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MASTERS THESIS

VARIATIONS IN ENVIRONMENTAL TRITIUM DOSES DUE TO METEOROLOGICAL DATA AVERAGING AND UNCERTAINTIES IN PATHWAY MODEL PARAMETERS

by

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ABSTRACT

The large amount of tritium produced at the Savannah River Site coupled with the commencement of a dose reconstruction study at the facility emphasize the importance of ensuring accurate and efficient prediction of tritium doses to the public. Presently, dose estimates at the site are calculated annually using a five year meteorological database. Determining whether detailed monthly dose estimates are necessary or whether annual averaged data is sufficient offers the potential for more efficient dose prediction. Although several uncertainties exist in the model parameters used to estimate off-site dose, a deterministic approach is often utilized for environmental dose estimates. Quantifying the uncertainties in model parameter values in order to predict a dose distribution will increase the realism of site environmental dose estimates. In the present study, off site collective doses and maximum individual doses due to atmospheric tritium releases to the terrestrial environment in one sector surrounding the Savannah River Site were calculated according to the methods outlined in the U.S. Nuclear Regulatory Commission's Regulatory Guide 1.109 and compared using monthly versus five year meteorological data and source terms. Additional site specific variables not included in current annual reports, such as seasonal human consumption, seasonal absolute humidity, and age dependent dose conversion factors were included. In addition, the range in the predicted doses, based on the distribution in model parameters given in the literature, were estimated. Finally, a sensitivity analysis was performed in order to decipher the influence of model parameters on dose estimates. In comparing monthly and annual averaged dose estimates, It was found that over a five year period, averaged meteorological data overestimates environmental doses by 2% to 6%, depending on the pathway of interest. Discrepancies existed between inhalation and ingestion doses due to the differential impact of departures from annual averaged air concentrations in monthly calculations. Results indicate that the primary contributor to infant tritium dose is the ingestion of milk, while for all other age groups, the most important pathway is the ingestion of vegetation. These relative pathway contributions remain constant throughout the year for infants; for children, teenagers, and adults, however, inhalation and absorption of tritium through the skin increases in relative importance in the months of June to September due to increased humidity values and decreasing vegetation concentrations. It was found that the model utilized was most sensitive to dose factors, the ratio of the specific activity of tritium oxide in vegetation to the specific activity of atmospheric tritium oxide, and breathing rates. Finally, the observation that adult and population mean doses in distribution predictions were higher than expected based on deterministic calculations confirmed the need to address uncertainties in modeling. Information gathered during this research has contributed assurance of radiological protection of the public and compliance with regulatory standards.

INTRODUCTION

The Savannah River Site (SRS) was constructed in 1952 for the production of plutonium and tritium. Operation of the site has resulted in the release of low- level radioactive materials to the atmosphere and waters. Dose assessments to off site populations have indicated that tritium is the most significant contributor to environmental dose. Further, atmospheric tritium release levels have consistently exceeded liquid tritium release levels (Murphy et al. 1990). Contrary to the results of reactor probabilistic studies, routine operation contributes an appreciable portion (~50%) of the risk posed by nonreactor tritium facilities, indicating that accurate dose assessments due to routine site operations are imperative (O'Kula et. al 1992). In addition, it is possible that tritium releases to the environment may increase due to the development of fusion technology for electrical power generation (Opkada and Momoshima 1993). For these reasons, it is imperative to predict tritium doses to the public accurately and efficiently.

Several uncertainties exist in the parameters used to model off site atmospheric tritium doses to populations in the vicinity of the Savannah River Site. Although a range of values is possible for each input parameter in a model, in many instances parameters are represented by a single quantity (or default value in the absence of site specific data) chosen through subjective judgment. The appropriateness of this single value is a function of the quality of the judgment (Hoffman and Miller 1983). Quantifying the uncertainties in parameter values and calculating a distribution of doses based on ranges of possible values will therefore increase the realism and objectiveness of Savannah River Site off site dose calculations. Often, sensitivity analysis may be utilized to specify the relative effect of changes in parameter values on model output (Hoffman and Miller 1983; Hamby, 1995).

