *Table 7.3*, the average consumption rates according to age and sex presented in *Table 7.4*, and the dose conversion factors for the age and sex groups presented in *Table 6.7* yields estimates of dose to the 10 post- natal groups for the eight scenarios considered. *Tables 7.5* to *7.12* provide the results obtained for each of the scenarios.

The variation with age of the thyroid doses for the eight scenarios presented in *Tables 7.5* to *7.12* shows that cows' milk is much more important for infants than for adults. Foodstuffs other than cows' milk are, on average, not significant, except in the absence of milk consumption. This may not be the case for specific individuals, however, because of the wide variability of consumption rates of foodstuffs such as goats' milk or cottage cheese.

The per capita doses corresponding to the eight scenarios are calculated by weighting the thyroid dose estimates from each age and sex category by the population size of each category (*Table 5.6*). Per capita thyroid dose estimates are also presented in *Tables 7.5* to *7.12* and are highest for the cows' milk consumption exposure route. Other pathways make only small contributions to the per capita doses. As a result, the per capita thyroid doses are about three times higher during the pasture season than during the off-season near the NTS (*Tables 7.11* and *7.12*). At the distant location, the differences in per capita doses for pasture and non-pasture seasons are larger.

Table 7.5. Estimated thyroid doses per unit deposition density (mrad per nCi m^{-2}) as a function of age for scenario 1. In scenario 1, dry deposition is assumed to occur at 3000 km from the NTS at a time when cows are on pasture.

	Age								Adult male	Adult female	Per capita
	0-2 mo	3-5 mo	6-8 mo	9-11 mo	1-4 y	5-9 y	10-14 y	15-19 y			
Ingestion											
Cows' milk	0.82	2.5	3.5	3.5	1.7	1.1	0.73	0.45	0.11	0.11	0.43
Goats' milk	0.0017	0.0049	0.0091	0.0091	0.0031	0.0031	0.0021	0.0014	0.00035	0.00034	0.0010
Cottage cheese	0.00014	0.0021	0.012	0.012	0.010	0.0066	0.0043	0.0030	0.0021	0.0029	0.0044
Eggs	0	0.021	0.038	0.077	0.10	0.052	0.035	0.036	0.029	0.023	0.053
Leafy vegetables	0	0.0060	0.011	0.017	0.017	0.019	0.019	0.013	0.015	0.021	0.025
Mothers' milk	0.082	0.031	0.0082	0	0	0	0	0	0	0	0.00066
Inhalation											
Air	0.011	0.014	0.018	0.022	0.021	0.018	0.017	0.013	0.011	0.012	0.015

Table 7.6. Estimated thyroid doses per unit deposition density (mrad per nCi m^{-2}) as a function of age for scenario 2. In scenario 2, dry deposition is assumed to occur at 3000 km from the NTS at a time when cows are not on pasture.

	Age								Adult male	Adult female	Per capita
	0-2 mo	3-5 mo	6-8 mo	9-11 mo	1-4 y	5-9 y	10-14 y	15-19 y			
Ingestion											
Cows' milk	0.068	0.21	0.29	0.29	0.14	0.095	0.060	0.038	0.0091	0.0088	0.036
Goats' milk	0.000068	0.00020	0.00036	0.00036	0.00012	0.00012	0.000081	0.000057	0.000014	0.000014	0.000041
Cottage cheese	0.000013	0.00018	0.0010	0.0010	0.00092	0.00057	0.00038	0.00027	0.00018	0.00025	0.00039
Eggs	0	0.0018	0.0034	0.0067	0.0092	0.0046	0.0030	0.0032	0.0025	0.0020	0.0046
Leafy vegetables	0	0	0	0	0	0	0	0	0	0	0
Mothers' milk	0.0072	0.0027	0.00072	0	0	0	0	0	0	0	0.000059
Inhalation											
Air	0.011	0.014	0.018	0.022	0.021	0.018	0.017	0.013	0.011	0.012	0.015

Table 7.7. Estimated thyroid doses per unit deposition density (mrad per nCi m^{-2}) as a function of age for scenario 3. In scenario 3, deposition with light rain is assumed to occur at 3000 km from the NTS at a time when cows are on pasture.

	Age								Adult male	Adult female	Per capita
	0-2 mo	3-5 mo	6-8 mo	9-11 mo	1-4 y	5-9 y	10-14 y	15-19 y			
Ingestion											
Cows' milk	1.0	3.1	4.4	4.4	2.1	1.4	0.90	0.56	0.14	0.13	0.53
Goats' milk	0.0021	0.00061	0.011	0.011	0.0039	0.0039	0.0025	0.0018	0.00043	0.00042	0.0013
Cottage cheese	0.00018	0.0025	0.014	0.014	0.013	0.0080	0.0053	0.0037	0.0025	0.0035	0.0054
Eggs	0	0.025	0.047	0.094	0.13	0.064	0.042	0.044	0.035	0.028	0.064
Leafy vegetables	0	0.0075	0.014	0.021	0.021	0.024	0.023	0.017	0.019	0.026	0.032
Mothers' milk	0.098	0.037	0.0098	0	0	0	0	0	0	0	0.0008
Inhalation											
Air	0.0030	0.0039	0.0048	0.0060	0.0057	0.0049	0.0046	0.0036	0.0030	0.0032	0.0041

Table 7.8. Estimated thyroid doses per unit deposition density (mrad per nCi m^{-2}) as a function of age for scenario 4. In scenario 4, deposition with light rain is assumed to occur at 3000 km from the NTS at a time when cows are not on pasture.

