Chapter 4

Transfer of ^{131}I from Deposition on the Ground to Fresh Cows' Milk

Contents: The parameters used to estimate the transfer of ^{131}I from deposition on the ground to fresh cows' milk via the ingestion of ^{131}I - contaminated pasture, the primary transfer route, are presented and discussed. The importance of all other exposure routes by which cows might be exposed to ^{131}I (ingestion of soil, water, and hay directly contaminated with ^{131}I, ingestion of vegetation contaminated with ^{131}I re-suspended from soil, and inhalation of ^{131}I in the air) is assessed relative to the pasture-cow-milk exposure route. The total time-integrated ^{131}I concentrations in fresh cows' milk from all tests are estimated and illustrated.

The transfer of ^{131}I from deposition on the ground to fresh cows' milk is well documented (e.g., Bergstrom 1967; Black et al. 1976; Dunster et al. 1958; Eisenbud and Wrenn 1963; Garner 1967; Kirchner et al. 1983; Knapp 1963; Ng et al. 1977; Stevens et al. 1992; Till and Meyer 1983; Whicker and Kirchner 1987). The environmental transfer processes resulting in the contamination of fresh cows' milk that usually are considered include: (a) ingestion of ^{131}I contaminated pasture, (b) ingestion of vegetation contaminated with ^{131}I resuspended from soil, (c) ingestion of ^{131}I contaminated soil, (d) ingestion of ^{131}I contaminated water, (e) ingestion of ^{131}I contaminated hay, and (f) inhalation of ^{131}I in the air. The largest contribution to the ^{131}I concentration in fresh cows' milk is usually due to the ingestion of ^{131}I contaminated pasture; this transfer process, often called the "pasture-cow-milk" exposure route, is considered separately.

In the remainder of the report:

- the ground is assumed to consist of soil and pasture grass;
- "fresh cows' milk" and "milk fresh from cow" mean milk collected directly from the cow.

4.1. ESTIMATION OF THE ^{131}I CONCENTRATIONS IN FRESH COWS' MILK RESULTING FROM THE CONSUMPTION OF ^{131}I CONTAMINATED PASTURE

The mechanisms involved in the estimation of the ^{131}I concentrations in fresh cows' milk resulting from the consumption of ^{131}I contaminated pasture are: (a) the interception by pasture grass of the ^{131}I activity that is deposited on the ground, (b) the retention of ^{131}I by pasture grass over a certain time period, (c) the consumption of ^{131}I contaminated pasture by the cow, and (d) the secretion of ^{131}I in the milk. *Figure 4.1* illustrates those mechanisms.

Following a single deposition of ^{131}I on pasture grass, the ^{131}I concentration in fresh cows' milk produced by cows assumed to consume pasture grass in a continuous manner at the same rate reaches a maximum a few hours after the time of deposition of ^{131}I on the ground and thereafter decreases by a factor of two about every five days. The total impact of the contamination of milk with ^{131}I is obtained by summing over time the ^{131}I concentrations in milk until the ^{131}I has decayed completely. The result, called the time-integrated concentration of ^{131}I in milk, is the quantity of interest in this report. The time-integrated concentration of ^{131}I in fresh cows' milk, IMC_p, resulting from the consumption of ^{131}I-contaminated pasture (p) in county, i, following deposition of ^{131}I on the ground on day, j, can be expressed as:

$$IMC_p\,(i, j) = \int_0^{\infty} C_p(i, j, t) \times PI(i, j, t) \times f_m \times dt \qquad (4.1)$$

where:

C_p(i,j,t) = average concentration of ^{131}I in pasture grass in county, i, at time, t, after deposition on day, j [nCi kg^{-1} (dry mass)],

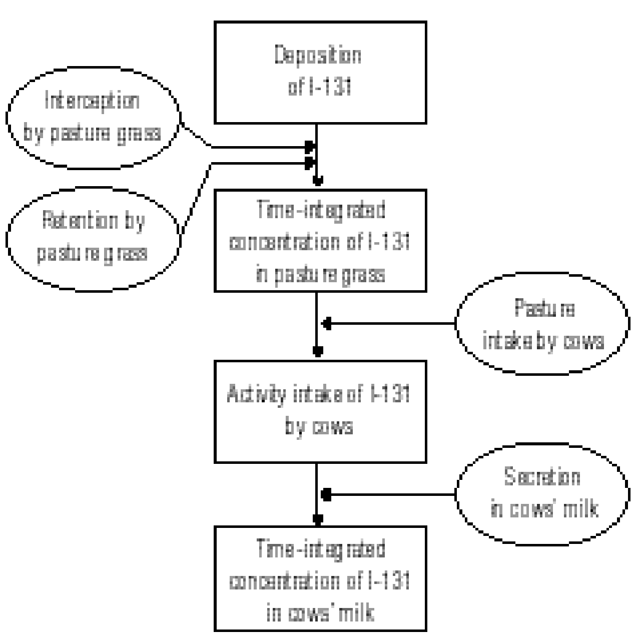
PI(i,j,t) = average amount of pasture consumed daily by the cow (hereafter called pasture intake) in county, i, at time, t, after deposition on day, j [kg (dry mass) d^{-1}],

f_m = average coefficient relating the amount of ^{131}I consumed by the cow per unit of time to the concentration of ^{131}I in milk obtained from the cow under equilibrium conditions (hereafter called intake-to-milk transfer coefficient of ^{131}I in cows and expressed in units of d L^{-1}), and

IMC_p(i,j) = expressed in nCi d L^{-1}.

The mechanisms involved in the pasture-cow-milk exposure route will be discussed in turn.

Figure 4.1. Transfer of I-131 from deposition to fresh cows' milk via the pasture-cow-milk exposure route.



4.1.1. Interception of ^{131}I by Pasture Grass

As illustrated in *Figure 4.2*, the activity of ^{131}I which is deposited per unit area of ground, DG(i,j), is distributed, in vegetated areas, between the activity that is intercepted by vegetation, A_p(i,j,0), and the activity that is deposited on the soil, A_{sl}(i,j,0):

$$DG(i, j) = A_p\,(i, j, 0) + A_{sl}\,(i, j, 0) \qquad (4.2)$$

The fraction of ^{131}I activity deposited on the ground which is intercepted by vegetation during the time of deposition is called the interception factor, F(i,j):

$$F\,(i, j) = \frac{A_p\,(i, j, 0)}{DG\,(i, j)} \qquad (4.3)$$

The value of the interception factor depends, among other factors, on the meteorological conditions, on the type of vegetation, and on the standing crop biomass (mass of vegetation above ground per unit area of ground). Values of interception factors obtained in laboratory or field experiments conducted under dry conditions or using a light water spray (equivalent to very light rain) spiked with radionuclides show a large range of variation between 0.02 and 0.82 (Miller 1980). However, the mass interception factor, F*, defined as the interception factor, F, divided by the standing crop biomass, Y, shows usually a much narrower range of 1 to 4 m^2 kg^{-1} (dry mass) (Miller 1980), and it is the quantity that is usually determined:

$$F^*\,(i, j) = \frac{F\,(i, j)}{Y} \qquad (4.4)$$

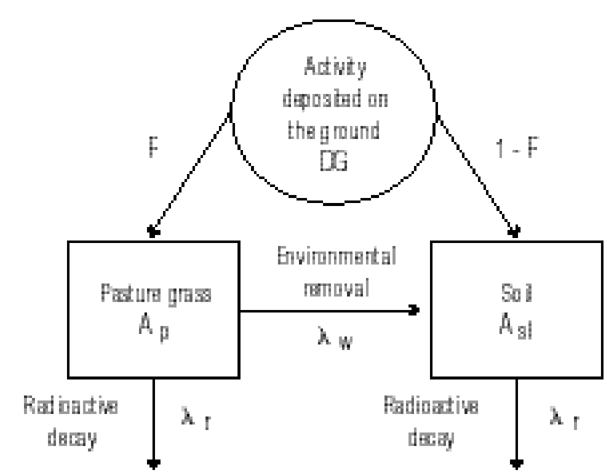
From *equations 4.4 and 4.3*:

$$F^*\,(i, j) = \frac{A_p\,(i, j, 0)}{Y \times DG\,(i, j)} = \frac{C_p\,(i, j, 0)}{DG\,(i,j)} \qquad (4.5)$$

where:

C_p(i,j,0) represents the concentration (nCi kg^{-1}) of ^{131}I on pasture grass immediately after deposition on day, j.

Figure 4.2. Schematic representation of the distribution of the activity of I-131 deposited on the ground.



The estimation of the mass interception factor is carried out differently according to whether ^{131}I is deposited under dry conditions or as a result of precipitation. To avoid ambiguities, the mass interception factor is denoted, in this section, as F^*_{dry} when ^{131}I is deposited under dry conditions and as F^*_{wet} when ^{131}I is deposited under wet conditions. Also, the indices i and j are not used explicitly to simplify presentation of the equations.

In the remainder of the report, "deposition on the ground" is usually shortened to "deposition" unless further clarification is needed.

4.1.1.1. Estimation of the mass interception factor of ^{131}I by vegetation under dry conditions

On the basis of experiments carried out under dry or light spray conditions, Chamberlain (1970) proposed that F_{dry} and Y can be related by means of the following equation:

$$F_{dry} = 1 - e^{-\alpha Y} \quad (4.6)$$

where:

F_{dry} = interception factor,

α = the foliar interception constant for elemental iodine and for particles up to 30 μm in diameter, and

Y = standing crop biomass (kg (dry mass) m^{-2}).

From *equation 4.6*, the mass interception factor under dry conditions can be estimated according to *equation 4.7:*

$$F^*_{dry} = \frac{F_{dry}}{Y} = \frac{1 - e^{-\alpha Y}}{Y} \quad (4.7)$$

This factor, therefore, is influenced by the standing crop biomass, Y, and by the foliar interception constant, α. Although α is called a constant, it will be shown in **Section 4.1.1.2** that in fact it depends on several parameters, including the particle size of the material intercepted by vegetation.

4.1.1.1.1. Influence of the standing crop biomass on the mass interception factor

The value of the standing crop biomass varies, among other factors, with the stage of the growing season and with the type of vegetation. For economic reasons, however, dairy cows are not expected to be put on pasture until the standing crop biomass of the grass is relatively high, thus resulting in a relative uniformity of the standing crop biomass consumed by dairy cows throughout the year and the country.

Baes and Orton (1979), on the basis of a compilation of more than 500 values of standing crop biomasses for forage grasses at harvest time, found a log-normal distribution with a median value of 0.3 kg m^{-2} (dry mass) and a geometric standard deviation of 1.8. Koranda (1965), using data from the U.S. Department of Agriculture, reported average forage crop yields for the U.S. of 0.20 kg m^{-2} for wild hay, 0.26 kg m^{-2} for lespedeza (a legume used for hay in southern states), 0.34 kg m^{-2} for clover and clover-grass mixtures, 0.28 kg m^{-2} for grain hay, 0.29 kg m^{-2} for other hay, 0.40 kg m^{-2} for sorghum forage, and 0.53 kg m^{-2} for alfalfa and alfalfa-grass mixtures. These values are in fairly good agreement with the results obtained by Baes and Orton (1979), which are used in this report for calculation purposes and are assumed to apply to any county of the contiguous United States. It can be shown (*Figure 4.3*) that the mass interception factor is not sensitive to the value of the standing crop biomass for a large range of values of the foliar interception constant. The foliar interception constant, whose value has a greater effect on F*, is discussed next.

4.1.1.1.2. Influence of the foliar interception constant on the mass interception factor

The foliar interception constant is an empirical parameter that includes the influence on the mass interception factor of all factors other than the standing crop biomass (e.g., meteorological conditions, physical and chemical form of ^{131}I, type of vegetation, etc.).

There is evidence that the value of the foliar interception constant, α, decreases as the particle size increases (Anspaugh et al. 1986; Romney et al. 1963; Whicker and Kirchner 1987) and, therefore, that the mass interception factor decreases as the particle size increases. In the case of atmospheric nuclear weapons tests, large-size particles (more than 100 μm in diameter) fall out near the detonation site and smaller particles are deposited as the radioactive cloud moves further away. Simon (1990), on the basis of limited measurements carried out near the NTS, estimated that the variation of the foliar interception constant α(X) for pasture grass, expressed in m^2 kg^{-1} (dry mass), as a function of the distance, X, from the NTS, expressed in km, can, in the absence of precipitation, be calculated as:

$$\alpha(X) = (7.0 \times 10^{-4}) \times (X^{1.13}) \quad (4.8)$$

Based upon this equation, the value of α(X) increases with distance from the NTS and is equal to 2.8 m^2 kg^{-1} (dry mass) for X = 1,540 km (*Figure 4.4*). Beyond that distance, the value of α(X) is taken to remain constant at 2.8 m^2 kg^{-1} in order to remain consistent with the value proposed by Chamberlain (1970) for elemental iodine and small-sized aerosols (see **Section 4.1.1.1**). The variation of F^*_{dry} as a function of distance can then be calculated:

$$F^*_{dry}(X) = \frac{1 - e^{-\alpha(X)\,Y}}{Y} \quad (4.9)$$

and is also presented in *Figure 4.4*, using a value of 0.3 kg m^{-2}

Figure 4.3. Variation of the mass interception factor F^*_{dry} as a function of the standing crop biomass Y for several values of the foliar interception constant α expressed in $m^2 kg^{-1}$ (dry mass).

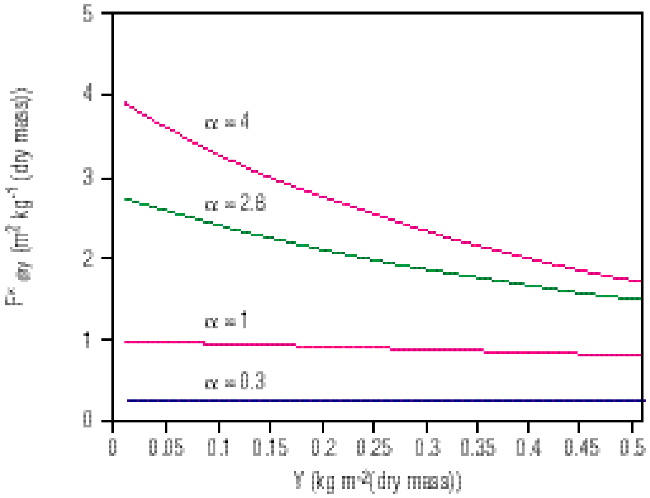
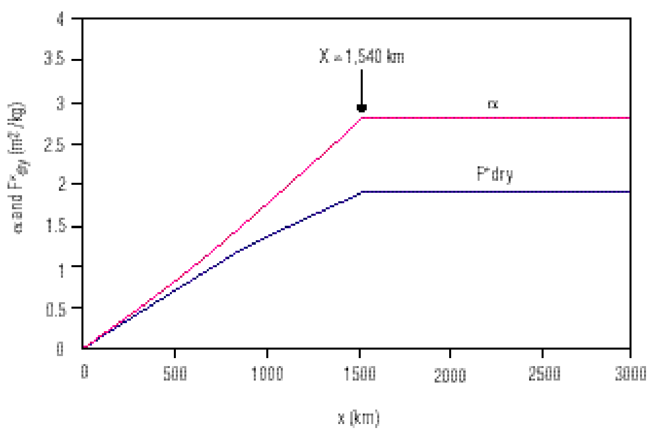


Figure 4.4. Variation of the foliar interception constant α and of the mass interception factor F^*_{dry} under dry meteorological conditions as a function of distance X from the NTS for Y = 0.3 kg m^{-2} (dry weight).



(dry mass) for Y.

Simon (1990) estimated that the GSDs attached to the values of α for distances from the NTS between 130 and 420 km are about 1.8. It is assumed that this value applies for any distance less than 1540 km from the NTS. For distances greater than 1540 km, the GSD for α, based upon the review of Chamberlain (1970), is estimated to be 1.3. Using the distribution of Y (median=0.3 kg m^{-2}, GSD=1.8) found by Baes and Orton (1979), it is found that the values of $F_{*dry}(X)$ can be relatively well approximated by lognormal distributions with GSDs of 1.5 for X smaller than 1540 km and of 1.2 for X greater than 1540 km.

4.1.1.2. Estimation of the mass interception factor of ^{131}I by vegetation in the presence of precipitation

As indicated in **Section 4.1.1**, most of the laboratory and field experiments investigating interception factors were conducted under dry or light spray conditions (Miller 1980) and do not, therefore, provide any information on the values to be expected in moderate or heavy rainfalls. In a limited number of cases, however, ^{131}I was measured in rain and vegetation after atmospheric nuclear weapons tests. The interception factor values derived from those measurements show a large range of variation, from less than 0.09 to about 0.9, with a high scatter for any given rainfall level, but with a tendency to decrease as the rainfall amount increases (Anspaugh 1987; Voillequé 1986 (included as **Appendix 8**)). By adapting an expression originally developed by Horton (1919) for the initial retention of rainwater by vegetation, Voillequé (1986) proposed that the variation of the mass interception factor as a function of the rainfall amount (mm), denoted as F^*_{wet} and expressed in m^2 per kg (dry mass) of vegetation, can be estimated:

$$F^*_{wet} = EF + \frac{RS}{R} = 1.3 + \frac{16}{R} \qquad (4.10)$$

where:

EF is a constant equal to 1.3 $m^2 kg^{-1}$ (dry mass),

RS is a constant equal to 16 mm kg^{-1} (dry mass) m^{-2}, and

R is the rainfall amount (mm or L m^{-2}).

In this expression, which describes in mathematical form Horton's model modified by Voillequé (1986), the mass interception factor for wet deposition, F^*_{wet}, is inversely related to the rainfall amount. The values of EF and of RS were obtained by fitting *equation 4.10* to available values of F^*_{wet} for fallout and the assorted precipitation data.

Because of the importance of the mass interception factor in the assessment of the ^{131}I exposures, and because of the limited amount of information on its value under conditions of moderate or heavy rainfall, a research program was designed to investigate the dependence of the mass interception factor on: (a) the physico-chemical form of the radionuclide, (b) the rainfall amount and intensity, and (c) the type and height of vegetation (Hoffman et al. 1989). Field experiments were conducted in which two mechanical rain simulators were used to study the interception by vegetation of radionuclides contained in rain. Rain simulator No. 1 had been designed to deliver rain at rates typical of moderate intensity storms (1 to 4 cm h^{-1}), while rain simulator No. 2 had been designed to reproduce rates common to very high intensity storms (4 to 12 cm h^{-1}). The simulated rain contained three radionuclides (^{141}Ce, ^{95}Nb, and ^{85}Sr) in three size classes (3, 9, and 25 μm, respectively) of insoluble polystyrene microspheres. The microspheres had been annealed at over 400 °C to seal the radionuclides inside (Hoffman et al. 1989). The deposition of those insoluble microspheres was taken to be representative of the deposition of ^{131}I attached to particles resulting from NTS tests. Also, the deposition of ^{131}I in soluble form was simulated by adding ^{131}I to the solution as either iodide or periodate. These materials were applied in simulated rain, in amounts varying from 1 to 30 mm in a given application, to pure stands of white clover and fescue, and to mixed stands of old field vegetation. In a separate experiment, simulated rain also was applied intermittently to fescue with approximately 30 min elapsing between the end of one application of rain and the beginning of another, up to cumulative amounts of 75 mm (Hoffman et al. 1989).

The results of these experiments are compared with those derived from Voillequé (1986) in *Figure 4.5* for particles and in *Figure 4.6* for ^{131}I in soluble form. When ^{131}I is attached to particles, which is the form most likely to have been predominant in fallout, there is good agreement between experimental and predicted values of the mass interception factor (*Figure 4.5*), especially for amounts of rainfall in excess of 10 mm. The initial estimates of EF and RS, however, were multiplied by 0.7 in order to obtain an even better agreement with the experimental values of the mass interception factor obtained by Hoffman et al. (1989) under controlled conditions. The resulting equation, which is used in this assessment, is:

$$F^*_{wet}(R) = EF_{cl} + \frac{RS_{cl}}{R} = 0.9 + \frac{11}{R} \qquad (4.11)$$

where:

$F^*_{wet}(R)$ = mass interception factor [m^2 kg^{-1} (dry mass)],

EF_{cl} = calibrated value of EF = 0.91 m^2 kg^{-1} (dry mass),

RS_{cl} = calibrated value of RS = 11 mm m^2 kg^{-1} (dry mass), and

R = rainfall amount (mm).

Figure 4.5. Variation of the mass interception factor as a function of rainfall amount. The curves represent the estimates derived from Horton's model, as modified by Voillequé (1986) as a dashed line and as further calibration in this report as a solid line. The crosses, points, and squares represent experimental values (to which the model was calibrated for interception) for radionuclides bound in particles by grass from continuous and intermittent applications using rainfall simulators (Hoffman et al. 1989).

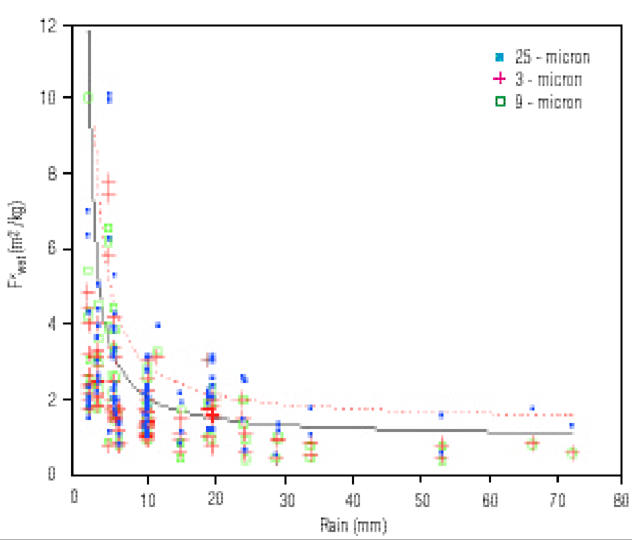
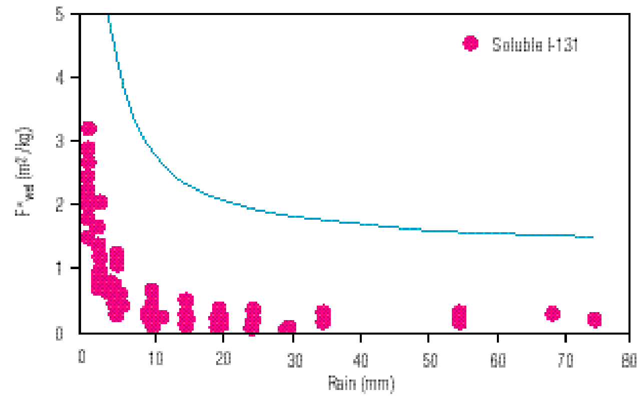


Figure 4.6. Variation of the mass interception factor as a function of rainfall amount. The solid curve represents the estimates derived from Horton's model as modified by Voillequé (1986), while the solid dots represent experimental values for soluble I-131 on grass from continuous and intermittent applications of water supplied by rainfall simulators (Hoffman et al. 1989).



When ^{131}I is in soluble form, the experimental values of the mass interception factor are about 10 times lower than those predicted by the model (*Figure 4.6*). However, ^{131}I is not thought to have been present in soluble form in fallout from the NTS in substantial amounts. It is shown in **Appendix 7** that the deposition of ^{131}I on pasture grass, as well as the resulting concentrations in cows' milk, can be adequately estimated using the assumption that all of ^{131}I in fallout from NTS was attached to particles. This assumption is used throughout the report.

For low rainfall amounts associated with high standing crop biomasses, the use of *equations 4.11* and *4.4* for ^{131}I attached to particles yields values of the interception factor, F, that are greater than one, which physically is impossible. To avoid this inconsistency, *equation 4.11* is only used for daily rainfall amounts that exceed 5 mm (denoted as R_2). On the basis of experimental data (*Figure 4.5* and **Appendix 8**), the values of $F^*_{wet}(R)$ for moderate and heavy rain (R > 5 mm) are considered approximately independent of the size of particles to which fallout ^{131}I is attached. This means that F^*_{wet} does not change with distance from the NTS.