Site specific parameters are especially imperative in estimating doses through the terrestrial food chain (Partanen and Savolainen 1986). For example, seasonal variations in production and consumption rates may lead to differences in dose estimates of up to a factor of 100 (Partanen and Savolainen 1986). Some model parameters are not modified to site-specific or seasonal values at the Savannah River Site. For example, although site methodology accounts for an area-specific absolute humidity value, seasonal humidity variations are not incorporated into the site model; however, it has been demonstrated that calculated air concentrations vary widely depending on the value of relative humidity utilized (Murphy 1984). At low environmental doses, the implications of model uncertainties are not expected to be significant. However, economic and political costs of parameter uncertainties may be profound if conservative models erroneously predict compliance or violation of the regulatory limits (WSRC 1991). Given the importance of off site tritium doses and emphasis on compliance with DOE regulations, quantifying uncertainties and determining their impact on dose estimates will be a significant achievement.

Calculation of age-dependent environmental tritium doses would be of value in site environmental dose assessments. The variability in eating habits among individuals of different age groups contributes to the uncertainties associated with dose assessments (Till and Etnier 1979; Rupp 1980); age dependent tritium doses have been shown to be 52% higher than doses calculated based on adult parameters. Although age dependent consumption is utilized in present site methodology, the use of current age-dependent dose factors is desirable. Previous studies have indicated that age dependence in relation to dose may be particularly significant in the case of tritium (Etnier and Till 1979).

Determining whether detailed monthly dose estimates are necessary or whether annual averaged data is sufficient offers the potential for more efficient future dose reconstruction studies. Dose estimates are presently calculated annually using five year meteorological databases (WSRC 1995; USNRC 1978). The degree to which monthly release and meteorological data are appropriate for population dose estimates and reconstructions is not known. Monthly estimates may provide more meaningful estimates, or five-year averaged data may prove to be adequate for routine monitoring and dose reconstruction purposes.

Tritium poses significant health physics challenges. It is the major contributor to population doses from nuclear industry (Etnier and Till 1979). It is easily spread from waste reservoirs; although several indices of leakage from tritium facilities suggest little health risk, larger quantities of tritium would pose a significant public health problem (Opkada and Momoshima 1993). Although external tritium emissions pose little threat due to a low beta energy, tritiated water vapor is easily incorporated into the human body. Further, once inhaled or ingested, tritium is completely and instantaneously absorbed (ICRP 1979). Incorporation of tritiated water into the body can occur by three pathways:

1) respiration 2) ingestion 3) absorption through the skin (Opkada and Momoshima 1993). A second form of tritium, elemental tritium, also poses some risk when inhaled, although only 0.004% of elemental tritium is converted to tritiated water which is retained by the body. Elemental tritium is approximately 25,000 times less radiotoxic than the oxide form (Murphy et al. 1990), and it is assumed for the purposes of this report that approximately 10% of elemental tritium emitted to the atmosphere is converted to the oxide form while being transported downwind. The radiation protection problem introduced by tritium is accentuated in the Savannah River Site environment; tritium accounts for the majority of off site doses at the Savannah River Site. For example, in 1994 approximately 88% of the site perimeter doses from atmospheric releases were attributed to the nuclide (WSRC 1994). The mobility of tritium and it's associated health hazards coupled with the magnitude of tritium released at the site warrants research efforts providing more efficient and meaningful dose assessments in regard to site operations.

OBJECTIVES: The objectives of this research are:

1) To calculate and compare off site doses from atmospheric tritium releases using monthly versus 5 year meteorological data and annual source terms, including additional seasonal and site specific parameters not included in present annual assessments; and

2) To calculate the range of the above dose estimates based on distributions in model parameters given by uncertainty estimates found in the literature. Consideration will be given to the sensitivity of parameters given in former studies.