	Age								Adult male	Adult female	Per capita
	0-2 mo	3-5 mo	6-8 mo	9-11 mo	1-4 y	5-9 y	10-14 y	15-19 y			
Ingestion											
Cows' milk	0.070	0.22	0.30	0.30	0.14	0.097	0.062	0.039	0.0094	0.0091	0.037
Goats' milk	0.000081	0.00023	0.00043	0.00043	0.00015	0.00015	0.000097	0.000068	0.000016	0.000016	0.000050
Cottage cheese	0.000012	0.00017	0.00094	0.00094	0.00085	0.00053	0.00035	0.00025	0.00017	0.00023	0.00036
Eggs	0	0.0017	0.0031	0.0062	0.0085	0.0043	0.0028	0.0030	0.0024	0.0019	0.0043
Leafy vegetables	0	0	0	0	0	0	0	0	0	0	0
Mothers' milk	0.0065	0.0025	0.00065	0	0	0	0	0	0	0	0.000053
Inhalation											
Air	0.0030	0.0039	0.0048	0.0060	0.0057	0.0049	0.0046	0.0036	0.0030	0.0032	0.0041

Table 7.9. Estimated thyroid doses per unit deposition density (mrad per nCi m^{-2}) as a function of age for scenario 5. In scenario 5, deposition with heavy rain is assumed to occur at 3000 km from the NTS at a time when cows are on pasture.

	Age								Adult male	Adult female	Per capita
	0-2 mo	3-5 mo	6-8 mo	9-11 mo	1-4 y	5-9 y	10-14 y	15-19 y			
Ingestion											
Cows' milk	0.43	1.3	1.8	1.8	0.88	0.60	0.38	0.24	0.057	0.055	0.22
Goats' milk	0.00090	0.0026	0.0048	0.0048	0.0016	0.0016	0.0011	0.000076	0.00018	0.00018	0.00055
Cottage cheese	0.000077	0.0011	0.0061	0.0061	0.0056	0.0035	0.0023	0.0016	0.0011	0.0015	0.0023
Eggs	0	0.011	0.020	0.041	0.056	0.028	0.018	0.019	0.015	0.012	0.028
Leafy vegetables	0	0.0031	0.0058	0.0086	0.0089	0.0098	0.0097	0.0068	0.0078	0.011	0.013
Mothers' milk	0.043	0.016	0.0043	0	0	0	0	0	0	0	0.00035
Inhalation											
Air	0.00099	0.0013	0.0016	0.0020	0.0019	0.0016	0.0015	0.0012	0.00099	0.0011	0.0014

Table 7.10. Estimated thyroid doses per unit deposition density (mrad per nCi m^{-2}) as a function of age for scenario 6. In scenario 6, deposition with heavy rain is assumed to occur at 3000 km from the NTS at a time when cows are not on pasture.

	Age								Adult male	Adult female	Per capita
	0-2 mo	3-5 mo	6-8 mo	9-11 mo	1-4 y	5-9 y	10-14 y	15-19 y			
Ingestion											
Cows' milk	0.041	0.13	0.18	0.18	0.084	0.057	0.036	0.023	0.0055	0.0053	0.021
Goats' milk	0.000043	0.00012	0.00023	0.00023	0.000078	0.000078	0.000051	0.000036	0.0000086	0.0000086	0.000026
Cottage cheese	0.0000063	0.000091	0.00050	0.00050	0.00046	0.00029	0.00019	0.00013	0.000091	0.00013	0.00023
Eggs	0	0.00098	0.0018	0.0036	0.0049	0.0025	0.0016	0.0017	0.0014	0.0011	0.0025
Leafy vegetables	0	0	0	0	0	0	0	0	0	0	0
Mothers' milk	0.0036	0.0014	0.00036	0	0	0	0	0	0	0	0.000029
Inhalation											
Air	0.00099	0.0013	0.0016	0.0020	0.0019	0.0016	0.0015	0.0012	0.00099	0.0011	0.0014

Table 7.11. Estimated thyroid doses per unit deposition density (mrad per nCi m^{-2}) as a function of age for scenario 7. In scenario 7, dry deposition is assumed to occur at 100 km from the NTS at a time when cows are on pasture.