For light rain (R< 5 mm), two rainfall intervals are considered:

- for values of daily rainfall between R_1 = 2.5 mm and R_2 = 5 mm, the mass interception factor is assumed to remain constant, irrespective of the distance from the NTS:

$$F^*_{wet}(R) = F^*_{wet}(R_2) = 3.1 \text{ m}^2 \text{ kg}^{-1} \text{ (dry mass) for } R_1 < R < R_2 \qquad (4.12)$$

- for values of daily rainfall between 0 and R_1 = 2.5 mm, the value of F^*_{wet} for a distance X from the NTS and a daily rainfall amount R is obtained by linear interpolation between the value of the mass interception factor used for dry conditions, $F^*_{dry}(X)$, in *equation 4.9* and the value of the mass interception factor in the presence of a rainfall R_1 of 2.5 mm, $F^*_{wet}(R_1)$:

$$F^*_{wet}(X,R) = F^*_{dry}(X) + [F^*_{wet}(R_1) - F^*_{dry}(X)] \times \frac{R}{R_1} \text{ for } R < R_1 \quad (4.13)$$

where:

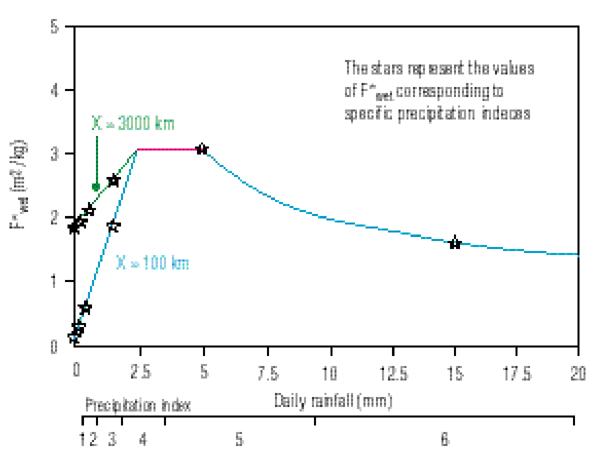
$F^*_{wet}(X,R)$ = mass interception factor at a given distance from the NTS and for less than 2.5 mm of rainfall.

$F^*_{dry}(X)$ = mass interception factor at a given distance from the NTS and no precipitation,

$F^*_{wet}(R_1)$ = mass interception factor for 2.5 mm of rainfall.

The variation of F^*_{wet} as a function of X and of R is illustrated in *Figure 4.7*. For the purposes of the uncertainty analysis, the values of F^*_{wet} are assumed to be log-normally distributed with GSDs of 1.4 and 1.6 for distances from the NTS that are less and greater than 1,540 km, respectively.

Figure 4.7. Variation of the mass interception factor, F^*_{wet}, as a function of daily rainfall, R. The straight solid lines for light daily rainfall (R < 2.5 mm) illustrate results obtained at two distances from NTS using the interpolation procedure adopted.



4.1.1.3. *Discussion*

The values of the mass interception factor F*(i,j) determined as indicated in the preceding **Sub-sections 4.1.1.1** and **4.1.1.2** are combined with the deposition density DG(i,j) to estimate the concentration of ^{131}I in pasture grass immediately after deposition. From *equation 4.5:*

$$C_p(i, j, 0) = DG(i, j) \times F^*(i, j) \quad (4.14)$$

The variation of the concentration of ^{131}I in pasture grass with time, t, after deposition, $C_p(i,j,t)$, is discussed in the following section.

4.1.2. *Retention of ^{131}I by Pasture Grass*

After ^{131}I is deposited on pasture grass, environmental removal processes combine with radioactive decay to reduce the initial amount, $A_p(0)$, on the vegetation surface per unit area of ground. *Figure 4.2* shows schematically the operative processes. The time necessary for one-half of the activity to be removed by environmental processes or diluted by plant growth is referred to as the environmental weathering half-life, T_w (Miller and Hoffman 1979). Literature values of T_w for particulate forms of iodine have a geometric mean of 8.2 d with a geometric standard deviation of 1.8 while those for I_2 vapor have a geometric mean of 6.8 d with a geometric standard deviation of 1.3 (Miller and Hoffman 1983). Within the framework of the research program related to this study, measurements of environmental weathering half-lifes of soluble ^{131}I and of insoluble particulates resulted in values ranging from 7.5 to 17.6 d with a median value of about 11 d (Hoffman et al. 1989). In this report, the mean value of T_w for ^{131}I in NTS fallout is taken to be 10 d, which is consistent with the findings of Miller and Hoffman (1983). This time value, together with that of the radioactive half-life, Tr = 8.04 d, determines the effective half-life of retention on vegetation, Te, according to:

$$T_e = \frac{T_w \times T_r}{T_w + T_r} \quad (4.15)$$

Using *equation 4.15* and the values for T_w and T_r given above, a value of 4.5 d is obtained for T_e.

The rate constants according to which the activity of ^{131}I decreases by environmental removal processes and by radioactive decay are denoted as λ_w and λ_r, respectively, and are related to T_w and to T_r as:

$$\lambda_w = \frac{ln(2)}{T_w} \quad (4.16)$$

and

$$\lambda_r = \frac{ln(2)}{T_r} \quad (4.17)$$

In the same way, the effective rate constant, λ_e, which is the sum of λ_w and of λ_r, is related to the effective half-life, T_e as:

$$\lambda_e = \lambda_w + \lambda_r = \frac{ln\ (2)}{T_e} \quad (4.18)$$

The activity of ^{131}I present on pasture grass per unit area of ground, A_p, decreases exponentially with time after deposition, t, according to:

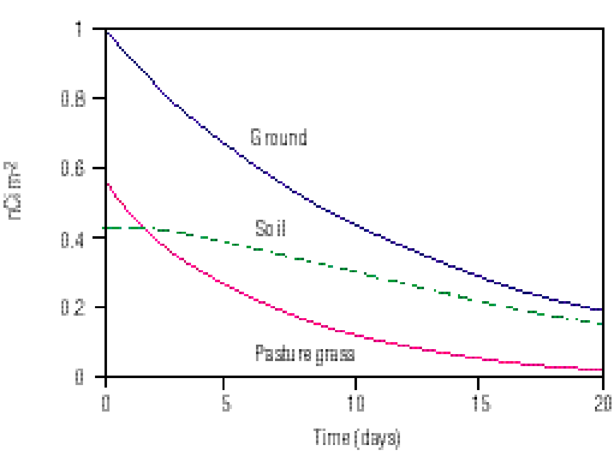
$$A_p\ (t) = A_p\ (0) \times e^{-\lambda_w t} \times e^{-\lambda_r t} \quad (4.19)$$

Since $A_p(0)$ = DG x F *(equation 4.3)* and $\lambda_e=\lambda_w+\lambda_r$ *(equation 4.18)*, *equation 4.19* can be written as:

$$A_p\ (t) = DG \times F \times e^{-\lambda_e t} \quad (4.20)$$

The variation of the activity of ^{131}I present in pasture grass per unit area of ground, A_p, as a function of time is presented in *Figure 4.8* for a single deposition, DG, of 1 nCi m^{-2} at time zero and for the value of F* corresponding to dry deposition far away (>1,540 km) from the NTS. The value of A_p decreases exponentially with time; it reaches 1% of its initial value after 5 weeks and 0.1% of its initial value after approximately 2 months. Also shown in *Figure 4.8* are the decreases with time of the activity of ^{131}I deposited on soil and the total ^{131}l activities per unit area of ground. The activity on soil is initially lower than the activity on pasture grass, but it becomes greater after a certain time because the activity removed from pasture grass by environmental processes is transferred to soil.

Figure 4.8. Variation with time of the activities of ^{131}I per unit area in pasture grass and in soil following a deposition of 1 nCi m^{-2} of ^{131}I on the ground (assuming that α=2.8 m^2 kg^{-1} and Y=0.3 kg m^{-2} (dry weight)).



The concentration of ^{131}I in pasture grass, $C_p(t)$, is obtained by dividing the activity $A_p(t)$ by the standing crop biomass, Y:

$$C_p\ (t) = \frac{A_p\ (t)}{Y} = DG \times F^* \times e^{-\lambda_e t} \quad (4.21)$$

The time-integrated concentration of ^{131}I in pasture grass, IC_p, resulting from a single deposition of ^{131}I on the ground, DG, is obtained by integrating $C_p(t)$ over time until complete decay of ^{131}I:

$$IC_p = \int_0^\infty C_p\ (t) \times dt = DG \times \frac{F^*}{\lambda_e} = DG \times F^* \times \tau_e \quad (4.22)$$

where:

τ_e, the reciprocal of λ_e, is the effective mean time of residence of ^{131}I on pasture grass.

Measurements carried out within the framework of the research program related to this study to investigate the influence of the physico-chemical form of the material deposited, the effect of plant growth dilution after deposition, and the wash-off effect of uncontaminated rain falling on vegetation showed: (a) no significant differences between the retention by vegetation of ^{131}I and of insoluble microspheres, (b) an effect of growth dilution of minor importance, and (c) unsuccessful attempts to correlate the removal of deposited materials with subsequent uncontaminated rain (Hoffman et al. 1989). If wash-off and growth dilution are not responsible for the reduction of the initial concentration with time, one can only speculate as to what are the important controlling processes. Some of the removal mechanisms may be surface abrasion and leaf bending from wind action, leading to tissue senescence of growing vegetation (Hoffman et al. 1989).

The uncertainties attached to the values of T_e and τ_e can be inferred from the uncertainties related to the environmental weathering half-life, T_w, as the radioactive half-life of ^{131}I, T_r = 8.04 d, can be assumed to be exactly known for the purposes of this report. Given the short radioactive half-life of ^{131}I, the effective half-life T_e is not particularly sensitive to large variations of the environmental weathering half-life T_w. In this assessment, the values of T_w are taken to be log-normally distributed with a geometric mean of 10 d and geometric standard deviation of 1.8 for any county of the contiguous U.S. for any time during the year. The corresponding geometric means of T_e and τ_e are 4.5 and 6.4 days, respectively, with a geometric standard deviation of 1.3.

4.1.3. Pasture Consumption by Dairy Cows and by "Backyard" Cows in the Continental U.S.

Fresh pasture is the portion of the cow's diet that is of primary interest in this report because it is the principal dietary component that was directly exposed to fallout and contaminated to a substantial extent by ^{131}I. Knowledge of the pasture consumption (also called intake) by cows is necessary to determine their ^{131}I activity intake due to the consumption of pasture contaminated following the deposition of ^{131}I resulting from a nuclear test at the NTS. The activity intake of ^{131}I, $AI_p(i,j)$, resulting from deposition on day, j, in county, i, is estimated as:

$$AI_p\,(i, j) = \int_0^{\infty} C_p\,(i, j, t) \times PI\,(i, j, t) \times dt \qquad (4.23)$$

where:

$C_p(i,j,t)$ is the concentration of ^{131}I in pasture grass in county, i, at time, t, after deposition on day, j (see *equation 4.21*), and PI(i,j,t) is the rate of pasture intake by cows in county, i, at time, t, after deposition on day, j.

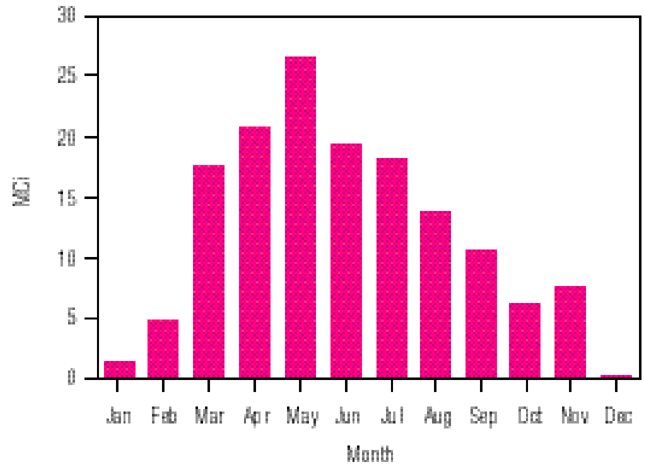
In order to estimate the amount of ^{131}I-contaminated pasture consumed by cows across the country, it is necessary to correlate temporal and spatial characteristics of the fallout patterns following each test with both the pasture intake by cows and the beginning and end of the pasture season for different regions of the U.S. These parameters in turn are influenced by the large climatic and agricultural variations that exist across the country. As shown in *Figure 4.9*, the atmospheric tests analyzed in this study released ^{131}I during each of the 12 months of the year, with maximum releases occurring during the spring.

Since the deposition of ^{131}I following an atmospheric test was usually widespread, the amounts of pasture consumed by cows were estimated for each week of the year and each region of the country.

Since the 1950s, the trends toward larger farms and the greater daily food intake requirements by high-milk-producing cows have reduced the importance of pasture feeding in favor of an increased reliance upon drylot feeding (Koranda 1965; McCullough 1981; Ward and Whicker 1987), which utilizes little or no pasture. Therefore, current dairy practices cannot be used as a surrogate for dairy practices that occurred during the 1950s.

Almost all of the cows' milk consumed in the United States in the 1950s originated from "dairy," or "commercial," cows. However, it was not unusual, during the 1950s, for families living in rural areas to keep one or two cows to provide the milk needed by the family. The diet of these "backyard" cows was not as carefully controlled as the diet of cows in commercial operations. The care of the cows and the pasture practices were more likely to have been motivated by ease of care and by reducing the maintenance costs to the extent practicable. To account for these differences, slightly different assumptions were made for the pasture practices of "backyard" cows.

Figure 4.9. Distribution of atmospheric releases of I-131 from NTS tests analysed in this study.



4.1.3.1. Pasture data available for dairy cows

No federal or state agricultural statistics exist regarding the consumption of pasture by dairy cows. Although occasional reports discuss pasture practices in terms of ideal conditions for cows or pasture, no direct information was found on the actual daily intakes of pasture by cows in the 1950s. Therefore, indirect methods were used to estimate the daily intake of pasture by cows throughout the country. The only nationwide standardized information source for dairy herd diets is the Dairy Herd Improvement Association (DHIA). Since 1905, the DHIA has maintained records to help its members improve the health of dairy cattle, increase milk production and increase efficiency of herd management. Since 1953, the Animal Improvement Program Laboratory of the U.S. Department of Agriculture (USDA) has maintained a national computer database of the DHIA data from the nine relatively independent regional Dairy Records Processing Center offices (DRPC 1987; Voelker 1985).

In 1950, over 1 million cows, about 5% of the number of dairy cows in the U.S., were included in the DHIA program. By 1960 the percentage of cows in the program doubled, and by 1970 about 20% of the cows were included (Voelker 1985). The success of the program is shown by higher average milk production rates of cows in the program, as compared to the average rate of all cows. For example, in 1950, cows in the DHIA program produced 58% more milk than the average U.S. cow. This increased production can be related to improved feeding programs, better herd management and the use of superior breeding stock (Voelker 1985).

The DHIA maintained records on breeding, diet, milk production, health, and operation costs of the cows for the farmers that were members of the association. The data collected included: number of cows in the herd, days-in-milk (number of days the cow produces milk as opposed to being "dry"), number of cows milked 3 times a day instead of twice, weight of the cows, milk and fat production of each cow, and feed costs.

Also, records were kept on estimates of the amount of protein, dry forage, succulent forage and concentrates that were fed to the cows. In addition, the fractions of the total net energy fed from dry forage, succulent forage and concentrates were estimated, as was the number of days the cows were on pasture during the year. A ratio called the feed index was reported as a measure of the amount of energy fed to the cows as compared to the amount of energy required by the animals for maintenance and milk production.

These data were estimated at the time by the farmers and the DHIA field staff and reported as monthly averages to the local DHIA office. Yearly, these data were compiled into annual herd summaries and the records were transferred to the Animal Improvement Laboratory in Beltsville, MD. The annual summaries of the data collected for the herds included in the DHIA program were obtained from the Animal Improvements Programs Laboratory.[1]

In reviewing the more than 270,000 records, some inconsistencies in recording, collecting and/or computational methods became apparent. In some states, the same value was recorded for certain factors for all the herds and all years. In other states, large portions of the data in a given record would be missing. For example, in California there were no data available for the time period of interest. It also appears that over the span of 10 years some of the different DHIA offices calculated estimates of net energy from dry forage, succulent forage and concentrates utilizing the annual herd average data in different ways. The values reported for the number of days on pasture were difficult to interpret in some states. It was not easy to determine if a value of zero indicated that no data were collected or that the herd was on feedlot.

In general, data for the number of cows, the milk and fat production for each cow, the weight of the cows and number of days on pasture are consistently reported. Using these data, the pasture intake by dairy cows has been calculated in two steps: (a) estimation of the total intake of dairy cows, averaged over the years 1953 to 1963, for each of the contiguous states, and (b) estimation of the fraction of total dry matter intake that was provided by pasture. In order to estimate the fraction of diet from pasture, the average cow's total diet was calculated using a method recommended by the National Research Council (NRC) (NRC 1978). The following DHIA annual herd data were utilized to calculate the total diet of dairy cows:

- average number of cows in the herd,
- average weight of the cows,
- average yearly milk production,
- average fat content in the milk, and
- number of days the cows were on pasture.

The estimates of the total daily dry matter intake that can be calculated from the DHIA data reported in the 1950s seem representative of the average cow's dry matter intake because these values are in fair agreement with the diets recommended in the manuals at that time (Morrison 1961). However, the greater milk production rates for DHIA herds suggest that the proportions of feed types (dry forage, succulent forage, and concentrates) in the rations may have differed. Information on the relative importance of the components of the diet in each state were obtained from experts (see list of contacts in **Appendix 3, Part 1**).

The geography, type of grasses, and climatological variation from year to year, as well as the economic climate at any given time, all influence the length of the pasture season as well as the fraction of the cow's diet obtained from pasture at different times of the year. In addition, the traditions followed by individual families can have a profound effect on the pasture practices. This study utilized the data provided by: (1) the DHIA (for the number of days on pasture), (b) interviews with USDA Extension Service experts (**Appendix 3, Part 1**), and (c) published reports to estimate the beginning and end of the pasture season, as well as the fluctuation in the fraction of the cow's diet that was provided by fresh pasture during the season.

A detailed discussion on the methods and results of the estimation of the pasture practices across the U.S. in the 1950s is found in **Sections 4.1.3.2, 4.1.3.3,** and **4.1.3.4.** The estimation of the backyard cow diet is discussed separately in **Section 4.1.3.5.**

4.1.3.2. Total daily consumption of feeds by dairy cows

There is considerable variation in the total daily consumption of feeds by dairy cows depending on the cow's body weight, level of milk production, and quality of the forage feeds. The variation is reduced if the food intake is described in terms of dry weight or "dry matter intake." The ability of cows to digest feed varies on a relatively small scale; however, their appetites, growth rates and milk production rates can vary considerably (NRC 1988). Feeding standards have been established to help farmers in selecting the properly balanced rations for optimum health of their animals and maximum milk production (Morrison 1961; NRC 1978, 1988). Using the National Research Council methodology (NRC 1978), the recommended daily intake, DM, expressed in terms of dry matter (kg d^{-1}), is estimated using:

$$DM = \frac{BWT \times PBWT}{100} \qquad (4.24)$$

where:

DM = daily dry matter intake (kg d^{-1}),

BWT = cow's body weight (kg), and

PBWT = percentage of cow's body weight to be fed to the cow per day.

Using the NRC methodology (NRC 1978), the values of PBWT are estimated as a function of the cow's body weight, BW, and of the daily production of milk normalized to 4% fat content, FCM, as shown in *Table 4.1* for a range of values of BW and of FCM.

[1]Personal communication (1985) with G. Wiggans and C. Ernst, at Animal Improvement Programs Laboratory, Agricultural Research Service-USDA, Building 263, Poultry Road, BARC-East, Beltsville, MD 20705.

Table 4.1. Estimates of percentage of body weight, PBWT, to be fed to dairy cows, as a function of the cow's body weight, BWT, and of the daily production of milk normalized to 4% fat content, FCM (NRC 1978).

Cow's body weight, BWT (kg)	300	400	500	600	700	800	900
FCM (kg d^{-1})							
5	2.4	2.2	2.1	2.0	2.0	2.0	2.0
10	2.7	2.5	2.3	2.2	2.1	2.0	2.0
15	3.0	2.8	2.5	2.4	2.3	2.2	2.1
21	3.3	3.1	2.8	2.7	2.6	2.4	2.2
25	3.5	3.4	3.1	3.0	2.8	2.6	2.4
30	3.9	3.7	3.4	3.2	3.0	2.8	2.6
35	4.0	4.0	3.6	3.4	3.2	3.0	2.8
40	4.0	4.0	3.8	3.6	3.4	3.2	3.0
45	4.0	4.0	4.0	3.8	3.6	3.4	3.2

The 4% fat-corrected daily milk production, FCM, is calculated for each herd average using the following empirical equation recommended in the NRC (1988) methodology:

$$FCM = (0.4 \times MY) + (15 \times FAT) \tag{4.25}$$

where:

FCM = 4% fat-corrected daily milk production (kg d^{-1}),

MY = milk yield (kg d^{-1}), and

FAT = fat yield (kg d^{-1}).

The annual herd averages for cows' body weight, milk production, and fat production reported to the DHIA from 1955 to 1965 were used to calculate, for each year that data were reported, in order: (1) the daily averages of the milk yield, MY, and of the fat yield, FAT; this was done by dividing the total yearly productions by the average number of days that cows produce milk during the year, 305 days, as cows are allowed an annual 60-day dry period for optimal milk production (DRPC 1987); (2) the 4% fat-corrected daily milk production, FCM, using equation 4.25; (3) the percentage of body weight to be fed to the cow, PBWT, using *Table 4.1;* (4) the average total daily dry matter intake for the herd, DM, using *equation 4.24*. It is assumed that the daily total dry matter intake of the cows remains constant throughout the year for all the cows in the herd.

Table 4.2 presents the arithmetic means of BWT, MY, and FAT for all of the herd data available in each state as well as the resulting values of PBWT and of DM obtained using *equations 4.24* and *4.25* and *Table 4.1.* For example, the average DHIA cow in New York state weighed 517 kg and produced 15.3 kg of milk and 0.58 kg of fat per day. From 3566 herd records in New York state, over a 10-year period, it is estimated that the mean daily dry matter intake for DHIA cows in New York state was 13 kg d^{-1} with a standard deviation of 1.4 kg d^{-1}. The distributions of the daily dry matter intakes in each state are relatively narrow and are fairly well approximated by normal distributions; consequently, the median daily dry matter intake in each state has been assumed to be equal to the mean value.

It is to be noted that the values of DM obtained by this method may be thought to be overestimates for two reasons: the NRC guidelines are intended to provide maximum dry matter intakes and the cows included in the DHIA program may not be representative of all cows because they may weigh more and produce more milk of better quality than those that are not listed in the DHIA program. However, the arithmetic means for the dry matter intake that are presented in *Table 4.2* are consistent with the range of 9 to 17 kg per day that is found in the literature for dairy cows of the 1950s (CES 1979; Koranda 1965; Leaver 1985; Morrison 1961; NRC 1978; Ward and Whicker 1987). The increased milk production represented by cows in the DHIA program may be due both to better nutrient quality of the DHIA recommended diet and to a somewhat greater total dry matter intake.

Table 4.2. Ten-year average state values and standard deviations (1 σ) of DHIA yearly herd data from 1953 to 1963 for the weight of the cows, daily milk and fat yield, and the estimated daily dry matter intake per cow. Each DHIA herd record provided average information on an individual herd for a given year.