BACKGROUND

Presently, the Savannah River Site Environmental Dosimetry Group calculates off site tritium air concentrations due to atmospheric releases using the Gaussian atmospheric dispersion model:

$$\chi = \frac{\dot{Q}}{2\pi\bar{u}\sigma_y\sigma_z} \times \exp\left[-\frac{y^2}{2\sigma_y^{\,2}}\right]\left[\exp\left[-\frac{(z-h)^2}{2\sigma_Z^{\,2}}\right] + \exp\left[-\frac{(z+h)^2}{2\sigma_z^{\,2}}\right]\right] \quad (1)$$

where:

$\dot{Q}$ = release rate (Ci/s)

h = stack height (m)

y = lateral distance from center of plume (m)

z = vertical distance from ground (m)

σ_y = lateral diffusion coefficient (m)

σ_z = vertical diffusion coefficient (m)

$\bar{u}$ = average wind speed (m/s)

Although some discrepancies exist in estimating air concentrations beyond 80 km from releases at the site, tests of the Gaussian model at the site indicate that this model is appropriate for estimations at intermediate distances (Murphy et. al 1992).

A constant lid height of 1000m is assumed at the site; this effectively constrains vertical dispersion to 1000 meters Wet and dry deposition are considered through the measurement of tritium in vegetation; however, deposition is not assumed to deplete the plume (WSRC 1994). In addition, resuspension is not considered by computer models utilized at the site (WSRC 1994).

Average annual air concentrations in sixteen sectors surrounding the site are calculated by averaging concentrations over the sector width and accounting for the frequency of occurrence of specific meteorological conditions:

$$\chi_{sector} = \sum \frac{6.301\dot{Q}}{\pi x \sigma_z u_i}\left(e^{-h^2/2(\sigma_z)^2}\right) * f_{ijk} \quad (2)$$

f_{ijk} = frequency of occurrence of windspeed i, atmospheric stability j, and wind direction k

These frequencies are determined through the use of meteorological measurements recorded at the H-area tower, near the center of the SRS, over a five year period. Frequency tables of wind speed, wind direction, and atmospheric stability class are constructed and used as input parameters for the atmospheric transport model. This model accounts for the direction and speed of the wind and the vertical and horizontal dispersion characteristics of the atmosphere.

Dispersion of atmospheric tritium released at the site is modeled through the incorporation of the diffusion variables σ_y and σ_z in the above Gaussian equation. These diffusion parameters are derived from dispersion versus distance curves for differential atmospheric stability classes generated by Pasquill and modified by Gifford (Kathren 1984). Atmospheric stability in H area is determined through the standard deviation of the horizontal wind direction measured at the meteorological tower. This method is well established and the correlation between measured and predicted stability is significant (Miller and Little 1980).

Meteorological data obtained at H tower are assumed to be representative of meteorological conditions at all areas of the site. This assumption was confirmed when it was found that air concentrations, and therefore dose estimates, using meteorological data from various site towers were within 20% of the mean (Hamby and Parker 1991).

The tritium facilities at the Savannah River Site are the largest contributor to atmospheric releases. H-Area tritium facilities extract, separate, purify, and package tritium. Tritium is extracted from irradiated lithium-aluminum targets, processed, and packaged for shipping to other DOE sites. The air in the facility is vented through three 61m stacks. H area canyon and seepage basin both contributed to atmospheric tritium releases until 1988 (Murphy et al. 1988).

Releases from H-Area operations typically include both elemental and oxide forms of tritium. Advanced stack sampling systems have permitted reliable elemental and oxide tritium measurements

(Murphy et al. 1988). Elemental and oxide releases are documented separately; due to the low risk posed by elemental tritium in relation to oxide tritium, only doses from the oxide form are considered significant.

The annual 50 mile collective committed dose and maximum individual dose at the site perimeter are calculated at the Savannah River Site for inhalation and ingestion of milk, meat, and vegetables for 16 area sectors surrounding the site using methods described in the U.S. Nuclear Regulatory Commission's Regulatory Guide 1.109. The major environmental pathways between atmospheric releases and man are depicted in Figure 1 and are the major pathways considered by the site. The direct radiation pathway indicated in the figure is not considered for tritium due to its low energy beta particle. Doses due to irrigation practices are not considered. Population distributions based on the 1990 census are utilized for population dose calculations. Fractions of individuals in each of four age categories are utilized according to methods outline in USNRC Regulatory Guide 1.109: infant (0-1yr), child (1-11 year), teen (11-17 yr), and adult (>17yr). Currently at SRS, adult internal dose factors for inhalation and ingestion are utilized for dose calculations (DOE/EH-0071). Age dependent consumption rates specific for the area surrounding the site are utilized in ingestion calculations. Dose due to absorption through the skin is calculated assuming individuals absorb approximately one-half as much tritium through the skin as is inhaled (ICRP 1979).