	Age								Adult male	Adult female	Per capita
	0-2 mo	3-5 mo	6-8 mo	9-11 mo	1-4 y	5-9 y	10-14 y	15-19 y			
Ingestion											
Cows' milk	0.11	0.34	0.48	0.48	0.23	0.15	0.098	0.062	0.015	0.014	0.058
Goats' milk	0.00026	0.00074	0.0014	0.0014	0.00047	0.00047	0.00031	0.00022	0.000052	0.000051	0.00016
Cottage cheese	0.000019	0.00028	0.0015	0.0015	0.0014	0.00088	0.00058	0.00041	0.00028	0.00039	0.00059
Eggs	0	0.0029	0.0053	0.011	0.014	0.0072	0.0048	0.0050	0.0040	0.0032	0.0073
Leafy vegetables	0	0.00039	0.00072	0.0011	0.0011	0.0012	0.0012	0.00086	0.00098	0.0014	0.0017
Mothers' milk	0.011	0.0042	0.0011	0	0	0	0	0	0	0	0.00009
Inhalation											
Air	0.0033	0.0043	0.0053	0.0066	0.0063	0.0054	0.0050	0.0040	0.0033	0.0036	0.0045

Table 7.12. Estimated thyroid doses per unit deposition density (mrad per nCi m^{-2}) as a function of age for scenario 8. In scenario 8, dry deposition is assumed to occur at 100 km from the NTS at a time when cows are not on pasture.

	Age								Adult male	Adult female	Per capita
	0-2 mo	3-5 mo	6-8 mo	9-11 mo	1-4 y	5-9 y	10-14 y	15-19 y			
Ingestion											
Cows' milk	0.037	0.11	0.16	0.16	0.076	0.051	0.033	0.021	0.0049	0.0048	0.019
Goats' milk	0.000012	0.000035	0.000065	0.000065	0.000022	0.000022	0.000015	0.000010	0.0000025	0.0000024	0.0000074
Cottage cheese	0.0000054	0.000078	0.00043	0.00043	0.00039	0.00025	0.00016	0.00011	0.000078	0.00011	0.00017
Eggs	0	0.00078	0.0014	0.0029	0.0039	0.0020	0.0013	0.0014	0.0011	0.00086	0.0020
Leafy vegetables	0	0	0	0	0	0	0	0	0	0	0
Mothers' milk	0.00031	0.00012	0.000031	0	0	0	0	0	0	0	0.0000025
Inhalation											
Air	0.0033	0.0043	0.0053	0.0066	0.0063	0.0054	0.0050	0.0040	0.0033	0.0036	0.0045

7.2. OVERALL CALCULATION PROCEDURES FOR THESE PATHWAYS

The overall calculation procedures used to estimate, for each test and each county of the contiguous United States, the thyroid doses resulting from the exposure routes to man other than the ingestion of cows' milk are similar to those described in **Chapter 4** for the estimation of thyroid doses due to the ingestion of cows' milk. The resulting time-integrated concentrations of ^{131}I in ground-level air and in the relevant foodstuffs, are presented in the Annexes for each of the tests considered in this report. The corresponding thyroid doses for each age and sex group are provided in the Sub-annexes for the tests considered.

7.2.1. Time-integrated Concentrations of ^{131}I

The time-integrated concentrations of ^{131}I in ground-level air, goats' milk, cottage cheese, eggs, leafy vegetables, and mothers' milk have been estimated for each county of the contiguous United States and for each day of ^{131}I deposition on the ground following a nuclear test at the NTS. The results are presented in the Annexes to this report for each test considered in the analysis.

7.2.2. Thyroid Doses

Thyroid doses from the pathways considered in this chapter have been estimated for 14 age and sex groups in each county of the contiguous United States. The results are available for each test, as totals for all exposure routes other than the ingestion of cows' milk in the Sub- annexes. Results for each test series are given in the Annexes. The per capita thyroid doses for the entire population of each county are presented by dose category in a map in the Annex for each test.

7.3. SUMMARY

- The methods and data used for calculating median thyroid doses resulting from exposure routes to man other than ingestion of cows' milk have been presented. The exposure routes considered are inhalation and the ingestion of goats' milk, cottage cheese, eggs, and leafy vegetables. The consumption of mothers' milk is also considered for infants under one year of age. Estimates of median time-integrated concentrations of ^{131}I in ground-level air and in the foodstuffs considered are presented in the Annexes for each test and each county of the contiguous United States. Estimates of median and per capita thyroid doses also are presented for each test and each county, but only as totals for all exposure routes other than the ingestion of cows' milk. These dose estimates for each of the tests considered are in the Sub-annexes.

- Example calculations of thyroid doses have been made for eight scenarios representing a range of precipitation intensities and of distances from the NTS. The results of these example calculations show that, when cows are on pasture, doses from ingestion of fresh cows' milk are, for all age groups, much more important than any of the other exposure routes considered. When cows are off pasture, ingestion of cows' milk is still the predominant pathway but inhalation is also important especially for adults when fallout was deposited by dry deposition.

- In the examples chosen, the per capita ^{131}I thyroid doses per unit deposition, all exposure routes to man included, vary in the range from 0.1 to 0.6 mrad per nCi m^{-2} when cows are on pasture and from 0.02 to 0.05 mrad per nCi m^{-2} when cows are off pasture.

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