	Average weight of cow(BWT)		Milk yield(MY)		Estimated fat yield (FAT)		Dry matter intake (DM)		Number of records
State	(kg)	(1σ)	(kg d^{-1})	(1σ)	(kg d^{-1})	(1σ)	(kg d^{-1})	(1σ)	
Alabama	520	148	10.7	2.7	0.446	0.1	12.1	2.4	1477
Arizona	616	101	14.2	2.5	0.54	0.084	14.4	1.8	1307
Arkansas	536	135	12.6	2.6	0.516	0.102	12.8	2.3	238
California*	700	-	17.4	3.5	0.685	0.103	17.0	1.1	5782
Colorado	704	113	13.8	2.8	0.547	0.089	15.8	2.0	1359
Connecticut	608	130	15.2	3.3	0.61	0.111	14.6	2.3	4557
Delaware	581	114	13.9	3.0	0.558	0.1	13.8	2.1	1037
Florida	500	144	10.8	1.9	0.478	0.092	11.9	2.3	648
Georgia	622	142	12.1	2.9	0.487	0.103	14.0	2.2	1641
Idaho	615	145	14.5	3.2	0.584	0.091	14.5	2.5	5386
Illinois	676	119	15.2	2.9	0.593	0.097	15.7	2.0	15334
Indiana	659	130	14.8	3.2	0.594	0.102	15.3	2.3	10753
Iowa	585	105	15.0	3.2	0.576	0.099	14.1	2.0	15626
Kansas	594	115	14.9	3.0	0.576	0.097	14.2	2.1	4501
Kentucky	604	141	13.1	3.0	0.523	0.096	13.9	2.3	2411
Louisiana	575	163	9.6	2.5	0.422	0.085	12.8	2.6	257
Maine	511	94	14.2	3.1	0.583	0.107	12.8	1.9	5201
Maryland	661	130	14.2	2.9	0.568	0.099	15.2	2.1	7127
Massachusetts	649	134	14.7	3.2	0.597	0.109	15.2	2.2	4794
Michigan	661	129	15.5	3.2	0.598	0.098	15.5	2.2	14556
Minnesota	553	83	15.4	3.0	0.576	0.092	13.6	1.7	27221
Mississippi	537	145	10.3	2.7	0.444	0.105	12.3	2.3	616
Missouri	602	142	13.2	3.1	0.55	0.101	14.0	2.4	2415
Montana	642	113	14.6	2.9	0.55	0.086	14.9	2.0	826
Nebraska	651	124	14.5	3.1	0.561	0.102	15.0	2.2	2789
Nevada	762	59	16.0	2.9	0.635	0.088	17.4	1.3	47
New Hampshire	651	135	14.1	3.0	0.574	0.111	15.0	2.1	2864
New Jersey	648	123	15.3	2.8	0.596	0.094	15.2	2.1	3718
New Mexico	754	68	13.7	2.7	0.551	0.087	16.6	1.3	118
New York	517	56	15.3	2.8	0.582	0.092	13.0	1.4	3566
North Carolina	561	124	13.4	2.9	0.529	0.096	13.3	2.1	4939
North Dakota	569	58	14.2	3.0	0.532	0.106	13.6	1.4	1153
Ohio	690	124	14.9	3.3	0.578	0.099	15.8	2.2	12398
Oklahoma	642	136	13.1	3.1	0.515	0.101	14.5	2.2	1085
Oregon	750	75	12.9	2.4	0.59	0.089	16.6	1.4	2967
Pennsylvania	662	126	15.0	3.0	0.59	0.1	15.4	2.1	38757
Rhode Island	631	128	14.9	3.1	0.593	0.1	14.9	2.2	519
South Carolina	573	142	12.2	2.7	0.501	0.938	13.3	2.3	893
South Dakota	616	108	15.1	3.1	0.553	0.104	14.5	2.0	1320
Tennessee	476	72	12.2	2.9	0.511	0.1	11.8	1.6	2033
Texas	614	147	12.6	3.3	0.512	0.104	14.0	2.4	2164
Utah	533	67	16.1	3.0	0.606	0.1	13.5	1.6	27629
Vermont	605	151	22.4	3.1	0.558	0.11	14.1	2.4	9653
Virginia	528	71	14.5	3.0	0.574	0.103	13.1	1.6	7507
Washington	770	16	14.2	3.2	0.614	0.099	17.2	0.9	3283
West Virginia	506	72	13.3	2.8	0.526	0.093	12.4	1.5	1690
Wisconsin	601	118	14.7	2.9	0.564	0.093	14.3	2.2	13430
Wyoming	665	77	13.7	2.9	0.501	0.085	15.0	1.4	71

* In the absence of data, the weight of California's DHIA cows was assumed to be 700 kg.

4.1.3.3. Fraction of total consumption of dry matter by dairy cows due to pasture

The fraction of the total daily consumption of dry matter by dairy cows that is obtained from pasture, FP, varies from one region of the country to another and from one time of the year to another. The DHIA records provide information on the total number of pasture days in the year and on the yearly averages of the fraction of diet on pasture, but not on the dates corresponding to the beginning and end of the pasture season, or on the variation of the value of FP during the pasture year. In order to reconstruct pasture feeding practices during the 1950s for the contiguous United States, the expert opinions of individual state USDA Extension Specialists throughout the country, and of other knowledgeable persons, were requested. The list of the persons who provided assistance can be found in **Appendix 3 (Part 1).** Most of the information was obtained during telephonic conversations and was based on subjective estimates from the experts. Problems related to spatial and temporal variations of FP were treated as follows:

(a) Spatial variations: Experts were requested to provide values of FP averaged over the entire state with which they were familiar. In some states, however, the environmental conditions and therefore the pasture practices varied considerably across the state. For example, in the southeastern states, the coastal areas are milder and therefore have significantly longer pasture seasons than do the inland sections. For the same reason, there are large intra-state variations in pasture season due to the dry climate in certain parts of Texas and California. Different pasture seasons were therefore assigned to parts of the states of California, Texas, Mississippi, Alabama, Georgia, and South and North Carolina. In addition, because there were substantial changes in pasture practices associated with sharp changes in fallout patterns across states close to the test site (Utah, Arizona, and part of California), it was considered that the use of a single pasture practice for the entire state would be too general. Therefore, smaller geographic areas were assigned within these states and the corresponding pasture practices were estimated on the basis of the work of Ward and Whicker (1987). In summary, the contiguous United States were divided into 71 pasture regions:

- 39 pasture regions correspond to the territories of the states that were not subdivided (Arkansas, Colorado, Connecticut, Delaware, Florida, Idaho, Illinois, Indiana, Iowa, Kansas, Kentucky, Louisiana, Maine, Maryland, Massachusetts, Michigan, Minnesota, Missouri, Montana, Nebraska, Nevada, New Hampshire, New Jersey, New Mexico, New York, North Dakota, Ohio, Oklahoma, Oregon, Pennsylvania, Rhode Island, South Dakota, Tennessee, Vermont, Virginia, Washington, West Virginia, Wisconsin, and Wyoming);
- 31 pasture regions are in states that were subdivided: Alabama (2), Arizona (2), California (4), Georgia (2), Mississippi (2), North Carolina (2), South Carolina (2), Texas (2), and Utah (13); and
- one pasture region for the District of Columbia, although there were no dairy cows in that area during the 1950s.

The distribution of the pasture regions across the contiguous United States is illustrated in *Figure 4.10*. A more detailed presentation of the geographical territories of the states that were subdivided can be found in **Appendix 3 (Part 3).** General information on the subdivided areas near the NTS is provided in **Appendix 2 (Section A2.3).**

(b) Temporal variations: The experts were initially requested to provide information on the variation of FP throughout the year on a monthly basis. However, in a number of responses, it was indicated that changes occurred “early,” “late,” or “in the middle of” a given month. It was therefore decided to divide each month into four parts, that would begin on the 1st, 8th, 16th, and 23rd days of each month, and to assign any change in the FP values to one of those days during the month. These four parts of the month are similar to calendar weeks, except that they begin on fixed days and may be 6 to 9 days long. They are denoted as “weeks” in this report.

The beginning and end of the pasture season for each pasture region, obtained on the basis of the experts’ advices, as well as the number of days on pasture between the designated start and stop dates, are presented in *Table 4.3*. The average number of days on pasture in DHIA records are presented on this table for comparison. Given the fact that the arithmetic standard deviation for the average number of days on pasture presented from the DHIA varied from approximately 40 to 150 days, there is a good agreement between the values for the length of the pasture season derived from the experts’ recommendations and recorded by DHIA.

Given the variability in the dates for the beginning and the end of the pasture season from one county to another in the same pasture region and also from one year to another, the fraction of intake from pasture, FP, has been assumed to increase gradually around those critical dates, as illustrated in *Figure 4.11* for Pennsylvania. The values of FP are assumed to vary linearly for a period of 2 “weeks” centered on the estimated mean date of the beginning of the pasture season. A similar procedure is used to estimate the decrease in pasture intake at the end of the pasture season.

Although subjective, the estimates of FP derived from the experts’ recommendations are the best obtainable information on the seasonal variation of pasture practices at that time. *Table 4.3* presents, for each pasture region, the yearly average values of the fraction of diet from pasture, FP, calculated from the experts’ estimates for each “week” of the year, as well as the corresponding values derived from the DHIA records. There is, here again, a reasonable (within a factor of about two) agreement between the two sets of values. The values estimated by the experts were used in this analysis.

Figure 4.10. Identification of pasture regions used in the dose assessment.

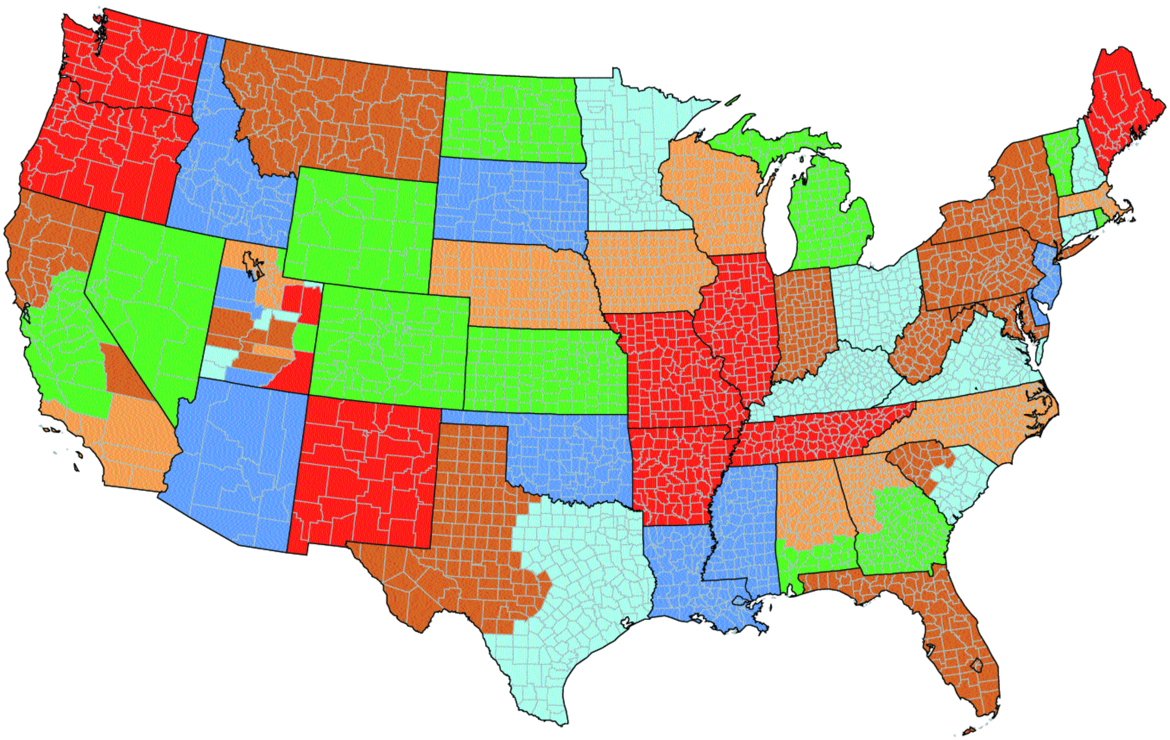


Figure 4.11. Estimated annual variation of the fraction of dry matter intake due to pasture for dairy cows in Pennsylvania during the 1950s.

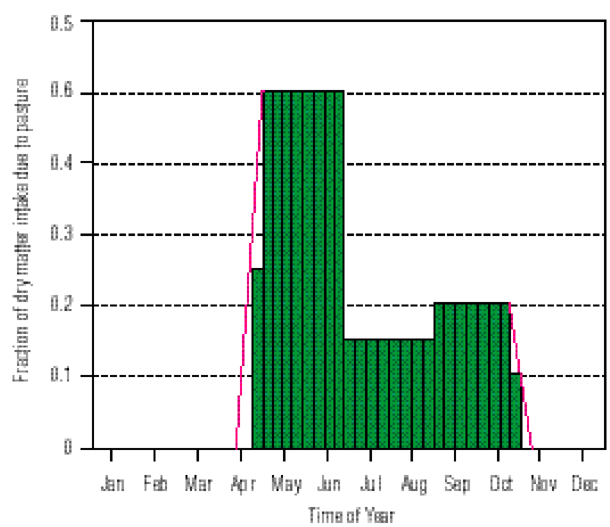


Table 4.3. Summary of pasture season data and of yearly average values of the fraction of diet from pasture for dairy cows in each pasture region, as derived from experts' recommendations. For comparison, average DHIA values for each state are included.

Area	Pasture season				Yearly average of the fraction of diet from pasture	
	beginning (day of year)	end (day of year	duration (days)	duration (days)		
	EXPERTS	EXPERTS	EXPERTS	EXPERTS	EXPERTS	DHIA
ALABAMA-north	60	334	275	260	0.31	0.26
ALABAMA-south	1	365	365	260	0.35	0.26
ARIZONA-remainder	1	365	365	nd[a]	0.05	nd
ARIZONA-northwest	106	288	183	nd	0.17	nd
ARKANSAS	60	304	245	208	0.31	0.25
CALIFORNIA-north	67	304	238	nd	0.24	nd
CALIFORNIA-middle	60	304	245	nd	0.14	nd
CALIFORNIA-south	47	304	258	nd	0.04	nd
CALIFORNIA-Inyo	136	258	123	nd	0.04	nd
COLORADO	136	258	123	48[b]	0.14	0.04[b]
CONNECTICUT	136	296	161	116	0.22	0.11
DELAWARE	106	319	214	174	0.23	0.19
DISTRICT OF COLUMBIA	---	---	---	---	---	---
FLORIDA	1	365	365	249	0.15	0.24
GEORGIA-north	60	334	275	244	0.27	0.24
GEORGIA-south	1	365	365	244	0.36	0.24
IDAHO	136	288	153	104	0.26	0.1
ILLINOIS	121	288	168	107	0.18	0.1
INDIANA	121	288	168	104	0.17	0.11
IOWA	121	288	168	135	0.18	0.14
KANSAS	121	304	184	165	0.26	0.15
KENTUCKY	91	288	198	139	0.19	0.15
LOUISIANA	1	365	365	209	0.46	0.26
MAINE	136	288	153	140	0.26	0.14
MARYLAND	106	319	214	119	0.26	0.12
MASSACHUSETTS	136	288	153	106	0.14	0.1
MICHIGAN	136	280	145	114	0.2	0.1
MINNESOTA	136	280	145	125	0.24	0.12
MISSISSIPPI-north	60	334	275	258	0.18	0.28
MISSISSIPPI-south	1	365	365	258	0.28	0.28
MISSOURI	121	304	184	146	0.27	0.15
MONTANA	136	273	138	101	0.23	0.09
NEBRASKA	121	280	160	108	0.2	0.1
NEVADA	136	273	138	23	0.06	0.03
NEW HAMPSHIRE	136	288	153	133	0.21	0.11
NEW JERSEY	121	296	176	133	0.16	0.12

Area	Pasture season				Yearly average of the fraction of diet from pasture	
	beginning (day of year)	end (day of year)	duration (days)	duration (days)		
	EXPERTS	EXPERTS	EXPERTS	EXPERTS	EXPERTS	DHIA
NEW MEXICO	114	304	191	10	0.08	0.13
NEW YORK	136	288	153	142	0.17	0.14
NORTH CAROLINA-east	75	319	245	177	0.22	0.16
NORTH CAROLINA-west	91	304	214	277	0.19	0.16
NORTH DAKOTA	136	273	138	126	0.18	0.13
OHIO	121	288	168	56	0.27	0.06
OKLAHOMA	60	334	275	178	0.24	0.17
OREGON	106	288	183	23	0.21	0.02
PENNSYLVANIA	121	304	184	147	0.14	0.1
RHODE ISLAND	136	296	161	119	0.25	0.1
SOUTH CAROLINA-east	60	319	260	238	0.27	0.23
SOUTH CAROLINA-west	67	319	253	238	0.26	0.23
SOUTH DAKOTA	136	273	138	105	0.17	0.1
TENNESSEE	75	273	199	214	0.2	0.23
TEXAS-east	67	334	268	142	0.34	0.2
TEXAS-west	1	365	365	142	0.15	0.2
UTAH - region 1	136	258	123	142	0.18	0.14
UTAH - region 2	152	243	92	142	0.2	0.14
UTAH - region 3	136	258	123	142	0.2	0.14
UTAH - region 4	136	258	123	142	0.17	0.14
UTAH - region 5	136	258	123	142	0.2	0.14
UTAH - region 6	152	243	92	142	0.17	0.14
UTAH - region 7	136	258	123	142	0.22	0.14
UTAH - region 8	152	243	92	142	0.19	0.14
UTAH - region 9	144	250	107	142	0.15	0.14
UTAH - region 10	128	266	139	142	0.03	0.14
UTAH - region 11	106	288	183	142	0.22	0.14
UTAH - region 12	121	273	153	142	0.33	0.14
UTAH - region 13	136	258	123	142	0.13	0.14
VERMONT	136	288	153	117	0.22	0.12
VIRGINIA	106	319	214	185	0.26	0.17
WASHINGTON	106	288	183	1[c]	0.21	0.00[c]
WEST VIRGINIA	114	304	191	168	0.23	0.19
WISCONSIN	136	280	145	71[c]	0.21	0.06[c]
WYOMING	136	273	138	24[b]	0.14	0.02[b]

[a] nd = no data available.
[b] DHIA data were either incomplete or a large proportion of herds were not fed fresh pasture.
[c] DHIA data were incomplete.

4.1.3.4. Estimates of daily consumption of pasture by dairy cows

The daily dry matter intake by cows which was obtained from pasture PI(i,j,t) (kg d^{-1}), in a given county, i, at a given time, t, after deposition on day, j, was calculated by:

$$PI\ (i,j,t) = DM(i) \times FP\ (i,j,t) \tag{4.26}$$

where:

DM(i) = total dry matter intake (kg d^{-1}), in the pasture region that includes the county, i, and

FP(i,j,t) = fraction of the diet from pasture at time, t, after deposition on day, j, in the pasture region that includes the county, i.

For each pasture region, an estimate of daily intake from pasture is calculated for each "week" of the year. As an example, the solid curve in *Figure 4.12* shows the estimated variation throughout the year of the daily pasture intake, PI, for dairy cows in the state of Pennsylvania. The complete set of estimates for the 71 pasture regions is provided in **Part 2 of Appendix 3** in tabular form and in **Part 4 of Appendix 3** in the form of histograms. Estimates, for each pasture region, of the yearly average of the daily pasture intake by dairy cows (including zero pasture months) are presented in *Table 4.4.* These estimates range from 0.6 kg (dry) d^{-1} for part of California to 5.9 kg (dry) d^{-1} for Louisiana.

The estimation of the time-integrated concentrations of ^{131}I in milk resulting from deposition of ^{131}I on the ground on day, j, in county, i, as described by *equation 4.1*, involves the calculation of a daily pasture intake equivalent, PI* (i,j), which is the quotient of the activity intake of ^{131}I by the cow from pasture, $AI_p(i,j)$, and of the time-integrated concentration of ^{131}I in the pasture grass consumed by the cow, $IC_p(i,j)$; the daily pasture intake equivalent represents an average of the daily pasture intake PI(i,j,t) over the time period during which ^{131}I is present on pasture, weighted according to the relative amount of ^{131}I present on pasture. From *equations 4.22 and 4.23,* the value of the daily pasture intake equivalent is obtained as:

$$PI^*\ (i,j) = \frac{AI_p\ (i,j)}{IC_p\ (i,j)} = \frac{\int_0^\infty PI\ (i,j,t) \times DG\ (i,j) \times F^*\ (i,j) \times e^{-\lambda_e t} \times dt}{DG\ (i,j) \times F^*\ (i,j)\ / \lambda_e} \tag{4.27}$$

where:

DG(i,j) = the average deposition density of ^{131}I on the ground in a given county, i, on day, j,

F*(i,j) = the average mass interception factor in county, i, on day, j, and

λ_e = the effective rate constant of removal of ^{131}I from pasture.

Since both DG(i,j) and F*(i,j) are independent of the variable t, *equation 4.27* can be simplified as:

$$PI^*\ (i,j) = \frac{\int_0^\infty PI\ (i,j,t) \times e^{-\lambda_e t} \times dt}{\tau_e} \tag{4.28}$$

The term exp($-\lambda_e$ t) reflects the decrease in the ^{131}I concentration in pasture, expressed as a fraction of the initial concentration on the day of deposition, j, as a function of time, t, after deposition. This term is equal to 0.34 one week after deposition, 0.02 one month after deposition, and 0.0003 two months after deposition. For practical purposes, the upper limit of the variable t in the integral of *equation 4.23* is taken to be equal to 60 days, at which time the concentration of ^{131}I in pasture will have decreased to less than 0.1% of the initial concentration.

The values of the daily pasture intake and of the pasture intake equivalent for dairy cows in the state of Pennsylvania are illustrated in *Figure 4.12.* It is shown on *Figure 4.12* and it also can be inferred from *equation 4.28* that the daily pasture equivalent, PI*(i,j), is equal to the pasture intake on the day of deposition, PI(i,j,0), if the value of PI(i,j,t) during the pasture season remains constant for a period of 2 months following deposition. However, the value of PI*(i,j) is greater than that of PI(i,j,0) if the deposition on the ground occurs before the beginning of the pasture season, and the value of PI*(i,j) is smaller than that of PI(i,j,0) if the deposition on the ground occurs towards the end of the pasture season.

In this report, uncertainties have been assigned to the daily pasture equivalent PI*(i,j). As observed by Breshears et al. (1989) within the framework of the ORERP study, the overall uncertainty of the time-integrated concentration of ^{131}I on milk varies according to the date of the fallout deposition, with the highest values when the cows are placed on, or removed from, pasture. It is assumed in this report that the values of PI*(i,j) are log-normally distributed with GSDs varying as a function of the time difference between the day of deposition, j, and the beginning of the pasture season, bp, as presented in *Table 4.5.* The largest GSDs, reflecting the largest uncertainty in PI*, are estimated for fallout depositions that occur within about 10 days of the start or finish of the pasture season.

Table 4.4. Estimates for each pasture region of the yearly averages including zero pasture months of the daily pasture intakes by dairy cows in kg (dry) /d.

Area	Yearly average pasture intake (kg(dry)/d)	Area	Yearly average pasture intake (kg(dry)/d)
ALABAMA-north	3.73	NEW JERSEY	2.42
ALABAMA-south	4.24	NEW MEXICO	1.29
ARIZONA-remainder	0.72	NEW YORK	2.36
ARIZONA-northwest	2.52	NORTH CAROLINA-east	2.86
ARKANSAS	4.03	NORTH CAROLINA-west	2.46
CALIFORNIA-north	4.08	NORTH DAKOTA	2.49
CALIFORNIA-middle	2.35	OHIO	4.22
CALIFORNIA-south	0.6	OKLAHOMA	3.51
CALIFORNIA-Inyo	0.73	OREGON	3.52
COLORADO	2.24	PENNSYLVANIA	2.19
CONNECTICUT	3.14	RHODE ISLAND	3.65
DELAWARE	3.22	SOUTH CAROLINA-east	3.55
DISTRICT OF COLUMBIA	----	SOUTH CAROLINA-west	3.4
FLORIDA	1.78	SOUTH DAKOTA	2.48
GEORGIA-north	3.79	TENNESSEE	2.36
GEORGIA-south	5.07	TEXAS-east	4.69
IDAHO	3.8	TEXAS-west	2.1
ILLINOIS	2.87	UTAH - region 1	2.47
INDIANA	2.68	UTAH - region 2	2.7
IOWA	2.52	UTAH - region 3	2.7
KANSAS	3.66	UTAH - region 4	2.25
KENTUCKY	2.67	UTAH - region 5	2.7
LOUISIANA	5.86	UTAH - region 6	2.27
MAINE	3.28	UTAH - region 7	3.01
MARYLAND	3.92	UTAH - region 8	2.54
MASSACHUSETTS	2.13	UTAH - region 9	1.97
MICHIGAN	3.1	UTAH - region 10	0.35
MINNESOTA	3.26	UTAH - region 11	3.04
MISSISSIPPI-north	2.25	UTAH - region 12	4.5
MISSISSIPPI-south	3.43	UTAH - region 13	1.8
MISSOURI	3.74	VERMONT	3.06
MONTANA	3.38	VIRGINIA	3.43
NEBRASKA	3.03	WASHINGTON	3.65
NEVADA	0.97	WEST VIRGINIA	2.86
NEW HAMPSHIRE	3.15	WISCONSIN	2.97
		WYOMING	2.13

Figure 4.12. Comparison of the daily pasture intake and of the daily pasture intake equivalent by dairy cows in the state of Pennsylvania during the 1950s.