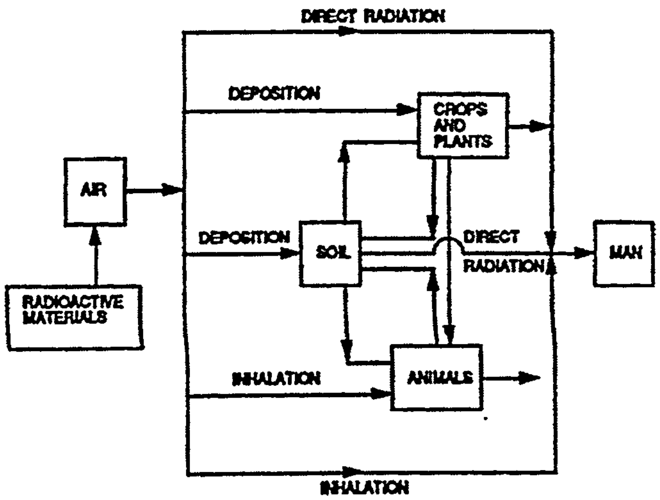


Figure 3.2. Simplified Pathways Between Radioactive Materials Released to the Atmosphere and Man

Figure 1

Presently, the site methodology utilizes several site specific parameters in modeling atmospheric releases as opposed to incorporating NRC default values. Site specific meat, milk, and vegetation production (including home vegetables), as well as the fraction of this local production consumed are considered. A site-specific absolute humidity value of $11 g/m^3$ is incorporated (WSRC 1991). Also, because chickens and swine are fed uncontaminated grains, local ingestion of pork and chicken is not considered. Area cattle forage consumption, the fraction of cattle diets which are fresh pasture grass in the area, specific transport times from milking or slaughter to consumption, the site specific fraction of the year which cattle graze, and a measured value of the ratio of the specific activity of tritium oxide in vegetation to the specific activity of tritium oxide in the air at the site are considered.

However, several parameters which may substantially influence off site dose estimates have not been modified to reflect site-specific conditions. Seasonal variation in consumption and age dependent dose factors are not considered at the site. In addition, seasonal variability in the absolute humidity and lid height at the site are not included in dose estimates.

The inclusion of these site specific parameters in the site dose models would provide more meaningful estimates of off site doses. Dose prediction variations for ingestion pathways significantly differ based on consumption rates used and absolute humidity (Hamby 1992). The use of site specific model parameters has been shown to result in a 4% decrease in population dose estimates at the Savannah River Site (Hamby 1992).

Present dose estimations do not include a range of doses calculated based on uncertainty analysis. A probability density function of dose to a maximally exposed adult has been calculated based on assumed parameter distributions and an estimate of the annual atmospheric tritium concentration at the site boundary (Hamby 1993). However, such a distribution has not been estimated when considering actual releases, different age groups, or population doses estimates. The sensitivity of the model to variations in several parameters has been estimated (Hamby 1993). These sensitivity estimates may be utilized in determining the parameters which have the most influence on estimates of environmental dose.

METHODS

Calculation of Air Concentrations. Monthly and annual air concentrations during the years of 1987 to 1991 were calculated in the west-northwest sector at the site boundary (7.35 miles) and 15, 25, 35, and 45 miles from an assumed centralized release point. In performing these calculations, monthly meteorological and H-Area release data were incorporated into the annual sector-average Gaussian dispersion model. Distances of 15, 25, 35, and 45 miles from the release were chosen to approximate air concentrations in the centers of sector regions from 10 to 20 miles, 20 to 30 miles, 30 to 40 miles, and 40 to 50 miles in the west northwest sector. This sector was chosen based on its large contribution to the total 50 mile population; the west-northwest sector encompasses 28% of the total 50 mile population.

Hourly wind direction, wind speed, and azimuth standard deviation data for each month in the five year period from 1987 to 1991 were characterized in terms of stability class, wind speed category, and wind direction. Sector assignments were defined according to sixteen 22.5° areas surrounding the facility. Atmospheric stability categories were determined by the standard deviation in the horizontal wind direction (σ_θ), as is standard practice at the site. Assignment of wind speed class also followed site criteria. The definitions for stability category and wind speed class used in this report are indicated in Tables 1 and 2.