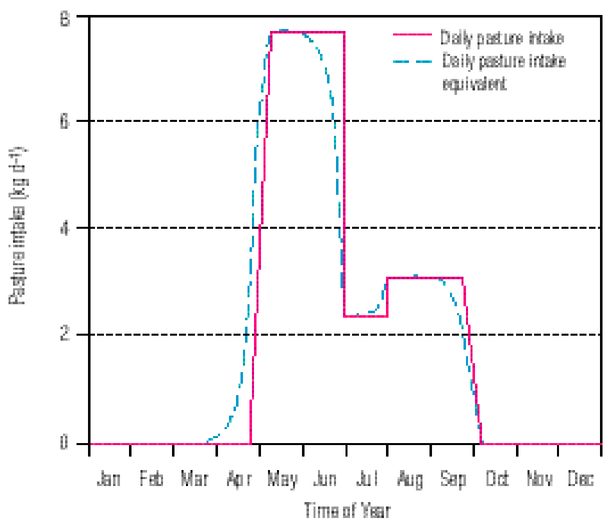


Table 4.5. Estimates of geometric standard deviations, GSD, associated with the daily pasture intakes of dairy cows.

Diff[a] (days)		GSD
From	To	
-60	-46	1.3
-45	-31	1.4
-30	-26	1.5
-25	-23	1.6
-22	-17	1.7
-16	-10	1.9
-9	+9	2.0
+10	+20	1.9
+21	+29	1.8

[a] Diff represents the algebraic difference in the number of days separating the day of fallout deposition, j, from the beginning of the pasture season, bp : Diff = j - bp

4.1.3.5. Estimation of "backyard" cow diet

It is assumed in this report that "backyard" cows were kept to provide the milk requirements of only an individual family. In these cases, the cows would be more likely to be placed on pasture for a larger portion of their diet than would herds of dairy cows, resulting in lower maintenance costs to the family. This feeding regime would also result in lower than average milk production rates; however, less than optimal milk production would be of little consequence to a non-commercial operation.

On the basis of discussions with an experienced dairy farmer (Till 1990), the following parameters were chosen for the average U.S. "backyard" cow:

- weight: 500 kg,
- milk production rate: 10 kg d^{-1} of 3.5% butterfat milk,
- diet during the pasture season: on the basis of the assumed values for the cows' body weight, and for the milk and fat yield, the total dry matter intake of the average U.S. backyard cow is estimated to be approximately 11 kg d^{-1} from *equations 4.24* and *4.25*. It is further assumed that 3 kg d^{-1} of concentrates (eg., grains roughage) are provided to the backyard cow and that the remainder of the diet is comprised totally of pasture. The estimated pasture intake is therefore 8 kg d^{-1} (dry mass): this value is assumed to represent the geometric mean of a log-normal distribution within each county with a geometric standard deviation of 1.3,
- length of the pasture season: it is assumed that the farmers put the backyard cows out to pasture as soon as possible in the spring and allowed them to graze as long as grass was available. The start and stop dates of the pasture season for backyard cows are taken to be one month before and one month after the start and stop dates, respectively, estimated for commercial herds that are presented in *Table 4.3* for all pasture regions.

4.1.4. Secretion of ^{131}I Into Milk

Iodine present in the diet in soluble form is rapidly and probably completely absorbed from the gastrointestinal tract into the blood. Some organs and tissues, notably the thyroid gland, but also the salivary glands, the gastric mucosa, and in some species, the ovaries, mammary glands and placenta, possess the capacity to concentrate iodine from the blood (Garner and Russell 1966; Honour et al. 1952). Iodine is eliminated from the body mainly in the urine with smaller amounts being excreted in the feces. Substantial amounts also are found in the milk of lactating animals and for this reason the transfer of radioactive iodine from the diet of animals to their milk has received particular attention.

Characteristics of all species is a rapid movement of iodine from the digestive tract to the blood and then to milk. Blood iodine is contained almost exclusively in the plasma and is either bound to proteins in the form of thyroxine and tri-iodothyronine or exists as inorganic iodide. Plasma iodide is the chief source of milk iodine as the mammary epithelial membranes are impermeable to protein-bound iodine in the cow and almost impermeable in other animals like the rat and the rabbit (Lengemann et al. 1974). Iodine in milk exists both as protein-bound iodine and as inorganic iodide. According to Lengemann et al. (1974), the milk/plasma iodide ratios are usually greater than one (average values are about 2 in cows, 7 in goats, 20 in dogs and humans, and 40 in sheep). These values indicate that mammary tissue possesses a mechanism (called "iodide pump") that is capable of concentrating iodide in the formation of milk and that this mechanism functions to different extents in different species. In addition, passive diffusion can supply blood iodide into the mammary gland, especially in cases in which the iodide pump is blocked or overwhelmed by a high concentration of plasma iodide (Van Middlesworth 1963).

This section is mainly devoted to the secretion of ^{131}I into cows' milk but the secretion into goats' milk and into human milk are also discussed as the contamination by ^{131}I of these foodstuffs is included in the estimation of the radiation exposures (see **Chapter 7**).

4.1.4.1. Cows' milk

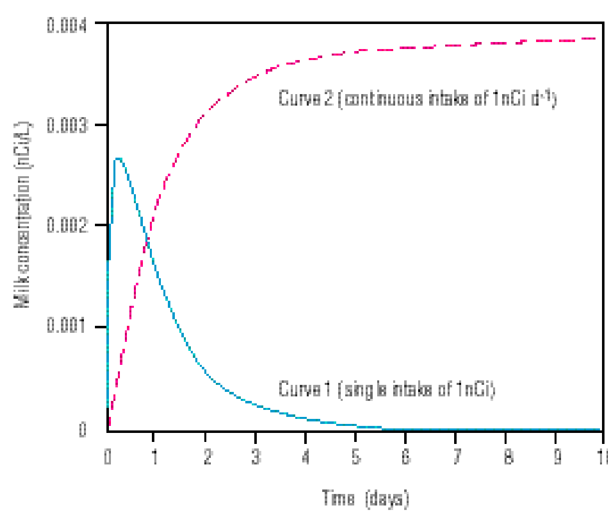
After the oral administration of a single dose of ^{131}I, the radionuclide appears in the milk within 30 minutes and reaches its maximum concentration within 12 hours. The concentration subsequently declines, at first with an effective half-life of about 16 hours, and then more slowly; it is approximately 1 percent of the maximum value 7 days after the intake (Garner and Sansom 1959). Curve 1 in *Figure 4.13* illustrates the variation with time of the ^{131}I concentration in cows' milk, in nCi L^{-1}, following a single intake of 1 nCi (Garner 1967). Curve 2 in *Figure 4.13* depicts the increase of ^{131}I concentration in milk (nCi L^{-1}) when ^{131}I is ingested at a constant rate of 1 nCi d^{-1}. For practical purposes, the equilibrium value is reached after 1 week of intake.

The cumulative fraction of the administered dose of ^{131}I that is secreted in cows' milk is about 5% (Comar 1966), with a range from 1 to 20% (Sasser and Hawley 1966). Considered as a machine for the transfer of ^{131}I from its diet to its milk, the dairy cow seems to be the most inefficient of the ruminants (Garner and Sansom 1959). Large variations in the fraction of the administered dose that is secreted in cows' milk have been observed, not only between individual animals, but also in the same animal at different times. Milk yield has been shown to be one factor, as the greater iodine secretion into milk appears to be related primarily to the greater volume of milk (Miller and Swanson 1963).

Describing the transfer in terms of the concentration in milk reduces the observed variations (Garner 1971). The intake-to-milk transfer coefficient for ^{131}I and for cows, f_m (d L^{-1}), is defined as the time-integrated concentration of ^{131}I in milk (nCi d L^{-1}) per unit of ^{131}I activity consumed by the cow (nCi) or, alternatively, the concentration of ^{131}I in milk (nCi L^{-1}) obtained at equilibrium for a constant rate of activity intake of ^{131}I (nCi d^{-1}). The latter ratio is expressed in nCi L^{-1} per nCi d^{-1} and is numerically equal to the time integral of the ^{131}I concentrations in milk, in nCi d L^{-1}, following a single intake of 1 nCi, represented by the area under curve 1 in *Figure 4.13.*

The transfer coefficient, f_m, has been determined experimentally in a large number of studies, including tracer experiments with stable or radioactive iodine and field studies in which pasture was contaminated by ^{131}I resulting from releases from nuclear facilities or from fallout from nuclear weapons tests. Reported values range from 2×10^{-3} to 4×10^{-2} d L^{-1} (Hoffman 1979; Ng et al. 1977; Voillequé 1989). The intake-to-milk transfer coefficient does not seem to depend on the chemical form of ^{131}I: Bretthauer et al. (1972) administered radioiodine-labelled elemental iodine, methyl iodide, sodium iodide, or sodium iodate to cows and found no significant differences in milk transfer among the compounds tested. There are, however, indications that the physical form of ^{131}I may influence the transfer coefficient. In their literature review, Ng et al. (1977) derived average values for f_m of 8.1×10^{-3} d L^{-1} for tracer experiments, of 4.3×10^{-3} d L^{-1} for ^{131}I in fission-product clouds, and of 2.4×10^{-3} d L^{-1} for ^{131}I in underground test debris.

Figure 4.13. Variation with time of the average concentration of ^{131}I in milk fresh from cow (nCi L^{-1}) in case of a single intake of 1nCi by the cow (curve 1) and of a continuous intake of 1nCi d^{-1} (curve 2).



Other factors that might have an influence on the secretion of ^{131}I in cows' milk have been investigated in a number of studies and reviewed by Tamplin (1965), Garner and Russell (1966), and Lengemann et al. (1974), among others:

- Breed: Tamplin (1965) analyzed the available data on the basis of breed and found the following means and ranges for the values of f_m (d L^{-1}):

Breed	Mean	Range	Number
Ayrshire	0.73	0.50-1.10	4
Holstein	0.90	0.17-2.06	20
Jersey	1.04	0.68-1.40	2
Guernsey	1.20	0.76-1.80	6

The number of animals in each group is too small to allow any substantial conclusions to be drawn from the data.

- The transfer coefficient f_m was found to be higher in the later stage of lactation: the effect of the stage of lactation on the transfer of stable iodine to milk was studied by Hanford et al. (1934) by comparing cows in different stages of lactation during the same season.The transfer coefficient f_m was found to be higher in the later stage of lactation than in the earlier stage, with an average ratio of 1.6 and a range of 1.3 to 5.3 (Hanford et al. 1934). In a typical dairy herd, cows will be at all stages of lactation during any season of the year. Therefore, the effect of stage of lactation will not be evident in the mixed milk of a dairy herd (Tamplin 1965).

- Iodine intake: the normal range of dietary intake of iodine is from 5 to 50 mg d^{-1}; within that range, the iodine content of the cows' diet has little effect on the transfer coefficient f_m (Alderman and Stranks 1967). A daily iodine intake of as much as 4 g causes only a 50% reduction in the f_m value (Lengemann and Swanson 1957). Therefore, the effect of the iodine intake does not appear to be significant under normal agricultural practices (Tamplin 1965). However, it has been suggested that the variations in the f_m values obtained in different countries or using different methods may be due to variations in stable iodine intake (Lengemann and Comar 1964; Voigt et al. 1989).

- Feed type: since iodine is present in milk in higher concentration than is found in blood, experiments were conducted to ascertain whether the iodine pump of the mammaries is inhibited by compounds such as thiocyanate, perchlorate, and nitrate that act on the thyroid gland (Bobek and Pelczarska 1963; Brown-Grant 1961; Garner et al. 1960; Lengemann and Thompson 1963; Miller et al. 1969; Piironen and Virtanen 1963). The results indicate that relatively large amounts of goitrogenic compounds are required to reduce the iodine concentration in milk by one-half (for example, in excess of 2 g of thiocyanate). Nevertheless, it is possible for cows to obtain these quantities in their food. Generally, the higher intakes of goitrogenic compounds would be expected during winter feeding when the cows are given silage, such as turnip or rutabaga (Tamplin 1965). However, differences in the transfer to milk also were observed according to type of pasture: cows fed ^{131}I-contaminated sudangrass were found to secrete half as much of the iodine in their milk as do cows fed similarly contaminated alfalfa (Black et al. 1975) or bromegrass (Moss et al. 1972). The chemical compound in the sudangrass that may affect the cows' mammary glands has not been positively identified (Moss et al. 1972).

- Season: Lengemann et al. (1957) found that seasonal changes in the amount of ^{131}I that reaches milk are so pronounced that they obscure the possible effects of other factors like the stage of lactation or the milk yield. The highest levels were recorded in the spring and summer months. The initial increase in iodine transfer coincided roughly with the onset of spring and was ascribed to the reduced iodine requirement of the thyroid gland. Later, during the spring to summer period, a high ^{131}I concentration in milk was maintained by active concentration in the blood (Lengemann et al. 1957). It is also to be noted that extremes of environmental temperature were found, in goats, to have a substantial effect on the amount of radioiodine transferred to milk; at 33 ºC, the amount transferred to milk was determined to be 6.5 times higher than at 5 ºC (Lengemann and Wentworth 1979). However, Hanford et al. (1934) found the stable iodine content of milk to be lowest from April to September and to exhibit a peak value from October to March. Further, Garner et al. (1960) found no evidence of a clear-cut seasonal effect on transfer of ^{131}I in milk in animals housed throughout the year and receiving a constant diet of hay and dairy nuts.

It is clear from the above that many factors are involved in the variability of the value of the transfer coefficient, f_m. The mechanism by which iodine moves into milk is not well understood; the overall situation is probably very complex involving interrelationships of feed type, breed, stage of lactation, and milk yield, among other factors. The available observations represent the integrated response to particular sets of interacting conditions.

Literature values related to the determination of feed-to-milk transfer coefficients for cows and ^{131}I are presented in *Table 4.6.* The values are classified into three categories according to the type of experiment or measurement that was carried out, as well as to the nature or origin of the iodine measured:

- the f_m values in category 1 result from controlled experiments using ^{131}I from weapons fallout; in these experiments, the activity intake of ^{131}I by a number of cows and the secretion of ^{131}I into milk of those same cows were measured;

- the f_m values in category 2 also result from controlled experiments using ^{131}I (and in some cases ^{125}I). However, the ^{131}I used did not originate in the detonation of nuclear weapons, and thus may have different physical and chemical properties;

- the f_m values in category 3 are derived from field measurements of ^{131}I in pasture grass and in cows' milk following unplanned environmental releases. Those measurements may have been carried out after atmospheric nuclear tests or when radioactive materials were inadvertently released after underground nuclear tests or in an accident such as Chernobyl. Also included are field measurements of ^{129}I around nuclear fuel reprocessing plants and field measurements of stable iodine. In this category, the activity intake of ^{131}I by the cow was not measured, but assessed from cows' consumption estimates.

The 17 average values of f_m listed in category 1 correspond most closely to the conditions considered in this report, i.e., the ingestion by cows of fallout ^{131}I resulting from nuclear tests at the NTS. The geometric mean of those 17 values is 2.1 x 10^{-3} d L^{-1} and the geometric standard deviation of their distribution is 1.9. However, most of the 17 values are related to tests that were conducted at the NTS in the 1960s, i.e. cratering tests and underground tests that inadvertently released radioactive materials into the atmosphere. The ^{131}I released by those tests, which amounts to only 2% of the total ^{131}I released by all NTS tests, may have been in different physical and chemical forms than the ^{131}I produced in the atmospheric tests of the 1950s. Unfortunately, experiments aiming at the determination of f_m values for ^{131}I from the NTS tests were not conducted in the 1950s because the radiological importance of the deposition-pasture-cow-milk exposure route had not been fully recognized in the United States. The only two controlled experiments that investigated the ingestion of ^{131}I from bomb fallout from the 1950s that were reported in the literature were conducted in England and were related to the Buffalo series of 1956 (Squire, Middleton, et al. 1961) and to the Grapple series of 1958 (Squire, Sansom, et al. 1961). These two controlled experiments resulted in an average f_m value of 4 x 10^{-3} d L^{-1}.

As indicated by Ng et al. (1977), the f_m values derived from tracer data (category 2) are usually higher than those derived from fallout ^{131}I (category 1). The geometric mean of the 45 average values of f_m listed under category 2 in *Table 4.6* is 5.9 x 10^{-3} d L^{-1} and the geometric standard deviation of their distribution is 1.9.

The f_m values inferred from field measurements (category 3) are less reliable than those obtained from controlled experiments (categories 1 and 2) because they require estimates of the consumption rates of pasture grass by cows. The geometric mean of the 16 average values of f_m listed under category 3 in Table 4.6 is 2.5 x 10^{-3} d L^{-1} and the geometric standard deviation of their distribution is 2.3.

The log-transformed values of the feed-to-milk transfer coefficient for cows presented in *Table 4.6* are plotted on probability scale in *Figure 4.14*; the overall distribution of the f_m values is relatively well approximated by a log-normal law with a geometric mean of 4.4 x 10^{-3} d L^{-1} and a geometric standard deviation of 2.1.

In this report, the geometric mean value of f_m for ^{131}I in NTS fallout and for cows is taken to be 4 x 10^{-3} d L^{-1} for any county of the contiguous United States and for any time of the year. This value corresponds to the results of controlled experiments on fallout ^{131}I from the 1950s carried out by Squire, Sansom, et al. (1961) and is in agreement with the geometric mean of all average f_m values that could be found in the literature. It is recognized that the value of f_m may be influenced by many factors such as the physical and chemical characteristics of the ^{131}I ingested, the breed of the cow, the stage of lactation, the milk yield, feed type, and time of year. However, the data needed to quantify the influence of these factors on the value of f_m are not available. The distribution of the f_m values is assumed to be lognormal for any county of the contiguous United States and for any time of the year, with a GSD of 2.1. This value is equal to that derived from the experiments, carried out under a large variety of conditions, which are reported in *Table 4.6*.

Figure 4.14. Distribution of the feed-to-milk transfer coefficients for ^{131}I and for cows.

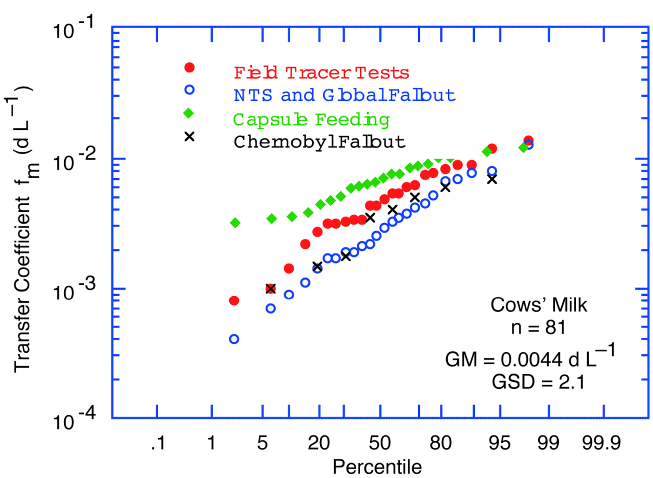


Table 4.6. Available data on the transfer of ^{131}I from feed to cows' milk.

Transfer coefficients f_m (d/L) Mean	Minimum	Maximum	Type of experiment	Type of feed	Physical or chemical form	No. of cows	Stable Iodine intake (mg/d)	Time of year	Breed	Milk yield (L/d)	References
1. CONTROLLED EXPERIMENTS WITH ^{131}I FROM WEAPONS FALLOUT.											
0.0069			Planned release of ^{131}I on spread hay (shot Palanquin)	Alfalfa		6	250	April	Holstein	13.9	Black et al. 1971a
0.0078			Planned release of ^{131}I on spread hay (shot Palanquin)	Alfalfa		3	250	April	Holstein	16.3	Black et al. 1971a
0.0035			Planned release of ^{131}I on spread green chop (shot Palanquin)	Alfalfa		6	250	April	Holstein	16.0	Black et al. 1971a
0.0011			Planned release of ^{131}I on baled hay (shot Cabriolet)	Alfalfa		4	250	January	Holstein	20.1	Black et al. 1971b
0.0007			Planned release of ^{131}I on spread hay (shot Buggy)	Alfalfa	0.6 μm median dia.	4	250	March	Holstein	17.8	Black et al. 1971b
0.0014			Planned release of ^{131}I on spread hay (shot Buggy)	Alfalfa	0.6 μm median dia.	4	250	March	Holstein	19.2	Black et al. 1971b
0.0009			Planned release of ^{131}I on spread hay (shot Buggy)	Alfalfa	0.6 μm median dia.	4	250	March	Holstein	15.1	Black et al. 1971b
0.0021			Planned release of ^{131}I on spread hay (shot Schooner)	Alfalfa	0.6 μm-0.9 μm median diameter	4	250	December	Holstein	19.1	Black et al. 1972
0.0017			Planned release of ^{131}I on spread hay (shot Schooner)	Alfalfa	0.6 μm-0.9 μm median diameter	4	250	December	Holstein	16.7	Black et al. 1972
0.0019			Planned release of ^{131}I on spread hay (shot Schooner)	Alfalfa	0.6 μm-0.9 μm median diameter	4	250	December	Holstein	13.7	Black et al. 1972
0.0037	0.0014	0.0082	Single dose of filters from fallout cloud collected 3-4 days after detonation	Alfalfa	Weapons fallout (Buffalo)	5		Sep-Oct	Ayrshire	7.7	Squire, Middleton et al. 1961
0.0017			Feeding of fallout debris (Schooner)		Weapons fallout	1		December			Porter et al. 1969
0.0041			Single dose of filters from fallout cloud collected 33 hours after detonation (3-d recovery only)		Weapons fallout (Grapple)	1				10.3	Squire, Sansom et al 1961
0.0019			Fallout from accidental underground venting								Porter, unp. (quoted in Ng et al. 1977)
0.0033			Fallout from Plowshare cratering event I								Porter, unp. (quoted in Ng et al. 1977)
0.0025			Fallout from Plowshare cratering event II								Porter, unp. (quoted in Ng et al. 1977)
0.0022			Fallout from accidental underground venting								Porter, unp. (quoted in Ng et al. 1977)
2. CONTROLLED EXPERIMENTS WITH RADIOIODINE TRACERS.											
0.0063			Single dose of carrier free ^{131}I	Brome		6			Holstein	16	Moss et al. 1972
0.0034			Single dose of carrier free ^{131}I	Sudan		6			Holstein	16	Moss et al. 1972
0.0037			Single dose of NaI with ^{131}I		Iodide	8	250	August	Holstein	23.1	Shimoda et al. 1970
0.0032			Controlled release of ^{131}I on spread hay	Alfalfa	Diatomaceous earth dry aerosol 23 μm median dia.	4	250	October	Holstein	20	Barth and Seal 1966