Monthly and annual frequency information regarding wind speed category and atmospheric stability for the west-northwest sector were generated. For monthly calculations, joint frequency distributions indicating the fraction of the month stability classes coupled with specific wind speed categories existed were determined from such tables. These joint frequency distributions were utilized in calculating monthly averaged sector air concentrations. Annual frequency distributions were generated based on occurrences of wind speed classes and stability rating occurrences during the 5 year period from 1987 to 1991 in the west-northwest sector. In addition, the average wind speed for each combination of wind speed class and stability rating was calculated and summarized for both monthly and annual calculations. Decay of tritium as the modeled plume disperses was assumed to be insignificant and was not considered due to the long half-life (12.3 years) of tritium.

Table 1- Atmospheric Stability Classes Assigned to Azimuth Standard Deviations

Stability	Category	σ_θ
Extremely unstable	A	>=22.5
Moderately unstable	B	22.5 > σ >= 17.5
Slightly unstable	C	17.5 > σ >= 12.5
Neutral	D	12.5 > σ >= 7.5
Slightly stable	E	7.5 > σ >= 3.8
Moderately stable	F	3.8 > σ >= 2.1
Extremely stable	G	2.1 > σ

Table 2- Wind Speed Categories

Wind speed (m/s)	Assigned wind speed category
0-2	1
2-4	2
4-6	3
6-8	4
8-12	5
>12	6

Joint frequency distribution data were incorporated into a spreadsheet in order to calculate monthly and annual air concentrations. The spreadsheet utilized the sector-averaged Gaussian equation in calculating air concentrations:

$$\chi_{sector} = \sum \frac{6.301\dot{Q}}{\pi x \sigma_z u_i}\left(e^{-h^2/2(\sigma_z)_j^2}\right) * f_{ijk} \quad \text{where} \quad (1)$$

$\dot{Q}$ = release rate (Ci/s)

h = stack height (m)

x = downwind distance (m)

σ_z = vertical diffusion coefficient (m)

$\bar{u}$ = average wind speed (m/s)

f_{ijk} = frequency of occurrence of windspeed i, atmospheric stability j, and wind direction k

Concentrations at particular distances were calculated under various stability and wind speed class occurrences. Concentrations were then summed over these differential meteorological conditions in order to obtain a final air concentration at the distance of interest. The H-area stack height of 61m was used in all calculations. The assumptions of no plume depletion from wet or dry deposition and no resuspension considered at the site were upheld. Flat terrain was also assumed (WSRC 1995).

The tritium release rate for each month was calculated from site release data. Fission product releases and elemental releases for 1987-1989 were available only on an annual basis. These releases were prorated over the years in which they occurred. Fission product tritium oxide releases are calculated by the Savannah River Site Environmental Dosimetry Group based on the megawatt-day of the fuel being processed. H-area tritium oxide releases are monitored on a monthly basis, and were available for direct use. It was assumed in this report that 10% of the elemental releases are converted to the oxide form during transport downwind. All release types were summed to obtain a total release in Ci for each month. Tritium oxide releases for each month were summed in order to obtain an annual oxide release. The total release rates for each year and month were calculated assuming the total annual activity was released continuously. The release rate for each month and year from 1987 to 1991 may be found in Appendix A.

Vertical diffusion (σ_z) was estimated using the methods outlined by Brodsky (1982). Brodsky determined mathematical relations of vertical dispersion based on data observed by Pasquill. The formulas developed by Brodsky and utilized in the present research for estimation of the vertical dispersion coefficient are indicated in Table 3.