Transfer coefficients f_m (d/L)			Type of experiment	Type of feed	Physical or chemical form	No. of cows	Stable Iodine intake (mg/d)	Time of year	Breed	Milk yield (L/d)	References
Mean	Minimum	Maximum									
0.0008			Controlled release of ^{131}I on green chop	Sudan	Diatomaceous earth dry aerosol 23 μm median dia.	4	250	October	Holstein	24.5	Barth and Seal 1966
0.001			Controlled release of ^{131}I on green chop	Sudan	Diatomaceous earth dry aerosol 23 μm median dia.	4	250	October	Holstein	21	Barth and Seal 1966
0.0031			Controlled release of ^{131}I on spread hay	Alfalfa	Diatomaceous earth dry aerosol 2 μm median dia.	4	250	June	Holstein	21.3	Stanley et al. 1969
0.0053			Controlled release of ^{131}I on spread green chop	Alfalfa	Diatomaceous earth dry aerosol 2 μm median dia.	4	250	June	Holstein	28.1	Stanley et al. 1969
0.0053			Controlled release of ^{131}I on green chop	Alfalfa	Diatomaceous earth dry aerosol 2 μm median dia.	6	250	June	Holstein	23.6	Stanley et al. 1969
0.0022			Controlled release of ^{131}I on spread hay	Alfalfa	$Na^{131}I$ 169 μm droplets	6	250	September	Holstein	20.4	Douglas et al. 1971
0.0034			Controlled release of ^{131}I on green chop	Alfalfa	$Na^{131}I$ 169 μm droplets	6	250	September	Holstein	17.8	Douglas et al. 1971
0.0034			Controlled release of ^{131}I on green chop	Alfalfa	Diatomaceous earth ^{131}I dry aerosol, 0.13 μm	6	250	June	Holstein	22.5	Mason et al. 1971
0.0060			Controlled release of ^{131}I on pasture	Alfalfa	Gaseous ^{131}I	6	250	September	Holstein	19.2	Black and Barth 1976
0.0044			Controlled release of ^{131}I on pasture	Alfalfa	Gaseous ^{131}I	6	250	September	Holstein	19.4	Black and Barth 1976
0.0014			Controlled release of ^{131}I on pasture	Sudan	Diatomaceous earth ^{131}I dry aerosol, 0.6 μm median diameter	3	250	September	Holstein	25.1	Black et al. 1975
0.0031			Controlled release of ^{131}I on pasture	Alfalfa	Diatomaceous earth ^{131}I dry aerosol, 0.6 μm median diameter	3	250	September	Holstein	23.4	Black et al. 1975
0.0048			Planned release of ^{131}I on spread hay (destruction of a rocket reactor)	Alfalfa		5	250	January	Holstein	15.5	Black et al. 1969
0.0136			Planned release of ^{131}I on spread hay (destruction of a rocket reactor)	Alfalfa		5	250	January	Holstein	16.6	Black et al. 1969
0.0075	0.003	0.024	Controlled release of ^{131}I over pasture	Mixed	Iodide gas	6			Holstein	12.6	Sasser & Hawley 1966
0.0044	0.0025	0.0066	Controlled release of ^{131}I over pasture	Mixed	Iodine gas	6		July	Holstein	13.4	Zimbrick & Voilleque 1969; Voilleque 1989
0.0031	0.0021	0.0045	Daily feeding of capsules spiked with Na ^{131}I	Mixed	Iodide	3		August	Holstein	15.0	Zimbrick & Voilleque 1969; Voilleque 1989
0.0089	0.0061	0.011	Controlled release of ^{131}I over open-range grass	Crested wheat grass	Iodide	6		May	Holstein	14.0	Bunch 1968;Bunch 1966
0.0061	0.0025	0.010	Controlled release of ^{131}I over open-range pasture	Mixed	Iodide	6		September	Holstein	12.6	Bunch 1968
0.0070	0.0055	0.0081	Chernobyl: dried grass pellets	Chernobyl fallout		3	6	May	Deutsches Flekvieh	13.6	Voigt et al. 1989

Transfer coefficients f_m (d/L)			Type of experiment	Type of feed	Physical or chemical form	No. of cows	Stable Iodine intake (mg/d)	Time of year	Breed	Milk yield (L/d)	References
Mean	Minimum	Maximum									
0.0090			Single doses of ^{131}I		Iodide	1			Deutsches Flekvieh		Voigt et al. 1988
0.0070	0.005	0.0112	Single dose of carrier free ^{131}I in gelatine capsules		NaI	4	> 4	May-Aug	Ayrshire		Garner, Sansom, and Jones 1960
0.0078	0.0047	0.0174	Single dose of ^{131}I deposited upon grass		Elemental ^{131}I	4	> 4	May-Aug	Ayrshire		Garner, Sansom, and Jones 1960
0.0050	0.0027	0.0171	Single dose of carrier-free ^{131}I								Squire, Middleton et al. 1961
0.0046			Single dose of 50g KI labelled with ^{131}I		Iodide	1			Shorthorn	7.6	Glascock 1954
0.0064			Single intravenous dose of Na I labelled with ^{131}I		Iodide	8				10.7	Miller and Swanson 1963
0.0073			Single intravenous dose of Na I labelled with ^{131}I		Iodide	8				4.9	Miller and Swanson 1963
0.0043			Twice daily feeding of a mixture of ^{131}I & ^{125}I		Iodide & iodate	3			2 Jersey & 1 Ayrshire	7.5	14 Lengemann 1969
0.0035			Single dose of ^{131}I		Salt solution	1			Red Poll	7.7	Steenberg 1959
0.0085	0.0071	0.010	Single dose and daily doses of ^{131}I		Sodium iodide	1			Jersey	6.6	Lengemann & Swanson 1959
0.011	0.005	0.022	Daily doses of carrier-free ^{131}I		Potassium iodide	9		Jan-Oct	Guernsey & Holstein	12.4	Lengemann & Comar 1964
0.0075			Single dose of ^{131}I			3			Jersey		Lengemann 1963
0.0058			Single dose of ^{131}I			3			Jersey		Lengemann 1963
0.0099	0.0038	0.034	Single dose of ^{131}I			5			Jersey		Lengemann, Swanson et al. 1957
0.0059			Administration of carrier-free ^{131}I		NaI	6				6.8	Miller et al. 1963
0.012			Twice daily doses of ^{131}I		NaI	2					Comar, Wentworth et al. 1970
0.0084			Sodium iodide								Porter, unp. (quoted in Ng et al. 1977)
0.012			Controlled release of ^{131}I over open-range grass		Elemental I	6		May-June	Holstein	7.6	Hawley et al. 1964 Hawley 1966
0.0082			Controlled release of ^{131}I over irrigated grass		Elemental I	6		September	Holstein	11.8	Hawley 1966
0.011	0.0084	0.013	Single dose and daily dose of ^{131}I		Sodium iodide	1			Jersey	7.1	Lengemann & Swanson 1957
0.010	0.007	0.017	Twice daily doses of ^{125}I								Miller et al. 1965

Transfer coefficients f_m (d/L)			Type of experiment	Type of feed	Physical or chemical form	No. of cows	Stable Iodine intake (mg/d)	Time of year	Breed	Milk yield (L/d)	References
Mean	Minimum	Maximum									
3. FIELD MEASUREMENTS OF STABLE IODINE, OR OF RADIOIODINE RESULTING FROM UNPLANNED RELEASES.											
0.0052			Accidental release of ^{131}I (shot Pinstripe)	Alfalfa		4	250	April	Holstein	20.1	Barth et al. 1969
0.0029			Accidental release of ^{131}I (shot Pinstripe)	Alfalfa		6	250	April	Holstein	16.7	Barth et al. 1969
0.0004			Measurements in pasture and milk following weapons tests		Fallout ^{131}I	5		Dec.		5.6	Straub & Fooks, 1963 Kahn et al. 1962
0.0015			Measurements in pasture and milk following the Chernobyl accident		Chernobyl ^{131}I	50	Small?	May	Deutsches Flekvieh		Voigt et al. 1989
0.0035			Measurements in pasture and milk following the Chernobyl accident		Chernobyl ^{131}I	1	Small?	May	Deutsches Flekvieh		Voigt et al. 1989
0.0040	0.0028	0.0051	Measurements in pasture and milk following the Chernobyl accident		Chernobyl ^{131}I	30	Small?	May	Deutsches Flekvieh Flekvieh		Voigt et al. 1989
0.0018	0.0004	0.0073	Measurements in pasture and milk following the Chernobyl accident		Chernobyl ^{131}I			May			BIOMOVS 1991
0.0045			Measurements following a Chinese test. Assumes a grass intake of 45 kg/d.	Pasture	Weapons fallout	1		January	Hereford-Angus	11.4	Porter et al. 1967
0.006			Measurements of ^{131}I in grass and milk following the Chernobyl accident	Pasture	Chernobyl ^{131}I	40		May	Holstein		Tracy et al. 1989
0.005			Measurements of ^{131}I in grass and milk following the Chernobyl accident	Pasture	Chernobyl ^{131}I			May			Assimakopoulos et al. 1988
0.001			Measurements of ^{131}I in grass and milk following the Chernobyl accident	Pasture	Chernobyl ^{131}I			May			Dreicer and Klusek 1988
0.0027	0.0017	0.0068	Measurements of stable iodine in feed and in milk			18 herds					Alderman and Stranks 1967
0.009	0.018	0.0048	Measurements of stable iodine in feed and in milk								Kirchgessner 1959
0.0026			Measurements of ^{129}I in grass and milk								Hauschild and Aumann 1989
0.0024			Measurements of ^{129}I released on pasture								Handl et al. 1990
0.0027			Measurements of ^{129}I in grass and milk								Wilkins 1989
0.0127	0.0061	0.0192	Measurements in pasture and milk around the Monticello reactor site following a weapon test	Pasture	Fallout ^{131}I	4		July	Holstein		Weiss et al. 1975
0.0067	0.0034	0.016	Measurements in pasture and milk around the Dresden reactor site following a weapon test	Pasture	Fallout ^{131}I	4		July	Holstein		Weiss et al. 1975
0.0081	0.0041	0.014	Measurements in pasture and milk around the Quad Cities reactor site following a weapon test	Pasture	Fallout ^{131}I	2		July-Oct.			Voilleque et al. 1981

4.1.4.2. Goats' milk

Because of the overwhelming economic importance of dairy cows, relative to dairy goats, much less attention has been given to the transfer of ^{131}I from diet to milk for dairy goats. Literature values are presented in *Table 4.7*, which is primarily based on a review by Hoffman (1978). The fraction of the ^{131}I activity administered or ingested that is transferred to milk is about 5 times higher for goats than for cows as the mammary gland of the goat is a very efficient iodine trap. Because the rate of milk production is about 10 times smaller for goats than for cows, the feed-to-milk transfer coefficient for goats, $f_{m,gt,}$ is about 50 times greater than that for cows. The $f_{m,gt}$ values presented in *Table 4.7* range from 0.03 to 0.65 d L^{-1} with an arithmetic mean of 0.27 d L^{-1}. The feed-to-milk transfer coefficients for goats presented in *Table 4.7* are plotted on a log probability chart in *Figure 4.15*. The distribution of the $f_{m,gt}$ values is relatively well approximated by a log-normal distribution with a geometric mean of 0.22 d L^{-1} and a geometric standard deviation of 2.5. The predicted mean of the log-normal distribution (0.33 d L^{-1}) exceeds the computed mean given above. It is assumed in this report that the $f_{m,gt}$ values are log-normally distributed with an average (geometric mean) of 0.2 d L^{-1} and a geometric standard deviation of 2.5 for any county of the contiguous United States and at any time of the year.

4.1.4.3. Human milk

The few experimental data available on the transfer of ^{131}I into human maternal, mt, milk, $f_{m,mt,}$ are related to the concern that the administration of radiopharmaceuticals containing ^{131}I to lactating women would result in unacceptable thyroid doses to the nursing infants (Karjaleinen, et al. 1971; Miller and Weetch 1955; Nurnberger and Lipscomb 1952; Weaver, et al. 1960; Wyburn 1973). These experiments showed: (a) that most of the ^{131}I secreted in milk occurs within 24 hours, (b) that most of the activity secreted in the milk is in the form of free or inorganic iodine, irrespective of the chemical form under which iodine is administered, and (c) that the percentage of the administered ^{131}I that is secreted in milk seems to increase with the rate of milk production, resulting in ^{131}I concentrations in milk roughly independent of the rate of milk production.

Table 4.8 summarizes the characteristics of the experiments and the values of the transfer coefficient $f_{m,mt}$ that can be derived from those experiments. The log-transformed values of $f_{m,mt}$ also are plotted on a probability scale in *Figure 4.16*. The values of $f_{m,mt}$ are resonably well represented by a log-normal distribution with a geometric mean of 0.1 d L-1 and a GSD of 2.9. The predicted mean of the log-normal distribution (0.21 d L^{-1}) exceeds the computed mean of 0.14 d L^{-1}. Most of the available data are related to women with health problems; it is assumed that the same distribution of $f_{m,mt}$ applies to healthy women for any county of the contiguous United States.

An indirect confirmation of the representativity of the average value for $f_{m,mt}$ given above can be inferred from the measurements of ^{131}I in cows' and human milk carried out in Europe after the Chernobyl accident (Campos Venuti et al. 1990; Gorlich et al. 1988; Haschke et al. 1987; Lindemann and Christensen 1987). In Vienna, Austria, Haschke et al. (1987) found that the ^{131}I concentration in pooled breast milk was about one-tenth of that in cows' milk on sale in the area. In Rome, Italy, the ^{131}I concentration in human milk was about one per cent of that in cows' milk from the Central Dairy (Campos Venuti et al. 1990), while in the canton Aargau in Switzerland the time-integrated concentration of ^{131}I in human milk was 7% of that in cows' milk (Gorlich et al. 1988). The ratio of the ^{131}I concentrations in human milk and in cows' milk seems therefore to be between 0.01 and 0.1. Assuming that the consumption of cows' milk by lactating women is high (0.8 L d^{-1}, see **Chapter 6**) and that the consumption of cows' milk contaminated by ^{131}I represented the bulk of the activity intake of ^{131}I by women after the Chernobyl accident, the value of the transfer coefficient $f_{m,mt}$ is estimated from those measurements to be in the range from 0.01 to 0.1 d L^{-1}, This range is lower than the range of values presented in *Table 4.8*. A lower assumed milk consumption would increase the post-Chernobyl estimates of $f_{m,mt}$.

Figure 4.15. Distribution of the feed-to-milk transfer coefficient for ^{131}I and for goats.

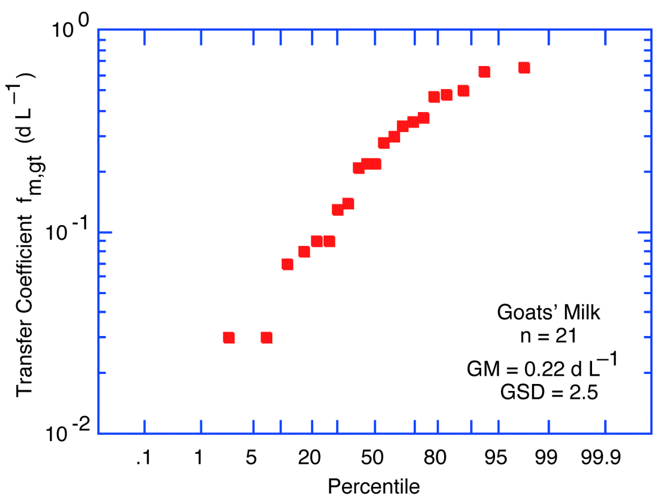


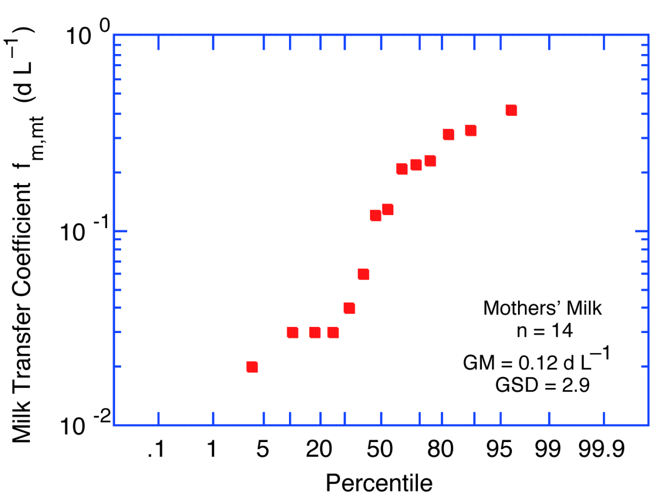
Table 4.7. Available data on the transfer of ^{131}I from diet to goats' milk.

Transfer coefficient $f_{m,gt}$ (d/L)	Fraction of intake trans-fered to milk	Milk pro-duction rate (L/d)	Number of goats	Comments	References
0.21	0.31		1	Value of $f_{m,gt}$ derived from an assumed milk production rate of 1.5 L/d.	Wright et al. 1955
0.30	0.45		1	Value of $f_{m,gt}$ derived from an assumed milk production rate of 1.5 L/d.	Wright et al. 1955
0.34	0.51		1	Value of $f_{m,gt}$ derived from an assumed milk production rate of 1.5 L/d.	Wright et al. 1955
0.35	0.53		1	Value of $f_{m,gt}$ derived from an assumed milk production rate of 1.5 L/d.	Wright et al. 1955
0.09	0.20	2.2	1	Single dose of ^{125}I.	Binnerts et al. 1962
0.03	0.06	2.2	1	Single dose of ^{125}I.	Binnerts et al. 1962
0.65				Average value for ^{131}I steady state; taken from unpublished data.	Comar 1963
0.28	0.45	1.6	14	Gelatine capsules containing ^{131}I fed twice daily for up to 25 days.	Lengemann and Wentworth 1966
0.09	0.14		4	Value of fm,gt derived from an assumed milk production rate of 1.5 L/d.	Cline et al. 1969
0.47	0.56	1.2	2	Twice daily doses of a ^{131}I iodine and ^{131}I iodate mixture given for 14 days.	Lengemann 1969
0.5			9	Daily oral administration of ^{131}I for 25 days.	Lengemann 1970
0.48	0.30	0.6	6	Daily doses of ^{131}I	Lengemann 1970
0.62	0.33	0.5	6	Daily doses of ^{131}I, in addition to 4 mg of stable iodine	Lengemann 1970
0.37			16	Daily doses of ^{131}I for 21 days	Lengemann 1970
0.03	0.08	2.3	1	Feeding for 8 days of alfalfa contaminated by ^{131}I released in gaseous form.	Black et al. 1976
0.07	0.16	2.4	1	Feeding for 8 days of alfalfa contaminated by ^{131}I released in gaseous form.	Black et al. 1976
0.13	0.19	1.5	1	Feeding for 8 days of alfalfa contaminated by ^{131}I released in gaseous form.	Black et al. 1976
0.22	0.29	1.3	1	Feeding for 8 days of alfalfa contaminated by ^{131}I released in gaseous form.	Black et al. 1976
0.08			12	Measurements in pasture and in milk in May (fresh pasture intake of 2.5 kg/d).	Bondietti and Garten 1984
0.22			12	Measurements in pasture and in milk in July (fresh pasture intake of 2.5 kg/d).	Bondietti and Garten 1984
0.14		0.25-1.4	12	Measurements in pasture and in milk in September (fresh pasture intake of 2.5 kg/d).	Bondietti and Garten 1984

Table 4.8. Available data on the transfer of ^{131}I into the milk of lactating women.

Number of lactating women	Chemical form of administered ^{131}I	Rate of milk production (L d^{-1})	Transfer coefficient $f_{m,mt}$ (d L^{-1})	Comments	References
6	Not indicated			Euthyroid patients	Weaver et al. 1960
(Case 1)		0.63	0.42		
(Case 2)		0.11	0.13		
(Case 3)		0.12	0.33		
(Case 4)		0.006	0.23		
(Case 5)		0.009	0.03		
(Case 6)		0.20	0.31		
7	Macroaggregated human serum albumin (MAA)		0.03	Patients subjected to lung scanning. Thyroid blocked with KI.	Karjalainen et al. 1971
25	Ortho-iodohippuric acid	0.27	0.03	Patients subjected to lung scanning. Thyroid blocked with KI.	Karjalainen et al. 1971
2					
(Case 1)	Macroaggregated human serum albumin (MAA)		0.12	Patient with pulmonary embolism.	Wyburn 1973
(Case 2)			0.02	Patient with suspected pulmonary embolus.	
1	Not indicated	0.22	0.21	Suspected case of thyroxicosis.	Miller and Weetch 1955
2	Carrier-free				Nurnberger and Lipscomb 1952
(Case 1)			0.06		
(Case 2)			0.04	Suspected case of thyrotoxicosis.	
(Case 2)			0.22	Same woman, 2 months later.	

Figure 4.16. Distribution of the diet-to-milk transfer coefficient for ^{131}I and for lactating women



4.1.5. Discussion

As indicated at the beginning of this Chapter, the time-integrated concentration of ^{131}I in fresh cows' milk, IMC_p, resulting from the consumption of ^{131}I-contaminated pasture in county, i, following deposition of ^{131}I on the ground on day, j, can be expressed as:

$$IMC_p\,(i, j) = \int_0^\infty C_p\,(i, j, t) \times PI\,(i, j, t) \times f_m \times dt \qquad (4.1)$$

Since the value of the intake-to-milk transfer coefficient for ^{131}I in cows, f_m, is assumed to be independent of the time of the year and of the location of the county in which the deposition took place, *equation 4.1* can be written:

$$IMC_p\,(i,j) = f_m \times \int_0^\infty C_p\,(i, j, t) \times PI\,(i, j, t) \times dt \qquad (4.29)$$

The integral represents the activity intake of ^{131}I by the cow, AI_p(i,j), (see *equation 4.23*), so that *equation 4.29* becomes:

$$IMC_p\,(i, j) = AI_p\,(i, j) \times f_m \qquad (4.30)$$

According to *equation 4.27*, $AI_p(i,j)$ can be expressed as the product of the daily pasture intake equivalent, PI*(i,j), and of the time-integrated concentration of ^{131}I in pasture, $IC_p(i,j)$. *Equation 4.30* can therefore be written:

$$IMC_p\,(i,\,j) = IC_p\,(i,j) \times PI^*\,(i,\,j) \times f_m \qquad (4.31)$$

The time-integrated concentration of ^{131}I in pasture, $IC_p(i,j)$, is, in turn, the product of: (a) the deposition density of ^{131}I, DG(i,j), (b) the mass interception factor, F*(i,j), and (c) the effective mean time of residence of ^{131}I on pasture grass, τ_e (see *equation 4.18*). Replacing $IC_p(i,j)$ by its value in *equation 4.31* yields:

$$IMC_p\,(i,\,j) = DG\,(i,\,j) \times F^*\,(i,\,j) \times \tau_e \times PI^*\,(i,\,j) \times f_m \qquad (4.32)$$

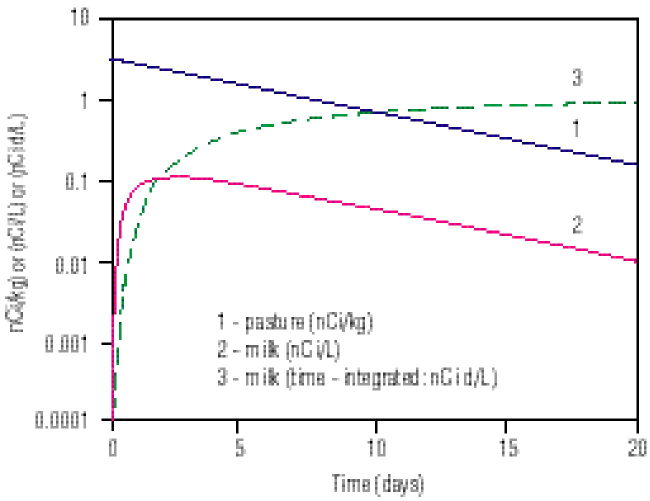
This equation was used to estimate the average time-integrated concentrations (until complete decay of ^{131}I) of ^{131}I in fresh cows' milk, $IMC_p(i,j)$, resulting from deposition, DG(i,j), of ^{131}I in county, i, on day, j. It is recalled that:

- DG(i,j) is expressed in nCi m^{-2} and is estimated, as indicated in **Chapter 3**, for each nuclear test under consideration for each county, i, of the contiguous United States and for a number of days, j, following the explosion,
- F*(i,j) is expressed in m^2 kg^{-1} (dry mass) and depends on the rainfall amount in county, i, on day, j, as well as on the distance of the county centroid from the NTS,
- τ_e is assumed to have an average value (geometric mean) of 6.4 days and to be log-normally distributed with a GSD of 1.3,
- PI*(i,j) is expressed in kg (dry mass) d^{-1} and is estimated as indicated in **Section 4.1.3** for each day of the year and for each county of the contiguous United States,
- f_m is assumed to have an average value (geometric mean) of 0.004 d L^{-1} and to be log-normally distributed with a GSD of 2.1,
- $IMC_p(i,j)$ is expressed in nCi d L^{-1}.

For a deposition density of 1 nCi m^{-2} during the pasture season, the average value of IMC_p varies from 0.003 to 1 nCi d L^{-1} according to the county and the day considered, using a range from 0.7 to 12 kg d^{-1} (**Appendix 3**) for the daily pasture intake equivalent and from 0.13 to 3.1 m^2 kg^{-1} (*Figure 4.7*) for the mass interception coefficient.

The variation with time of the concentration and of the time-integrated concentration of ^{131}I in milk corresponding to the maximum values given in the preceding paragraph are shown in *Figure 4.17*; for comparison purposes, the variation with time of the concentration of ^{131}I in pasture also is shown.

Figure 4.17. Variation with time of the average concentration (nCi/L) and of the time-intergrated concentration (nCi d/L) of ^{131}I in milk fresh from cows due to ingestion of contaminated pasture following a unit deposition of ^{131}I on the ground (1 nCi m^{-2}) for a daily pasture intake equivalent of 12 kg d^{-1} and a mass interception factor of 3.1 m^2 kg^{-1}. The variation with time of the ^{131}I concentration in pasture also is shown.



4.2. ESTIMATION OF THE ^{131}I CONCENTRATIONS IN FRESH COWS' MILK RESULTING FROM TRANSFER PROCESSES OTHER THAN THE CONSUMPTION OF ^{131}I CONTAMINATED PASTURE

Although the largest contribution to the ^{131}I concentrations in cows' milk is usually due to the pasture-cow-milk exposure route, there are other exposure routes by means of which cows can be exposed to ^{131}I, with consequent milk contamination (*Figure 4.18*):

- ingestion of ^{131}I contaminated soil,
- ingestion of vegetation contaminated with ^{131}I resuspended from soil,
- inhalation of ^{131}I in the air,
- ingestion of ^{131}I contaminated water, and
- ingestion of ^{131}I contaminated stored hay.

The respective contributions of these sources of ^{131}I contamination to the total ^{131}I concentration in milk will be compared to that of the ingestion of pasture for the conditions described below. With the exception of inhalation of ^{131}I in the air, these exposure routes are poorly known and difficult to quantify. Very crude assumptions have been made, which are likely to have resulted in overestimates, rather than underestimates, of the ^{131}I concentrations in milk.

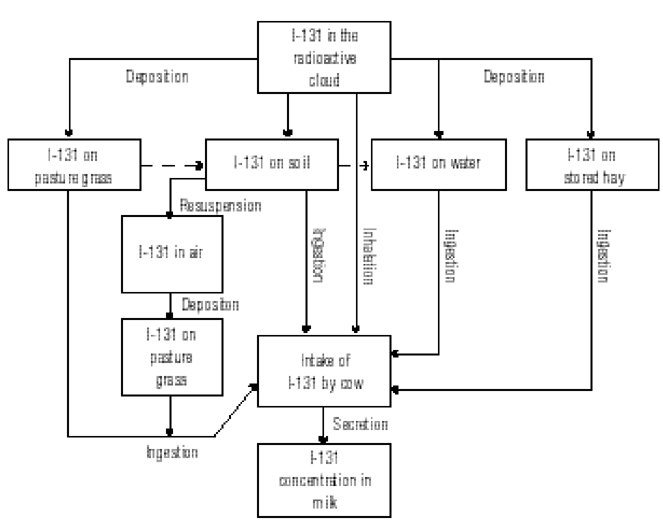
4.2.1. *Scenario Descriptions and General Assumptions*

For illustration purposes, eight scenarios 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), in an arid region. The factors considered are the amount 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	Daily rainfall amount (L m^{-2})	Distance from the NTS (km)	Presence of cows on pasture
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} per unit area of ground has occurred at time t = 0.

Figure 4.18. Exposure routes resulting in the contamination of cows' milk.



The values used for parameters common to several exposure routes, all of which were discussed earlier in this chapter, include:

- Y (standing crop biomass of pasture) = 0.3 kg (dry mass) m^{-2} (**Section 4.1.1.1.1**).
- PI* (daily pasture intake equivalent): PI* = 8 kg d^{-1} (dry mass) for deposition during the pasture season (scenarios 1, 3, 5, and 7), and PI* = 0.1 kg d^{-1} (dry mass) for deposition during the off-pasture season (scenarios 2, 4, 6, and 8). In all cases, the daily pasture intake is assumed to remain constant until the ^{131}I initially deposited on pasture decays to negligible levels (about 60 days), so that the daily pasture intake equivalent is numerically equal to the daily pasture intake during that period (**Section 4.1.3.5**).
- 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 λw = 0.069 d^{-1} (**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 6.4 d and to a rate constant λ_e of 0.156 d^{-1} (**Section 4.1.2**).
- f_m (feed-to-milk transfer coefficient for cows) = 4×10^{-3} d L^{-1} (**Section 4.1.4**).

4.2.2. *Milk Concentration Due to Ingestion of Pasture (reference conditions)*

Figure 4.19 illustrates the processes involved, which were discussed in detail in **Section 4.1**. The time-integrated concentrations due to the ingestion of pasture, IMC_p, for each of the eight scenarios, sc, are calculated using a modified version of *equation 4.32* (see *Section 4.1.5*):

$$IMC_p\,(sc) = DG \times F^*\,(sc) \times \tau_e \times PI^*\,(sc) \times f_m \qquad (4.33)$$

All parameter values have been determined in the preceding **Section 4.2.1**, with the exception of the mass interception factor, F*. The values of F* are estimated as indicated in **Sections 4.1.1.1.2** and **4.1.1.2**:

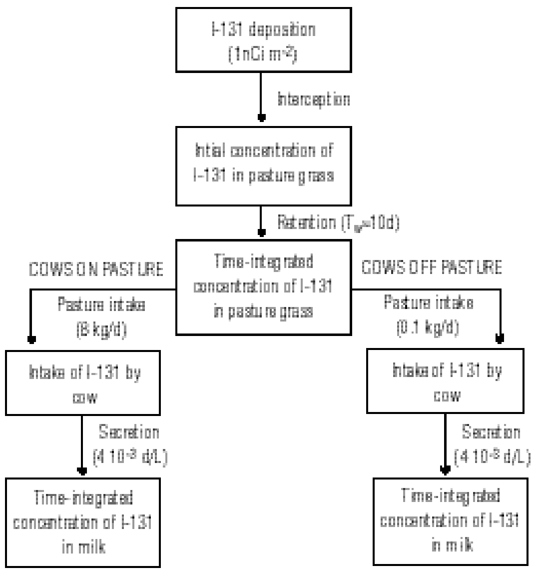
- in the absence of precipitation and for a distance from the NTS, X, equal to 3000 km (scenarios 1 and 2):

$$F^*_{dry} = \frac{(1-e^{-\alpha(X)Y})}{Y} \qquad (4.34)$$

with:

$$\alpha(X) = (7.0 \times 10^{-4}) \times (X^{1.13}) \qquad (4.35)$$

Figure 4.19. Deposition-pasture grass-cows' milk exposure route (reference conditions).



For distances from the NTS greater than 1,540 km, the value of α is constant and equal to 2.8 m^2 kg^{-1} (**Section 4.1.1.1.2**). For scenarios 1 through 6, with X=3,000 km, F^*_{dry} (sc) = 1.9 m^2 kg^{-1}.

- in the presence of light precipitation (R = 1 mm d^{-1}) and for a distance from the NTS, X, equal to 3,000 km (scenarios 3 and 4), we find from *equation 4.13* that:

$$F^*_{wet} = F^*_{dry}(3) + [3.1 - F_{dry}(3)] \times \frac{R}{2.5} \qquad (4.36)$$

Since F^*_{dry} (3) = F^*_{dry} (4) = 1.9 m^2 kg^{-1} and R = 1 mm d^{-1}, F^*_{wet} (3) = F^*_{wet} (4) = 2.4 m^2 kg^{-1}.

- in the presence of heavy precipitation (R = 100 mm d^{-1}) and for a distance from the NTS, X, equal to 3,000 km (scenarios 5 and 6), F^*_{wet} is computed using *equation 4.11*:

$$F^*_{wet} = 0.9 + \frac{11}{R} \qquad (4.37)$$

Since R = 100 mm d^{-1}, $F^*_{wet}(5)$ = $F^*_{wet}(6)$ = 1.0 m^2 kg^{-1}.

- in the absence of precipitation and for a distance from the NTS, X, equal to 100 km (scenarios 7 and 8), *equation 4.9* is used to compute F^*_{dry} :

$$F^*_{dry} = \frac{1 - e^{-\alpha(X)\,Y}}{Y} \qquad (4.38)$$

together with *equation 4.8*:

$$\alpha(X) = (7.0 \times 10^{-4}) \times (X^{1.13}) \qquad (4.39)$$

For X = 100 km, α = 0.13 m^2 kg^{-1}, and $F^*_{dry}(7)$ = $F^*_{dry}(8)$ = 0.13 m^2 kg^{-1}.

The values of F* (i.e., F^*_{dry} for scenarios 1,2,7, and 8, and F^*_{wet} for scenarios 3,4,5, and 6) are summarized below along with the values of the time-integrated concentrations of ^{131}I in pasture grass, IC_p(sc), and the values of the time-integrated concentrations of ^{131}I in milk, IMC_p(sc), obtained from *equation 4.33*, for each scenario, sc:

Scenario number, sc	F* (sc) (m^2 kg^{-1})	IC_p (sc) (nCi d kg^{-1})	IMC_p (sc) (nCi d L^{-1})
1	1.9	12	0.40
2	1.9	12	0.005
3	2.4	16	0.50
4	2.4	16	0.006
5	1.0	6.5	0.21
6	1.0	6.5	0.003
7	0.13	0.85	0.03
8	0.13	0.85	0.0003

In the table above, the time-integrated concentrations of ^{131}I in pasture grass, IC_p(sc), are derived from *equation 4.22* and estimated as:

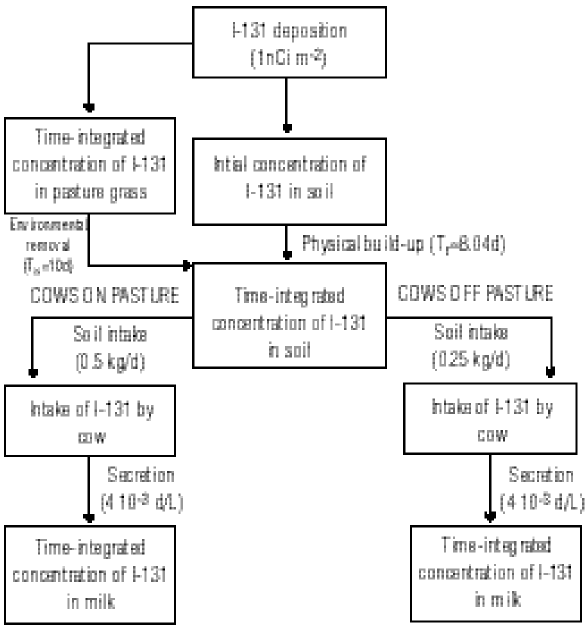
$$IC_p(sc) = DG \times F^*(sc) \times \tau_e \qquad (4.40)$$

4.2.3. *Milk Concentration Due to Ingestion of Soil*

Cows on pasture ingest a certain amount of soil that can be contaminated with ^{131}I. Some of the ^{131}I taken in by the cow via this route is then secreted into milk. *Figure 4.20* illustrates the processes involved in this exposure route.

The daily consumption rate of soil, sl, consumed daily by dairy cows, $CR_{sl,c}$, depends on feeding practices as well as on the extent of vegetation cover. Only a few estimates of average values of $CR_{sl,c}$ have been reported (Gilbert et al. 1988a, 1988b; Mayland and Florence 1975; McKone and Ryan 1989; Simmonds and Linsley 1981; Small 1984; Whicker and Kirchner 1987). The estimates range from 0.1 to 0.72 kg d^{-1}. Results from a study conducted in Idaho indicated that the rate of soil consumption by cattle varied from about 0.1 to 0.72 kg d^{-1} with a median of 0.50 kg d^{-1} (Mayland and Florence 1975). It is assumed in this report that the average value of $CR_{s,c}$ is 0.5 kg d^{-1} during the pasture season and is half that value, or 0.25 kg d^{-1}, when cows are not on pasture.

Figure 4.20. Contamination of fresh cows' milk by ^{131}I resulting from the ingestion of soil.



The ways in which soil can be contaminated with ^{131}I are schematically presented in *Figure 4.2*, reproduced here for the reader's convenience. The activity of ^{131}I deposited per unit area of ground, DG, is distributed between the activity intercepted by vegetation, A_p, and the activity that is deposited on the soil, A_{sl}. At time of deposition (t=0), that sum is:

$$DG = A_p\,(sc, 0) + A_{sl}\,(sc, 0) \qquad (4.41)$$

As illustrated in *Figure 4.2*,

$$A_p\,(sc, 0) = DG \times F(sc) \qquad (4.42)$$

where

F(sc) is the fraction of the activity deposited per unit area of ground that is intercepted by vegetation in scenario, sc. Combining the two equations, one finds:

$$A_{sl}\,(sc, 0) = DG - A_p\,(sc, 0) = DG \times (1 - F\,(sc)) \qquad (4.43)$$

The value of F(sc) for a particular scenario is the product of the mass interception factor, F*(sc), tabulated above, and of the standing crop biomass, Y=0.3 kg m^{-2} (**Section 4.2.1**). The values of F(sc) and of A_{sl}(sc,0), from *equation 4.43*, are as follows:

Scenario number, sc	Daily rainfall	Distance from NTS (km)	Cows on pasture	F (sc) (dimension - less)	A_{sl}(sc,0) (nCi m^{-2})
1	none	3000	yes	0.57	0.43
2	none	3000	no	0.57	0.43
3	light	3000	yes	0.72	0.28
4	light	3000	no	0.72	0.28
5	heavy	3000	yes	0.30	0.70
6	heavy	3000	no	0.30	0.70
7	none	100	yes	0.04	0.96
8	none	100	no	0.04	0.96

The variation of A_{sl} with time, t, after deposition is obtained by solving the following differential equations, which represent the processes shown in *Figure 4.2:*

$$\frac{dA_{sl}\,(sc, t)}{dt} = +\lambda_w A_p\,(sc, t) - \lambda_r A_{sl}\,(sc, t) \qquad (4.44)$$

with:

$$\frac{dA_p\,(sc, t)}{dt} = -(\lambda_r + \lambda_w)\,A_p\,(sc,t) = -\lambda_e A_p\,(sc, t) \qquad (4.45)$$

Equation 4.44 reflects the fact that the activity on soil is increased by the activity removed from pasture by environmental processes but is depleted at the same time by the radioactive decay of ^{131}I. The activity on pasture (*equation 4.45*) decreases monotonically with time because of removal by environmental processes and by radioactive decay. It is to be noted that this approach ignores the amount of ^{131}I that is resuspended from soil into the atmosphere as a result of wind action, rainsplash, or re-volatilization, and any redeposition on pasture grass. The influence of resuspension on the ^{131}I concentration in milk is discussed in **Section 4.2.4**. The solution of *equation 4.44* is:

$$A_{sl}\,(sc, t) = A_{sl}\,(sc, 0)e^{-\lambda_r t} + A_p(sc, 0)\,(e^{-\lambda_r t} - e^{-\lambda_e t}) \qquad (4.46)$$

The time-integrated activity on soil per unit area of ground, IA_{sl}, is obtained by integrating the function in *equation 4.46*. For scenario, sc, the result is:

$$IA_{sl}\,(sc) = \int_0^\infty A_{sl}\,(sc, t)\,dt = \frac{1}{\lambda_r}\left(\frac{\lambda_w}{\lambda_e}\,A_p\,(sc, o) + A_{sl}\,(sc, 0)\right) \qquad (4.47)$$

Replacing A_p(sc,0) and A_{sl}(sc,0) by their values as a function of DG and F(sc) (*equations 4.42* and *4.43*) in *equation 4.47* yields:

$$IA_{sl}\,(sc) = \frac{DG}{\lambda_r}\left(1 - F\,(sc)\,\frac{\lambda_r}{\lambda_e}\right) \qquad (4.48)$$

In order to estimate the time-integrated concentrations of ^{131}I in soil, IC_{sl}, for each scenario, it is assumed that the activity deposited is uniformly distributed over a certain depth of soil, H_{sl}. Taking the soil density, U_{sl}, to be 1.5 x 10^3 kg (dry mass) m^{-3}, IC_{sl} (sc) is calculated using:

$$IC_{sl}\,(sc) = \frac{IA_{sl}\,(sc)}{H_{sl}\,(sc) \times U_{sl}} \qquad (4.49)$$

The depth of soil, H_{sl}, over which the activity is assumed to be uniformly distributed, depends on the weather conditions at the time of deposition. On the basis of measurements made after the Chernobyl accident (UNSCEAR 1988), the activity deposited with heavy rain ($R > 5$ mm d^{-1}) is taken to migrate down to 10 mm. Therefore, for scenarios 5 and 6, $H_{sl}(5) = H_{sl}(6) = 10^{-2}$ m. The activity deposited in the absence of precipitation, or with only traces of precipitation, is considered to remain in the upper millimeter of soil. This condition applies in scenarios 1, 2, 7 and 8 ($H_{sl}(1) = H_{sl}(2) = H_{sl}(7) = H_{sl}(8) = 10^{-3}$ m). For light rain ($R < 5$ mm d^{-1}), an intermediate value of 5 mm has been assumed and $H_{sl}(3) = H_{sl}(4) = 5 \times 10^{-3}$ m.

The time-integrated activities of ^{131}I in soil per unit area of ground, IA_{sl}, and the time-integrated concentrations in soil, IC_{sl}, obtained for each scenario from *equations 4.48* and *4.49*, respectively, are as follows:

Scenario number, sc	Daily rainfall	Distance from NTS (km)	Cows on pasture	IA_{sl}(sc) (nCi m^{-2})	IC_{sl}(sc) (nCi m^{-2})
1	none	3000	yes	7.8	5.2
2	none	3000	no	7.8	5.2
3	light	3000	yes	6.8	0.91
4	light	3000	no	6.8	0.91
5	heavy	3000	yes	9.6	0.64
6	heavy	3000	no	9.6	0.64
7	none	100	yes	11.4	7.6
8	none	100	no	11.4	7.6

Assuming that all the soil eaten by the cow is contaminated, the activity intake of the cow, AI_{sl}, is the product of the time-integrated concentration of ^{131}I in soil, IC_{sl}, and of the soil consumption rate, $CR_{sl,c}$. For a given scenario:

$$AI\,(sc) = IC_{sl}\,(sc) \times CR_{sl,\,c}\,(sc) \qquad (4.50)$$

As indicated at the beginning of this **Section (4.2.3.)**, it is assumed that the rates of soil consumption, $CR_{sl,c,}$ are 0.5 kg d^{-1} during the pasture season, and 0.25 kg d^{-1} during the off-pasture season.

The time-integrated concentration in milk due to soil consumption, IMC_{sl}, is the product of the activity intake of the cows, AI_{sl}, and of the intake-to-milk transfer coefficient for ^{131}I and for cows, f_m:

$$IMC_{sl}\,(sc) = AI_{sl}(sc) \times f_m \qquad (4.51)$$

The values of AI_{sl} and of IMC_{sl}, calculated from *equations 4.50* and *4.51*, are given below:

Scenario number, sc	Daily rainfall	Distance from NTS (km)	Cows on pasture	IA_{sl}(sc) (nCi)	IC_{sl}(sc) (nCi m^{-2})
1	none	3000	yes	2.6	0.01
2	none	3000	no	0.00	0.005
3	light	3000	yes	0.46	0.002
4	light	3000	no	0.00	0.0009
5	heavy	3000	yes	0.32	0.001
6	heavy	3000	no	0.00	0.0006
7	none	100	yes	3.80	0.02
8	none	100	no	0.00	0.008

The relationship between IMC_{sl}(sc) and DG, derived from *equations 4.48* to *4.51*, is:

$$IMC_{sl}\,(sc) = DG \times \frac{1}{\lambda_r \times H_{sl}\,(sc) \times U_s} \times \left(1 - F\,(sc) \times \frac{\lambda_r}{\lambda_e}\right) \times CR_{sl,c} \times f_m \qquad (4.52)$$

4.2.4. *^{131}I Concentration in Milk Due to Resuspension of Particles From Soil*

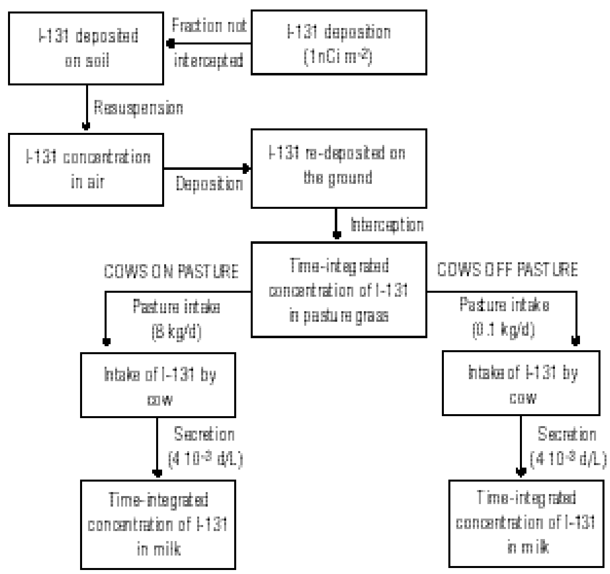
Pasture grass is contaminated to some extent by ^{131}I resuspended from soil into the atmosphere as a result of wind action, rainsplash, or re-volatilization (Amiro and Johnston 1989; Dreicer et al. 1984; Healy 1980). *Figure 4.21* illustrates the processes involved that lead to the contamination of cows' milk. Although this exposure route is conceptually different from the deposition-pasture grass-cows' milk route illustrated in *Figure 4.19*, in practice the ^{131}I concentrations measured in pasture grass reflect the combined effect of the two exposure routes because the value of the half-time of retention of ^{131}I on pasture grass, which was determined experimentally, incorporates the effect of resuspension from soil.

For illustrative purposes, the contribution from resuspension to the ^{131}I concentration in fresh cows' milk is assessed separately in this section and is shown to be quite small under most conditions. Resuspension from soil, however, is later ignored in the estimation of the time-integrated concentrations of ^{131}I in fresh cows' milk resulting from nuclear weapons testing at the NTS.

The evaluation of the resuspension from soil, carried out in this section for illustrative purposes, includes two parts:

- determination of the ^{131}I activity re-deposited per unit area of ground; and
- transfer of the redeposited activity to fresh cows' milk.

Figure 4.21. Contamination of fresh cows' milk by ^{131}I resulting from resuspension from soil.



4.2.4.1. Determination of the ^{131}I activity re-deposited per unit area of ground

The activity that is re-deposited per unit area of ground after resuspension from soil is derived from the time-integrated activity in soil per unit area of ground, IA_{sl}, by calculating first the time-integrated concentration in air due to resuspension, $IC_{air,rs}$, and then the activity re-deposited on the ground, DG_{rs}. It is assumed that wind action accounts for the resuspension from soil into the atmosphere and that the re-deposition occurs under dry conditions. The mechanisms that result in movement of particles deposited onto surfaces as an effect of wind action are: (a) surface creep (essentially, particles rolling across the surface; (b) saltation (akin to bouncing of particles whereby they become airborne for distances of the order of 10 m); and (c) true suspension (in which particles that were once deposited on the ground may become completely airborne and travel up to thousands of meters (Peterson 1983; Travis 1976)).

The time-integrated concentration in air due to resuspension, $IC_{air,rs}$, is obtained for a particular scenario using:

$$IC_{air,rs}(sc) = IA_{sl}(sc) \times RC \qquad (4.53)$$

where:

IA_{sl} = time-integrated fallout activity on soil per unit area of ground, in nCi d m^{-2} (*equation 4.48*)

RC = resuspension coefficient, in m^{-1}

The resuspension coefficient is an empirical quantity that relates the activity deposited on soil per unit area of ground and the concentration in ground-level air. The resuspension coefficient varies according to age of deposit, nature of the surface onto which the activity is deposited, and meteorological conditions (Anspaugh et al. 1974; Healy 1980; Phelps and Anspaugh 1974). Values for the resuspension coefficient are poorly established; they range from 10^{-13} to 10^{-2} m^{-1} and are in the higher part of the range for fresh deposits (Gilbert et al. 1988b; Hawley 1966; Mishima 1964; Peterson 1983; Shinn et al. 1985; Shinn et al. 1986; Stewart 1964). In experiments conducted at the Nevada Test Site, concentrations in air of particles moving in suspension were observed to decrease with half-times of 35-80 d following the nuclear cratering test Schooner and the venting of the underground test Baneberry (Anspaugh et al. 1973). This decrease is believed to be due to weathering and migration of surface deposits deeper into the soil, which reduces the fraction of the activity deposited that is subject to resuspension.