Table 3 Formulas for the Determination of σ_z (x, σ_z in meters)

Stability Class	σ_z
A	0.20x
B	0.12x
C	$0.08x(1+2x10^{-4}\,x)^{-1/2}$
D	$0.06x\,(1+1.5x\,10^{-4}\,x)^{-1/2}$
E	$0.03x(1+3x10^{-4}\,x)^{-1}$
F	$0.02x\,(1+3x10^{-4}\,x)^{-1}$
G	$0.012x(1+3E\text{-}4x)^{-1}$

*** "x" represents the distance from the release**

In addition, seasonal lid height data taken from Garett (1981) were incorporated into monthly spreadsheets. Values listed in Table 4 are observed lid heights averaged over the regions of Athens, Ga, Greensboro, NC, Charleston, SC, and Jacksonville, Fl. for the entire year of 1978.

Table 4- Lid Heights Used in the Calculation of Air Concentrations

MONTH	VALUE (m)
January	875
February	1063
March	1500
April	1813
May	1438
June	1343
July	1145
August	1135
September	1155
October	1283
November	1105
December	918

An average lid height of 1000m was assumed for each annual calculation, as is site practice. Values of σ_z were constrained in downwind concentration estimates as to not to exceed the monthly or annual lid height.

Calculation of Doses. Collective committed doses within 50 miles of the center of the site and maximum individual doses at the site boundary were calculated using the 1987 to 1991 meteorological database. Dose calculation methodology paralleled Savannah River Site methodology with inclusion of age dependent dose factors and seasonal consumption data. Derived monthly and annual air concentrations were incorporated into dose calculations. A spreadsheet was designed for the purpose of calculating monthly and annual maximum individual and collective doses.

Concentration calculations. The concentration of tritium in leafy vegetables, beef, milk, and non-leafy vegetables, fruits, and grains was determined on an annual and monthly basis for pathway analysis. Tritium concentrations in pasture grass, stored feed, leafy vegetables, and vegetation were calculated at the site boundary and 15, 25,35, and 45 miles from releases utilizing the method suggested in NRC Regulatory Guide 1.109:

$$C_T^V = \frac{\chi}{H} 0.75 * \mathrm{R}e^{-(\lambda t)} \qquad (2)$$

where:

χ= air concentration of tritium at receptor location (pCi/m^3)

H= absolute humidity (kg/m^3)

0.75 = the fraction of plant mass that is water (unitless)

R = the ratio of tritium concentration in plant water to tritium in atmospheric water (unitless)

λ= tritium decay constant (0.0054/day)

t = transport time from harvest to consumption for specific types of vegetation

The site specific value for the vegetation to air concentration ratio (0.54) was utilized in dose calculations (Hamby and Bauer 1994). Site methodology was modified to include monthly humidity data. Average humidity values reported by Hamby and Jumper (1990) from June 1987- June 1989 were utilized, and these values are indicated in Table 5. Monthly averages were determined from a plot of absolute humidity as a function of month from June 1987-June 1989. The absolute humidity in all annual calculations was assumed to be 11.4 g/m^3 based on the finding of Hamby and Jumper that this represents the mean absolute humidity at the site (1990).

The transport times for pasture grass, stored feed, and vegetation were as dictated by NRC Regulatory Guide 1.109 for maximum and average individuals. These values are indicated in the parameter characterization section.

Table 5-Average Absolute Humidity Values Used in Monthly Vegetation Concentration Calculations

Month	1987 Monthly Average (g/m³)	1988 Monthly Average (g/m³)	1989 Monthly Average (g/m³)	Average of 1987-1989 Monthly Average (g/m³)
January	-	5	8	6.5
February	-	5.5	7.5	6.5
March	-	8	9.5	8.8
April	-	8.5	11.5	10.0
May	-	11	13.5	12.3
June	23	14.5	19	18.8
July	21	17.5	-	19.3
August	20.5	17	-	18.8
September	16	16.5	-	16.3
October	9	8.5	-	8.8
November	8.5	8.0	-	8.8
December	9	6.5	-	7.8

The average concentration of tritium in animal feed weighted by the fraction of the year that animals graze (f_p) and the fraction of daily feed that is pasture grass (f_s) at the site boundary and 15, 25, 35, and 45 miles from H area releases was calculated based on NRC Regulatory Guide 1.109 methodology:

$$C_i^v = f_p f_s C_i^p + (1-f_p)C_i^s + f_p(1-f_s)C_i^s \qquad (3)$$

where:

C_i^p = concentration of tritium on pasture grass, calculated using the vegetation equation above (pCi/kg), with transport time= 0 days

C_i^s = concentration of tritium in stored feeds, calculated using the above vegetation equation decayed by the time of storage. (pCi/kg)

f_p = fraction of the year that animals graze on the pasture (unitless)

f_s = fraction of daily feed that is pasture grass (unitless)

Site specific values for the fraction of the year that cattle graze and the fraction of feed taken from the pasture for dairy and beef cows were utilized. Specific values are indicated in the parameter characterization section.