Recommended values for the resuspension coefficient for fresh deposits are 10^{-4} m^{-1} for desert environments (Anspaugh et al. 1974) and 10^{-6} m^{-1} for well-vegetated soils (Linsley 1979).

The ^{131}I activities that are re-deposited per unit area of ground after resuspension, DG_{rs}, are estimated as:

$$DG_{rs}(sc) = IC_{air,rs}(sc) \times v_{g,rs} \qquad (4.54)$$

where

$v_{g,rs}$ = deposition velocity for particles associated with ^{131}I after resuspension, in m d^{-1}.

The deposition velocity is an empirical quantity that relates the time-integrated concentration in ground-level air and the activity deposited per unit area of ground. The deposition velocity depends upon the physical and chemical nature of ^{131}I in ground-level air, on the type of surface, and on environmental conditions. The manner in which the deposition velocity of ^{131}I in the radioactive cloud formed after a test is estimated to vary according to distance from the NTS is presented in **Section A7.4.1** of **Appendix 7**. For ^{131}I attached to particles, the deposition velocity increases with particle size.

The size of the particles associated with resuspended ^{131}I is assumed to be the same for all scenarios and to be independent of the size of the particles that were deposited initially. The value of $v_{g,rs}$ is thus assumed to be the same for all scenarios. A representative size of the particles re-suspended from soil is considered to be intermediate between the size of particles associated with ^{131}I in the radioactive cloud near the NTS (100 km) and far away from the NTS (3000 km). The numerical value of vg,rs is taken to be the geometric mean of the values selected in **Section A7.4.1.4** of **Appendix 7** for those two distances:

$$v_{g,rs} = (4000 \times 1200)^{0.5} = 2000 \text{ m d}^{-1}$$

The values of $DG_{rs}(sc)$, for each scenario, are computed using *equations 4.53* and *4.54* and the values of $IA_{sl}(sc)$ that were tabulated in **Section 4.2.3**. The values are shown below:

Scenario number, sc	Daily rainfall	Distance from NTS (km)	Cows on pasture	DG_{re} (sc) (nCi m^{-2})
1	none	3000	yes	0.16
2	none	3000	no	0.16
3	light	3000	yes	0.14
4	light	3000	no	0.14
5	heavy	3000	yes	0.19
6	heavy	3000	no	0.19
7	none	100	yes	0.23
8	none	100	no	0.23

The estimated activities re-deposited per unit area of ground after resuspension from soil are substantially less than the activities initially deposited (1 nCi m^{-2}).

4.2.4.2. Transfer of the re-deposited activity to fresh cows' milk

Only the most important exposure route (the deposition-pasture grass-cow-milk exposure route) is considered in the transfer of redeposited ^{131}l to fresh cows' milk. The resulting time-integrated concentration of ^{131}I in fresh cows' milk is estimated using the approach discussed in **Section 4.2.2.** For this pathway, *equation 4.33* is revised to consider the redeposited activity, $Dg_{rs}(sc)$:

$$IMC_{rs}(sc) = DG_{rs}(sc) \times F^*_{rs} \times \tau_e \times PI^*(sc) \times f_m \qquad (4.55)$$

Here F^*_{rs} represents the mass interception factor in the absence of precipitation for resuspended particles. The value of F^*_{rs} is determined in the same way as that of $v_{g,rs}$, namely, by taking it to be the geometric mean of the values selected in **Section A7.4.3.1** of **Appendix 7** for the deposition of ^{131}I in particulate form in the radioactive cloud close-in (100 km) and far away (3,000 km) from the NTS. The values selected in **Section A7.4.3.1** are 0.13 and 1.9 $m^2\ kg^{-1}$(dry); the geometric mean is 0.05 $m^2\ kg^{-1}$(dry).

The values of $IMC_{rs}(sc)$, are calculated for each scenario using *equation 4.55*, the tabled values of $DG_{rs}(sc)$ above, and values of the other parameters found in the list of general assumptions for the analysis (**Section 4.2.1**).

Scenario number, sc	IMC_{rs}(sc) (nCi d L^{-1})
1	0.02
2	0.0002
3	0.01
4	0.0002
5	0.02
6	0.0002
7	0.02
8	0.0003

The relationship between $IMC_{rs}(sc)$ and DG, derived from *equations 4.48* and *4.53* to *4.55*, is:

$$IMC_{rs}(sc) = DG \times \frac{1}{\lambda_r} \times \left(1 - F(sc) \times \frac{\lambda_r}{\lambda_e}\right) \times RC \times V_{g,rs} \times F^*_{rs} \times \tau_e \times PI^* \times f_m \qquad (4.56)$$

For scenarios 7 and 8, the estimated milk concentrations are comparable to those in the reference calculations (**Section 4.2.2**). However, as indicated in the first paragraph of **Section 4.2.4**, the values of $IMC_{rs}(sc)$ are not used in the estimation of the ^{131}I concentrations in fresh cows' milk, because the effect of resuspension from soil is implicitly taken into account in the determination of the half-time of retention of ^{131}I on pasture grass.

4.2.5. ^{131}I Concentration in Milk Due to Inhalation of ^{131}I

During the passage of the radioactive cloud that results in the deposition of ^{131}I on the ground, cows are subject to inhalation of ^{131}I. *Figure 4.22* shows the processes involved in that exposure route.

The time-integrated concentration of ^{131}I in ground-level air, IC_{air}, that corresponds to a deposition on the ground of 1 nCi 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 affect substantially the dose estimates. The equations used to relate the time-integrated concentrations of ^{131}I in ground-level air and the depositions per unit area of ground are also presented in **Appendix 7**, along with the selection of the parameter values.

The time-integrated concentration of ^{131}I in ground-level air, IC_{air}, corresponding to deposition via dry processes, is estimated using:

$$IC_{air}(sc) = \frac{DG_{dry}}{v_g(sc)} \qquad (4.57)$$

where:

DG_{dry} is the activity of ^{131}I per unit area of ground deposited via dry processes, in nCi m d-2, and

$v_g(sc)$ in m d^{-1}, is the dry deposition velocity for ^{131}I in particulate form appropriate for the scenario, sc.

The variation of v_g as a function of the distance, X, in km, from the NTS is estimated (**Appendix 7**) using:

$$v_g(x) = 20150 \times X^{-0.35} \qquad (4.58)$$

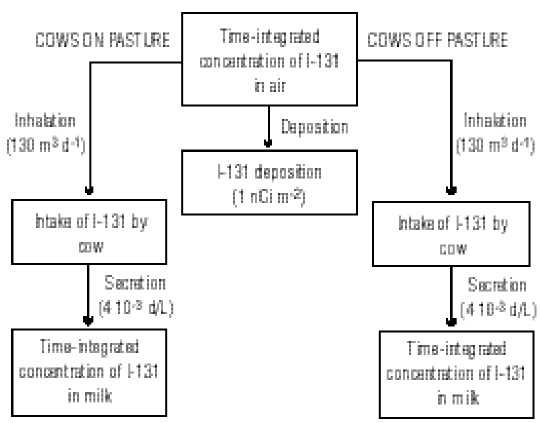
For X = 3,000 km (scenarios 1 to 6), v_g = 1,200 m d^{-1}, while for X = 100 km (scenarios 7 and 8), v_g = 4,000 m d^{-1}.

When precipitation occurs, scavenging of the airborne particles by rainfall adds to the activity deposited by dry processes. The ^{131}I activity deposited via wet processes, DG_{wet}, is proportional to the ^{131}I time-integrated concentrations in rain,

IC_{rain} in nCi d kg^{-1}, and to the daily rainfall. A rainfall amount of 1 mm d^{-1} onto 1 m^2 of ground results in the transfer of 1 kg of water to that area. Here the rainfall rate is expressed in those units (kg m^{-2} d^{-1}):

$$DG_{wet} = IC_{rain} \times R \tag{4.59}$$

Figure 4.22. Contamination of fresh cows' milk by ^{131}I resulting from inhalation.



The time-integrated concentrations of ^{131}I in rain and in air at ground level are related by:

$$IC_{rain} = \frac{IC_{air}}{AD} \times WR\ (X, R) \tag{4.60}$$

where:

AD is the average density of air at ground level (1.2 kg m^{-3}), so that IC_{air}/AD represents the time-integrated concentration of ^{131}I in ground-level air expressed in nCi d kg^{-1}, and

WR is the washout ratio, which is the ratio of the time-integrated concentrations of ^{131}I in rain and in ground-level air.

The washout ratio, WR, depends not only on the daily rainfall, but also, more generally, on the characteristics of the rainfall cloud and of the radioactive cloud as well as on the extent to which the two clouds interact, according to processes that are not well quantified. The values of WR are therefore extremely uncertain. In **Appendix 7**, they are calculated as a function of the daily rainfall, R, and of the distance from the NTS, X, using:

$$WR\ (X, R) = 13000 \times R^{-0.7} \times \left(\frac{X}{100}\right)^{-0.43} \tag{4.61}$$

It is worth noting that the washout ratio is dimensionless but it has a different value according to whether the time-integrated concentrations are expressed per unit mass or per unit volume. The values calculated using *equation 4.61* correspond to time-integrated concentrations expressed in terms of unit mass (nCi d kg^{-1}). It is for that reason that IC_{air} is divided by the air density in *equation 4.60*.

Combining *equations 4.59* and *4.60* yields:

$$DG_{wet}\ (sc) = \frac{IC_{air}\ (sc) \times R\ (sc) \times WR\ (sc)}{AD} \tag{4.62}$$

From *equations 4.57* and *4.59*, the relationship for the total deposition (DG_{dry} + DG_{wet}) can be written:

$$DG\ (sc) = IC_{air}\ (sc) \times v_g\ (sc) + \frac{IC_{air}\ (sc) \times R\ (sc) \times WR\ (sc)}{AD} \tag{4.63}$$

For the unit deposition of DG = 1 nCi m^{-2} considered in each scenario, the time-integrated concentrations in air, $IC_{air}(sc)$, can be obtained by rearranging *equation 4.63* to yield:

$$IC_{air}\ (sc) = \frac{DG}{v_g\ (sc) + \frac{R\ (sc) \times WR\ (sc)}{AD}} \tag{4.64}$$

It is assumed that the time-integrated concentrations of ^{131}I in air are the same outdoors and indoors. This implies that the stables in which the cows are kept when they were not on pasture were drafty enough that they did not provide substantial filtration of incoming air.

The values of v_g, WR, and R used to compute $IC_{air}(sc)$ for each scenario are given below, together with the results:

Scenario number, sc	V_g (sc) (m d^{-1})	R (sc) (kg m^2 d^{-1})	WR (sc) (kg kg^{-1})	IC_{air} (sc) (nCi d m^{-3})
1	1200	0	0.0	.0004
2	1200	0	0.0	.0004
3	1200	1	3000	.0001
4	1200	1	3000	.0001
5	1200	100	120	.00005
6	1200	100	120	.00005
7	4000	0	0.0	.0001
8	4000	0	0.0	.0001

The time-integrated concentrations of ^{131}I in milk due to inhalation of ^{131}I by the cow, IMC_{inh}, are obtained from the relationship:

$$IMC_{inh}\ (sc) = IC_{air}\ (sc) \times BR_c \times f_m \qquad (4.65)$$

where:

BR is the average breathing rate of the cow, taken to be 90 L min^{-1}, or 130 m^3 d^{-1} (Comar 1966)

f_m is the average intake-to-milk transfer coefficient for ^{131}I in cows, (4 x 10^{-3} d L^{-1}) assumed to be the same for inhalation and for ingestion

The numerical values of the time-integrated concentrations of ^{131}I in milk due to inhalation by the cow are obtained from the values of IC_{air}(sc) tabulated above and the stated values of BR_c and f_m using *equation 4.65*.

Scenario number, sc	Daily rainfall	Distance from NTS (km)	Cows on pasture	IMC_{inh} (sc) (nCi d L^{-1})
1	none	3000	yes	0.0004
2	none	3000	no	0.0004
3	light	3000	yes	0.0001
4	light	3000	no	0.0001
5	heavy	3000	yes	0.00005
6	heavy	3000	no	0.00005
7	none	100	yes	0.0001
8	none	100	no	0.0001

The relationship between IMC_{inh} and DG, derived from *equations 4.64* and *4.65*, is:

$$IMC_{inh}\ (sc) = \frac{DG}{v_g\ (sc) + \dfrac{R\ (sc) \times WR\ (sc)}{AD}} \times BR_c \times f_m \qquad (4.66)$$

4.2.6. ^{131}I Concentration in Milk Due to Ingestion of Water

Water drunk by cows can be contaminated with ^{131}I as a result of deposition on the water surface, of run-off of the activity deposited on soil, or of transfer from other materials. *Figure 4.23* illustrates the exposure route leading to the contamination of milk. The time-integrated milk concentration of ^{131}I due to ingestion of ^{131}I-contaminated water, IMC_w, (nCi d L^{-1}) is very much site specific as the time-integrated concentration of ^{131}I in water, IC_w, (nCi d L^{-1}) depends critically on the size of the body of water and on its watershed, among other factors. The values of IMC_w are estimated as:

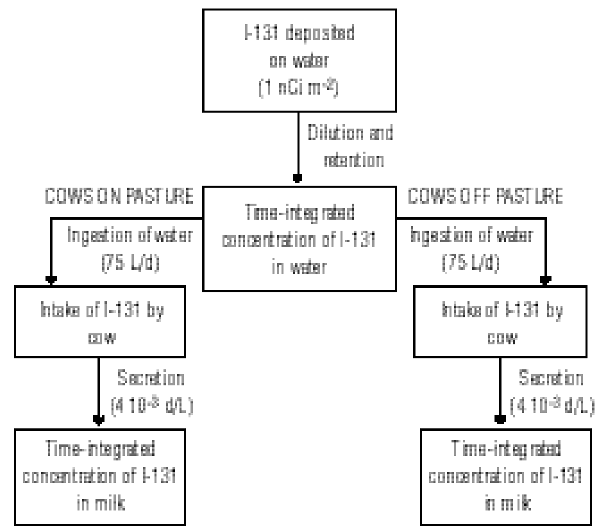
$$IMC_w = IC_w \times CR_{w,c} \times f_m \qquad (4.67)$$

where

$CR_{w,c}$ is the daily rate of water consumption by the cow, in L d^{-1}.

A rough and conservative estimate of IC_w is made in the case of a shallow pond, assumed to be contaminated by direct deposition (no run-off). If the average depth of the pond, H_w, is assumed to be 0.5 m, the ^{131}I concentration in the water, C_w, can be calculated as:

Figure 4.23. Contamination of fresh cows' milk by ^{131}I resulting from ingestion of water.



$$C_w = k_1 \times \frac{DG}{H_w} = 0.002\ nCi\ L^{-1} \qquad (4.68)$$

where

$k_1 = 10^{-3}$ m^3 L^{-1} is a unit conversion factor.

Assuming that the ^{131}I concentration in the pond decreases only by radioactive decay, the time-integrated concentration of ^{131}I in water, IC_w, is:

$$IC_w = \frac{C_w}{\lambda_r} = 0.023\ nCi\ d\ L^{-1} \qquad (4.69)$$

The time-integrated concentration of ^{131}I in water, IC_w, is thus estimated to be about 0.2% to 3% of the time-integrated concentration in pasture grass, IC_p, depending on the scenario considered (see **Section 4.2.2**). The only known experiment in which time-integrated concentrations of ^{131}I in both water and pasture grass could be derived from long-term measurements of fallout is that of Barth et al. (1969). Following the Pin Stripe event, Barth et al. (1969) monitored the ^{131}I concentrations in grain, water, hay, green chop, and field forage on two farms in Nevada. The ratios of the time-integrated concentration of ^{131}I in water and in green chop were found to be 0.6 - 0.7%, in good agreement with the ratios obtained in the eight scenarios. It should be noted that Barth et al. (1969) attributed the ^{131}I concentration in water to resuspension or to contamination by ^{131}I contained in the cow's saliva or food.

The rate of water consumption by the cow, $CR_{w,c}$, is 50-100 L d^{-1} (Comar 1966). An average figure of 75 L d^{-1} is used here. Assuming that the same source of water is used whether the cows are on or off pasture, the time-integrated concentrations of ^{131}I in milk due to ingestion of water, IMC_w, are estimated to be the same for all eight scenarios. Using the central value of $CR_{w,c}$, the result from *equation 4.69*, and, as before, the value of f_m =4 x10^{-3} d L^{-1}, *equation 4.67* predicts IMC_w =0.007 nCi d L^{-1} for all scenarios.

The relationship between IMC_w and DG, derived from *equations 4.67* to *4.69*, is:

$$IMC_w = DG \times \frac{k_1}{H_w \lambda_r} \times CR_{w,c} \times f_m \qquad (4.70)$$

4.2.7. ^{131}I Concentration in Milk Due to the Ingestion of ^{131}I Contaminated Stored Hay

Stored hay may be contaminated by direct or indirect deposition of ^{131}I and its consumption by cows off pasture will lead to the contamination of milk *(Figure 4.24)* by the same process described previously. The time-integrated concentration of ^{131}I in milk is the product of the intake of activity and the milk transfer coefficient. The time-integrated concentration of ^{131}I in milk, IMC_{hay}(sc) (nCi d L^{-1}) due to consumption of contaminated stored hay is obtained using:

$$IMC_{hay}\,(sc) = IC_{hay}\,(sc) \times CR_{hay,c}\,(sc) \times f_m \qquad (4.71)$$

where:

IC_{hay} is the time-integrated concentration of ^{131}I in stored hay, in nCi d kg^{-1}, and

$CR_{hay,c}$ is the daily rate of intake of stored hay by the cow, in kg d^{-1}.

It is very difficult to estimate with accuracy the contamination of milk resulting from this exposure route because the concentration of ^{131}I in hay is very sensitive to the conditions of storage.

Information on the contamination of stored hay may be derived from an experiment conducted in December 1961 in Oregon in which ten lactating cows were divided into two herds: one sheltered and one placed on pasture (Kahn et al. 1962). The sheltered cows, eating stored feed, gave milk containing no detectable ^{131}I (at or below the detection limit of 20 pCi L^{-1}) while levels in milk from cows on pasture were as high as 270 pCi L^{-1}. Assuming that: (a) the actual concentration in milk from sheltered cows was half the detection limit, that is 10 pCi L^{-1}, (b) the daily intake of hay by sheltered cows was equal to that of pasture grass for the cows on pasture in terms of dry weight, (c) the mean time of retention of ^{131}I in stored hay the same as that on pasture grass, and (d) there was no other source of contamination in the feed other than stored hay for the sheltered cows and pasture grass for the cows on pasture, the ratio,

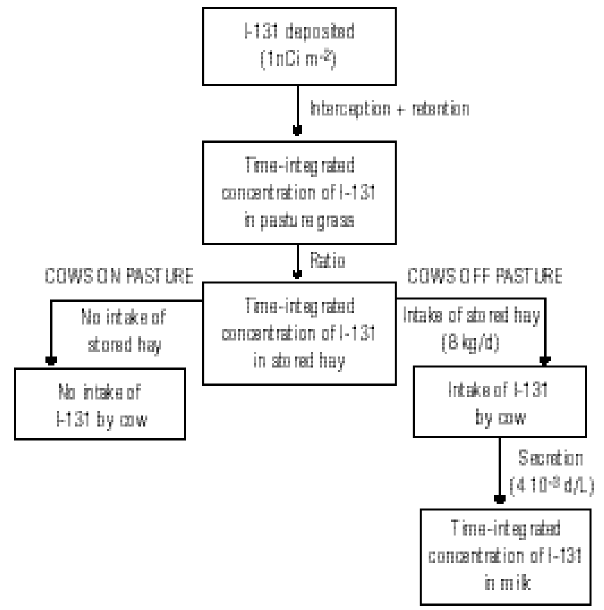


Figure 4.24. Contamination of fresh cows' milk by ^{131}I resulting from ingestion of stored hay.

PR_{hay}, of the time-integrated concentrations of ^{131}I in stored hay (IC_{hay}, nCi d kg^{-1}) and in pasture grass (IC_p, nCi d kg^{-1}) is:

$$PR_{hay} = \frac{IC_{hay}}{IC_p} = \frac{10}{270} = 0.04 \qquad (4.72)$$

The measurements conducted by Barth et al. (1969) in 2 farms in Nevada following the Pin Stripe event resulted in time-integrated concentrations of ^{131}I in hay of about 9% of those in green chop. However, the hay samples were collected in the feed manger and some of the ^{131}I activity in hay was probably due to resuspension or cross-contamination because of some of the ^{131}I contamination of the feed manger by green chop. The ratio of 0.09 for PR_{hay} obtained from the measurements of Barth et al. (1969) is thus an overestimate.

Using the ratio PR_{hay} = 0.04 derived from the experiment of Kahn et al. (1962) and the time-integrated concentrations in pasture, IC_p (sc), obtained for the reference conditions (**Section 4.2.2**), the following values are obtained for the time-integrated concentrations of ^{131}I in stored hay, IC_{hay}(sc) (*equation 4.72*):

Scenario number, sc	Daily rainfall	Distance from NTS (km)	Cows on pasture	IC_{hay} (sc) (nCi d L^{-1})
1	none	3000	yes	0.5
2	none	3000	no	0.5
3	light	3000	yes	0.6
4	light	3000	no	0.6
5	heavy	3000	yes	0.3
6	heavy	3000	no	0.3
7	none	100	yes	0.03
8	none	100	no	0.03

The rate of consumption of stored hay, $CR_{hay,c}$(sc), is assumed to be equal to 8 kg (dry) d^{-1} when the cows are off pasture and to be equal to 0.1 kg d^{-1} when the cows are on pasture. Using *equation 4.71*, the time-integrated milk concentrations due to the ingestion of stored hay are:

Scenario number, sc	IMC_{hay}(sc) (nCi d L^{-1})
1	0.0002
2	0.02
3	0.0002
4	0.02
5	0.0001
6	0.008
7	0.00001
8	0.001

The relationship between IMC_{hay}(sc) and DG, derived from *equations 4.71, 4.72,* and *4.40* is:

$$IMC_{hay}\,(sc) = DG \times F^*\,(sc) \times \tau_e \times PR_{hay} \times CR_{hay,c} \times f_m \qquad (4.73)$$

4.2.8. Discussion

The estimated time-integrated concentrations of ^{131}I in milk resulting from the various exposure routes considered are summarized in *Table 4.9*. Exposure routes other than pasture consumption represent only about 2 to 4% of the total time-integrated concentration in milk when cows are on pasture far away from the NTS. Close to the NTS, however, exposure routes other than pasture consumption are estimated to be about as important as pasture consumption. When cows are off pasture, routes other than pasture consumption are the only contributions to the milk contamination, and the ^{131}I intakes are estimated to be about 10 times less than when cows are on pasture.

The time-integrated concentrations in milk obtained in the eight example scenarios are highly uncertain, but they show that, under the assumptions made, exposure routes other than pasture consumption should not be neglected. Milk contamination by ^{131}I for the routes other than pasture consumption 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 using equations presented in **Sections 4.2.3**, **4.2.5**, **4.2.6**, and **4.2.7.** Those equations were modified only to change the variable indices (i and j replacing sc in most cases) and to include the explicit form of the mass interception factor. Those equations, as revised, are summarized below. Definitions of individual variables are given in the sections referenced.

- for the contamination by ^{131}I resulting from the ingestion of soil, *equation 4.52* from **Section 4.2.3** becomes:

$$IMC_{sl}\,(i,j) = DG\,(i,j) \times \frac{1}{\lambda_r \times H_{sl}\,(i,j) \times U_{sl}} \times \left(1 - \frac{F^*\,(i,j) \times Y \times \lambda_r}{\lambda_e}\right) \times CR_{sl,c} \times f_m \qquad (4.74)$$

- for the contamination by ^{131}I resulting from inhalation, *equation 4.66* from **Section 4.2.5** becomes:

$$IMC_{inh}\,(i,j) = DG\,(i,j) \times \frac{1}{v_g\,(i) + \dfrac{R\,(i,j) \times WR\,(i,j)}{AD}} \times BR_c \times f_m \qquad (4.75)$$

- for the contamination by ^{131}I resulting from the ingestion of water, *equation 4.70* from **Section 4.2.6** becomes:

$$IMC_w\,(i,j) = DG\,(i,j) \times \frac{k_1}{H_w \times \lambda_r} \times CR_{w,c} \times f_m \qquad (4.76)$$

- for the contamination by ^{131}I resulting from the ingestion of stored hay, *equation 4.73* from **Section 4.2.7** becomes:

$$IMC_{hay}\,(i,j) = DG\,(i,J) \times F^*\,(i,j) \times \tau_e \times PR_{hay} \times CR_{hay,c} \times f_m \qquad (4.77)$$

The time-integrated concentration in milk resulting from these other exposure, oe, routes, besides pasture consumption, $IMC_{oe,}$ was estimated by adding the separate contributions:

$$\begin{aligned} IMC_{oe}\,(i,j) &= IMC_{sl}\,(i,j) + IMC_{inh}\,(i,j) + IMC_w\,(i,j) + IMC_{hay}\,(i,j) \\ &= DG\,(i,j) \times f_m \times TF_{oe}\,(i,j) \end{aligned} \qquad (4.78)$$

with:

$$\begin{aligned} TF_{oe}\,(i,j) = {} & \left(\frac{CR_{sl,c}}{\lambda_r \times H_{sl}\,(i,j) \times U_{sl}} \times \left(1 - \frac{F^*\,(i,j) \times Y \times \lambda_r}{\lambda_e}\right)\right) + \\ & \left(\frac{BR_c}{v_g + \dfrac{R\,(i,j) \times WR\,(i,j)}{AD}}\right) + \left(\frac{k_1}{H_w \times \lambda_r} \times CR_{w,c}\right) + \\ & (F^*\,(i,j) \times \tau_e \times PR_{hay} \times CR_{hay,c}) \end{aligned} \qquad (4.79)$$

The parameter TF_{oe}(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 cow. It is expressed in nCi per nCi m^{-2}.

The uncertainty attached to the values of TF_{oe}(i,j) is admittedly large and extremely difficult to quantify as some of

Table 4.9. Median time-integrated ^{131}I concentration in fresh cows' milk resulting from various exposure routes for a unit deposition density of ^{131}I (nCi d L^{-1} per nCi m^{-2}).

	Distance from the NTS : 3000km						Distance for the NTS: 100km	
	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
Other exposure routes:								
• 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

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 $TF_{oe}(i,j)$ derived from *equation 4.79* were assumed to represent the geometric means of log-normal distributions with GSDs of 4.

4.3. OVERALL CALCULATIONAL PROCEDURES

The average time-integrated ^{131}I concentrations in fresh cows' milk due to all routes of exposure, <IMC(i,j)>, have been estimated for each county, i, of the contiguous United States and for each day, j, of deposition following atmospheric nuclear tests at the NTS as the geometric means of the distributions resulting from the additions of the distributions of the time-integrated ^{131}I in fresh cows' milk from pasture consumption, $IMC_p(i,j)$, and from other exposure routes, $IMC_{oe}(i,j)$. Similar calculations have been made for the average time-integrated ^{131}I concentrations in fresh cows' milk in county, i, resulting from a given test, te, from a given test series, ts, and from all tests.

4.3.1. Time-Integrated ^{131}I Concentrations in Fresh Cows' Milk Resulting From ^{131}I Deposition on a Given Day

The time-integrated ^{131}I concentration in fresh cows' milk in county, i, due to all routes of exposure and resulting from ^{131}I deposition on a day, j, following an atmospheric nuclear test at the NTS is denoted as IMC(i,j) and can be expressed as:

$$IMC\,(i, j) = IMC_p\,(i, j) + IMC_{oe}\,(i, j) \qquad (4.80)$$

From *equation 4.32*, $IMC_p(i,j)$ is calculated as:

$$IMC_p\,(i, j) = DG\,(i, j) \times f_m \times F^*\,(i, j) \times \tau_e \times PI^*\,(i, j) = DG\,(i, j) \times f_m \times TF_{p,c}\,(i, j) \qquad (4.81)$$

where:

$TF_{p,c}(i,j)$ is the transfer coefficient from deposition of ^{131}I on the ground to the activity intake by the cow resulting from pasture consumption:

$$TF_{p,c}\,(i, j) = F^*\,(i, j) \times \tau_e \times PI^*\,(i, j) \qquad (4.82)$$

From *equation 4.78*, $IMC_{oe}(i,j)$ is calculated as:

$$IMC_{oe}\,(i, j) = DG\,(i, j) \times f_m \times TF_{oe,\,c}\,(i, j) \qquad (4.83)$$

From *equations 4.80, 4.82,* and *4.83,* the time-integrated ^{131}I concentrations in fresh cows' milk due to all routes of exposure, IMC(i,j), can be expressed as:

$$IMC\,(i, j) = DG\,(i, j) \times f_m \times [TF_{p,c}\,(i,j) + TF_{oe,c}\,(i, j)] = DG\,(i, j) \times f_m \times TF_c\,(i, j) \qquad (4.84)$$

where

$TF_c(i,j)$ is the transfer coefficient from deposition of ^{131}I on the ground on day, j, and county, i, to the activity intake by the cow resulting from all exposure routes. The distribution of $TF_c(i,j)$ is assumed to be log-normal for any values of j and i.

The median time-integrated ^{131}I concentrations in fresh cows' milk due to all routes of exposure, <IMC(i,j)>, are the products of the median depositions of ^{131}I per unit area of ground, <DG(i,j)>, of the median feed-to-milk transfer coefficient, $<f_m>$, and of the median transfer coefficients from deposition to activity intake by the cow, $<TF_c(i,j)>$:

$$< \mathrm{IMC}\ (i, j) > \ = \ < DG\ (i, j) > \ \times \ < f_m > \ \times \ < TF_c\ (i, j) > \qquad (4.85)$$

The values of <DG(i,j)> are estimated as indicated in **Chapter 3**, while the value of $<f_m>$ is taken to be 4 x 10^{-3} d L^{-1}. Since $TF_{p,c}(i,j)$, $TF_{oe,c}(i,j)$, and $TF_c(i,j)$ are assumed to be log-normally distributed, the values of $<TF_c(i,j)>$ can be derived from the arithmetic means and the standard deviations associated with the distributions of $TF_c(i,j)$, which are in turn inferred from the characteristics of the distributions of $TF_{p,c}(i,j)$ and of $TF_{oe,c}(i,j)$. The arithmetic means of $TF_c(i,j)$, denoted as $m(TF_c(i,j))$, are calculated as:

$$m(TF_c\ (i, j)) = e^{\mu(TF_{p,c}\ (i, j))\ +\ 0.5\,\sigma^2\ (TF_{p,c}\ (i, j))} + e^{\mu(TF_{oe,c}\ (i, j))\ +\ 0.5\,\sigma^2\ (TF_{oe,c}\ (i, j))} \qquad (4.86)$$

where:

$$\mu(TF_{p,c}\ (i, j)) = \ln\ (< TF_{p,c}\ (i, j) >) \qquad (4.87)$$

$$\mu(TF_{oe,c}\ (i, j)) = \ln\ (< TF_{oe,c}\ (i, j) >) \qquad (4.88)$$

$$\sigma(TF_{p,c}\ (i, j)) = \ln\ (\ GSD\ (< TF_{p,c}\ (i, j) >)) \qquad (4.89)$$

$$\sigma(TF_{oe,c}\ (i, j)) = \ln\ (\ GSD\ (< TF_{oe,c}\ (i, j) >)) \qquad (4.90)$$

while the variances of $TF_c(i,j)$, denoted as $s^2(TF_c(i,j))$, are:

$$s^2(TF_c\ (i, j)) = [e^{2\ \times\ \mu(TF_{p,c}\ (i, j))\ +\ \sigma^2\ (TF_{p,c}\ (i, j))} \times (e^{\sigma^2\ (TF_{p,c}\ (i, j))} - 1)] + [e^{2\ \times\ \mu(TF_{oe,c}\ (i, j))\ +\ \sigma^2\ (TF_{oe,c}\ (i, j))} \times (e^{\sigma^2 (TF_{oe,c}\ (i, j))} - 1)] \qquad (4.91)$$

It follows from the properties of log-normal distributions that the geometric means of $TF_c(i,j)$, denoted as $<TF_c(i,j)>$, are:

$$< TF_c\ (i, j) > \ = \ \frac{m(TF_c\ (i, j))}{\left(1 + \left(\dfrac{s\ (TF_c\ (i, j))}{m\ (TF_c\ (i, j))}\right)^2\right)^{0.5}} \qquad (4.92)$$

while the GSDs of $TF_c(i,j)$ are obtained as:

$$GSD\ (TFc\ (i, j)) = e^{\sigma\ (TFc\ (i, j))} \qquad (4.93)$$

with:

$$\sigma TF_c\ (i, j) = \left| \log_e\left(1 + \left(\frac{s\ (TF_c\ (i, j))}{m\ (TF_c\ (i, j))}\right)^2\right) \right|^{0.05} \qquad (4.94)$$

The average time-integrated ^{131}I concentration in fresh cows' milk due to all routes of exposure, <IMC(i,j)>, can then be calculated from *equation 4.85* while the GSD associated with IMC(i,j) is obtained as:

$$GSD\ (IMC\ (i, j)) \ = \ e^{[\sigma^2(DG\ (I, j))\ +\ \sigma^2\ (fm)\ +\ \sigma^2(Tc\ (i, j))]^{0.5}} \qquad (4.95)$$

Since the distribution of IMC(i,j) is log-normal, its arithmetic mean, m(IMC(i,j)), can be calculated as:

$$m(IMC\ (i, j)) = < \mathrm{IMC}\ (i, j) > \ \times\ e^{(0.5 \times \sigma^2\ (IMC\ (i, j))} \qquad (4.96)$$

and its variance, s^2(IMC(i,j)), as:

$$s^2\ (IMC\ (i, j) = < \mathrm{IMC}\ (i, j) >^{2} \times e^{(\sigma^2(\mathrm{IMC}(i, j))} \times (e^{(\sigma^2(\mathrm{IMC}\ (i, j)))} - 1) \qquad (4.97)$$

4.3.2. Time-integrated ^{131}I concentrations in fresh cows' milk resulting from ^{131}I deposition from a given test

The deposition of ^{131}I on the ground often occurred for several days following a given nuclear test. The time-integrated concentration of ^{131}I in fresh cows' milk in county, i, resulting from a given test, te, is obtained by adding the contributions from each day of deposition, j:

$$IMC\ (i, te) = \sum_{j=1}^{jj} IMC\ (i, j) \qquad (4.98)$$

where:

jj is the number of days of ^{131}I deposition in county, i, after test, te.

The median time-integrated concentration, <IMC(i,te)>, is the geometric mean of the distribution resulting from the addition of the distributions of IMC(i,j). In most cases, the value of IMC(i,te) is dominated by the contributions from the ^{131}I depositions on 1 or 2 days. The distribution of IMC(i,te) can be assumed to be log-normal and its geometric mean can be calculated as:

$$<IMC\ (i, te)> = \frac{\sum_{j=1}^{jj} m(IMC(i,j))}{\sqrt{\left(1 + \dfrac{\sum_{j=1}^{jj} s^2(IMC(i,j))}{\left(\sum_{j=1}^{jj} m(IMC(i,j))\right)^2}\right)}} \qquad (4.99)$$

where

m(IMC(i,j)) and s^2(IMC(i,j)) are the arithmetic mean and the variance of IMC(i,j) and are determined in *equations 4.97* and *4.98*, respectively.

Other parameters of the distribution of IMC(i,te) are:

- its geometric standard deviation, GSD(IMC(i,te)):

$$GSD\,(IMC\,(i,\,te)) = e^{\sigma(IMC\,(i,\,te))} \qquad (4.100)$$

with:

$$\sigma^2\,(IMC\,(i,\,te)) = \log_e\left(1 + \frac{\sum_{j=1}^{jj} s^2\,(IMC\,(i,\,j))}{(\sum_{j=1}^{jj} m\,\,(IMC(i,\,j))^2)}\right) \qquad (4.101)$$

- its arithmetic mean, m(IMC(i,te)) :

$$m(IMC\,(i,\,te)) = \,<IMC\,(i,\,te)>\,\times\,e^{0.5\times\sigma^2\,(IMC\,(i,\,te))} \qquad (4.102)$$

- its variance, s^2(IMC(i,te)):

$$s^2\,(IMC\,(i,\,te)) = \,<IMC\,(i,\,te)>^2\times e^{\sigma^2(IMC\,(i,\,te))}\times(e^{\sigma^2\,(IMC\,(i,\,te))}-1) \qquad (4.103)$$

4.3.3. Time-integrated ^{131}I concentrations in fresh cows' milk resulting from ^{131}I deposition from a given test series.

The time-integrated concentration of ^{131}I in fresh cows' milk in county, i, resulting from a given test series, ts, is obtained by adding the contributions from each test, te, in the series:

$$IMC\,(i,\,ts) = \sum_{te=1}^{nte} IMC\,(i,\,te) \qquad (4.104)$$

where nte is the number of tests in the series, ts.

The parameters of the distribution of IMC(i,ts) are obtained in the similar way as those of IMC(i,te), which were determined in **Section 4.3.2**:

$$<IMC\,(i,ts)> = \frac{\sum_{te=1}^{nte} m(IMC(i,\,te))}{\sqrt{\left(1 + \frac{\sum_{te=1}^{nte} s^2(IMC(i,\,te))}{(\sum_{te=1}^{nte} m(IMC(i,\,te))^2)}\right)}} \qquad (4.105)$$

where

m(IMC(i,te)) and s^2(IMC(i,te)) are the arithmetic mean and the standard deviation of IMC(i,te) and are determined in *equations 4.102* and *4.103,* respectively.

- geometric standard deviation, GSD(IMC(i,ts)):

$$GSD(IMC\,(i,\,te)) = e^{(\sigma(IMC(i,\,ts)))} \qquad (4.106)$$

with:

$$\sigma^2\,(IMC\,(i,\,ts)) = \log_e\left(1 + \frac{\sum_{te=1}^{nte} s^2\,(IMC\,(i,\,te))}{(\sum_{te=1}^{nte} m\,\,(IMC(i,te))^2)}\right) \qquad (4.107)$$

- arithmetic mean, m(IMC(i,ts)):

$$m(IMC(i,\,ts)) = \,<IMC\,(i,\,ts)>\,\times\,e^{0.5\times\sigma^2\,(IMC\,(i,\,ts))} \qquad (4.108)$$

- variance, s^2(IMC(i,ts)):

$$s^2\,(IMC\,(i,\,ts)) = \,<IMC\,(i,\,ts)>^2\times e^{\sigma^2(IMC\,(i,\,ts))}\times(e^{\sigma^2(IMC\,(i,\,ts))}-1) \qquad (4.109)$$

4.3.4. Time-integrated ^{131}I concentrations in fresh cows' milk resulting from ^{131}I deposition from all tests

The time-integrated concentration of ^{131}I in fresh cows' milk in county, i, resulting from all tests, is obtained by adding the contributions from each of the eight test series (Ranger, Buster-Jangle, Tumbler-Snapper, Upshot-Knothole, Teapot, Plumbbob, Hardtack, and Underground Era):

$$IMC\,(i) = \sum_{ts=1}^{8} IMC\,(i,\,ts) \qquad (4.110)$$

The parameters of the distribution of IMC(i) are obtained in the similar way as those of IMC(i,te), which were determined in **Section 4.3.2**:

- geometric mean, <IMC(i)>:

$$<IMC\,(i)> = \frac{\sum_{ts=1}^{8} m(IMC(i,\,ts))}{\sqrt{\left(1 + \frac{\sum_{ts=1}^{8} s^2(IMC(i,\,ts))}{(\sum_{ts=1}^{8} m(IMC(i,\,ts))^2)}\right)}} \qquad (4.111)$$

where

m(IMC(i,ts)) and s^2(IMC(i,ts)) are the arithmetic mean and the standard deviation of IMC(i,ts) and are determined in *equations 4.108* and *4.109,* respectively.

- geometric standard deviation, GSD(IMC(i)):

$$GSD\,(IMC\,(i)) = e^{\sigma(IMC\,(i))} \qquad (4.112)$$

with:

$$\sigma 2(IMC\,(i)) = \log_e\left(1 + \frac{\sum_{ts=1}^{8} s^2\,(IMC\,(i,\,ts))}{(\sum_{ts=1}^{8} m\,\,(IMC(i,\,ts))^2)}\right) \qquad (4.113)$$

• arithmetic mean, m(IMC(i)):

$$m(IMC\ (i)) = < IMC\ (i) > \times e^{0.5 \times \sigma^2\ (IMC(i))} \qquad (4.114)$$

• variance, s^2(IMC(i)):

$$s^2\ (IMC\ (i)) = \ < IMC\ (i) >^2 \times e^{\sigma 2(IMC\ (i))} \times (e^{\sigma^2(IMC\ (i))}\text{-}1) \qquad (4.115)$$

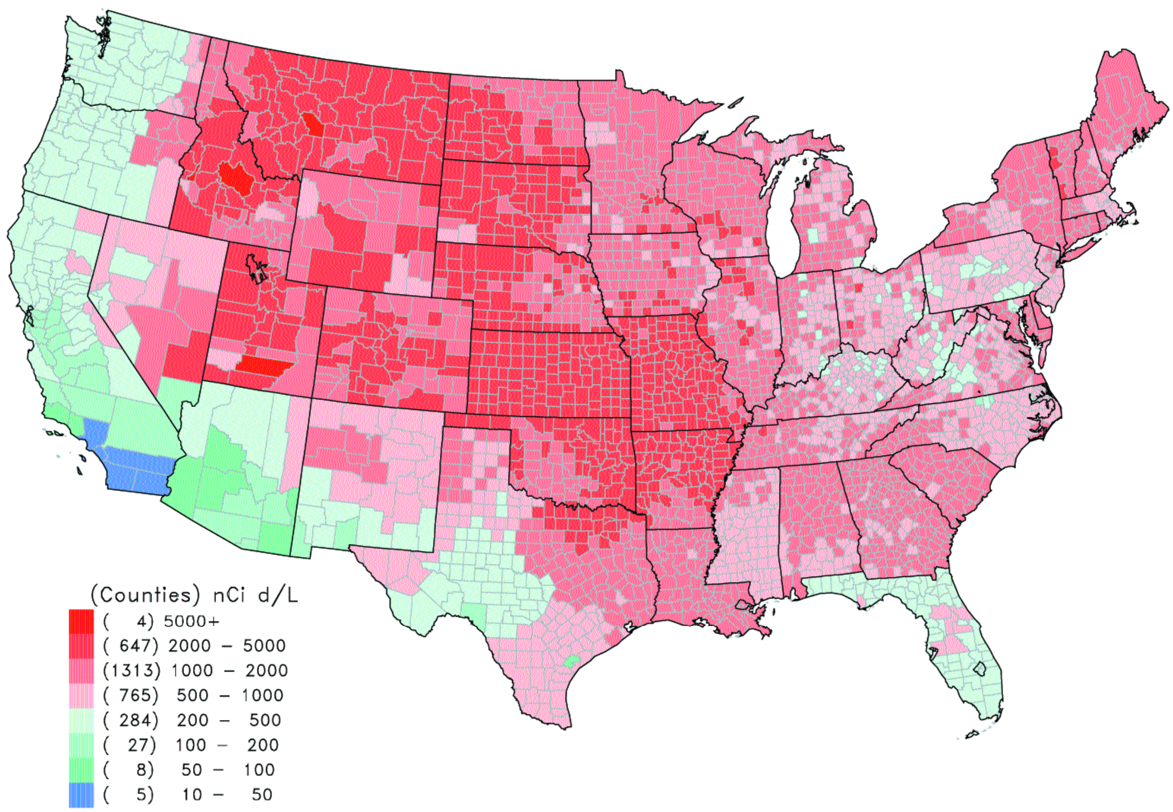
4.4. RESULTS

Figure 4.25 illustrates the spatial distribution over the contiguous United States of the county median estimates for each county of the time-integrated ^{131}I concentrations in fresh cows' milk from all tests, <IMC(i)>. Milk was contaminated with ^{131}I to some extent, at one time or another, in all counties of the contiguous U.S. as a result of the nuclear weapons tests conducted at the NTS. The averages of the total time-integrated concentrations of ^{131}I in fresh cows' milk are estimated to have been as low as 10-20 nCi d L^{-1} in a few counties in California and as high as about 5000 nCi d L^{-1} in several counties in Idaho. The pattern of the ^{131}I time-integrated concentrations in fresh cows' milk reflects by and large the pattern of ^{131}I depositions presented in **Chapter 3**.

The county averages of the time-integrated ^{131}I concentrations in fresh cows' milk, for each test (<IMC(i,te)>) and for each test series (<IMC(i,ts)>), are available in the Annexes (in tables denoted as ts/te/M, where ts is the abbreviation for the test series and te is the test number in the test series) along with the GSDs associated with their distributions. The GSDs vary according to the location of the county and to the time of the year, but are usually rather large, with typical values of 3 to 4.

The county averages of the time-integrated ^{131}I concentrations in fresh cows' milk, for each day of ^{131}I deposition following a given test (<IMC(i,te)>) are intermediate results that are not provided in this report because they are not directly used in the estimation of the thyroid doses.

Figure 4.25. Estimated time-integrated concentrations of ^{131}I in fresh cows' milk in all counties of the contiguous U.S. resulting from all tests conducted at the Nevada Test Site.



4.5. SUMMARY

- The transfer of ^{131}I from deposition on the ground to fresh cows' milk resulted from several environmental pathways, the most important of which was the pasture-cow-milk route.
- The major parameters involved in the pasture-cow-milk exposure route are the mass interception factor of ^{131}I by vegetation, the mean-time of retention of ^{131}I on vegetation, the amount of ^{131}I-contaminated pasture ingested by cows, and the transfer coefficient of ^{131}I from feed to milk for cows.
- The mass interception factor of ^{131}I by vegetation varies, in the absence of precipitation, as a function of the distance from the NTS because large particles, which are less abundant as one moves further away from the NTS, are not intercepted as efficiently by vegetation as are small particles. In the presence of precipitation, results of field experiments that were conducted specifically for this study show that vegetation intercepts water-soluble ^{131}I much less readily than it intercepts ^{131}I attached on particles.
- The mean time of retention of ^{131}I by vegetation is about 1 week. Results of experiments conducted specifically for this study confirmed the values published in the literature.
- The daily amount of pasture consumed by cows in the 1950s was estimated according to the region of the country and the time of the year. The country was divided into 71 separate pasture regions and daily pasture intakes were assigned on each pasture region for each week of the year.
- The transfer coefficient of ^{131}I from feed to milk for cows is found in the literature to range from 1 x 10^{-3} d L^{-1} to 4 x 10^{-2} d L^{-1}. Values pertaining to ^{131}I in fallout seem to be in the lower part of the range. An average value of 4 x 10^{-3} d L^{-1} has been used in the report.
- Milk from cows can be contaminated by pathways other than the deposition of ^{131}I fallout on pasture and subsequent ingestion of pasture by the cow. Milk from cows also can be contaminated by ingestion of ^{131}I-contaminated soil, of ^{131}I-contaminated water, of ^{131}I-contaminated stored hay, of vegetation contaminated with ^{131}I resuspended from soil, and by inhalation of ^{131}I in air. Altogether, these pathways are estimated to be about 10 times less important than is the pasture-cow-milk exposure route.
- Time-integrated ^{131}I concentrations in fresh cows' milk have been estimated for each test and for each county of the contiguous U.S. The pattern of ^{131}I concentrations in milk generally reflects the pattern of ^{131}I depositions. The uncertainties attached to the best estimates, expressed as geometric standard deviations, vary from county to county and from test to test, but are usually rather large, with typical values of about 3 to 4. The time-integrated ^{131}I concentrations in fresh cows' milk in the contiguous U.S., summed for all tests, are estimated to have been as low as 10-20 nCi d L^{-1} in California and as high as about 5000 nCi d L^{-1} in parts of Idaho.

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