The concentration of tritium in milk at the site boundary and 15, 25, 35, and 45 miles from the release point was calculated based on NRC Regulatory Guide 1.109 methodology:

$$C_i^m = F_m C_i^v Q_F \exp(-\lambda_i t_f) \quad (4)$$

where

F_m = the average fraction of the animals daily intake of tritium which appears in each liter of milk. (d/L)

C_i^v = concentration of nuclide in the animal's feed (pCi/kg)

Q_f = amount of feed consumed by the animal per day (kg/d)

t_f = transport time from milking to consumption (d)

λ_i = radiological decay constant of tritium (d^{-1})

The value for the tritium transfer coefficient for milk indicated in NRC Regulatory Guide 1.109 was utilized in calculations, as indicated in the parameter characterization section. However, site specific values for the feed consumption rate and the transport time for average individuals were used (Hamby 1992; Hamby 1993). These values are also listed in the parameter characterization section. The transport time for the maximum individual was assumed to be 1 day based on area-specific transportation time data (Hamby 1993; Hamby 1991).

Tritium concentrations in beef at the site boundary and 15, 25, 35, and 45 miles from the center of the site were calculated based on NRC Regulatory Guide 1.109 methods:

$$C_i^f = F_f C_i^v Q_f \exp(-\lambda_i t_s) \qquad (5)$$

where:

F_f = fraction of the animal's daily intake of tritium appears in each kilogram of flesh (d/kg)

t_s = average time from slaughter to consumption (d)

Q_f = daily consumption of feed by beef cows (kg/d)

All other variables have been previously defined.

The beef transfer coefficient for tritium suggested by the NRC was utilized in dose calculations, as indicated in the parameter characterization section. A site specific value for beef cow consumption was used (Hamby 1992). In addition, a site specific transport time for average individuals was used (Hamby 1992; Hamby 1993). These values are listed in the parameter characterization section. The time between slaughter and consumption for maximum individuals was assumed to be 2 days based on area specific data (Hamby 1993).

Maximum Individual Doses. Maximum individual was characterized as "maximum" with regard to occupancy at the site perimeter, consumption, and usage of the region in the vicinity of the site (USNRC 1977). However, it was assumed that with regard to physiology and metabolism, maximum individuals have the characteristics of average individuals in their age group (USNRC 1977). Monthly and annual air, vegetation, leafy vegetable, beef, and milk concentrations at the site perimeter were incorporated into these calculations. Age dependent dose factors and season and age dependent consumption were also incorporated in dose calculations.

Monthly and annual inhalation and absorption doses for infants, children, teenagers, and adults were calculated according to the methods outlined in NRC Regulatory Guide 1.109:

$$Dose_{inh+abs\,A}\,(mrem) = 1.5 * BR * \chi * DF_{inh\,A} \qquad (6)$$

where

$Dose_{inh+Abs}$ = The dose in mrem to a maximum individual of age group A due to inhalation and absorption of tritium through the skin

BR = Breathing rate of maximum individual in age class A (m^3/month or m^3/yr)

χ = Monthly or annual air concentration at the site boundary (pCi/m^3)

DF_{inh} = Tritium inhalation dose factor for age group A (mrem/pCi)

The factor of 1.5 was incorporated to account for absorption of tritium through the skin (ICRP 1979). Age dependent inhalation dose factors were taken from ICRP publication 56. Infant dose factors at 3 months of age were utilized for conservatism. In addition, individual dose factors at age 5 were chosen to represent child dose factors. Finally, exposure at age 15 was chosen to represent teenage dose factors. The resultant inhalation effective dose equivalents per unit activity ingested or inhaled are indicated in Table 6.

Table 6- Age Dependent Inhalation and Ingestion Dose Factors Used in Calculations

	Infant	Child	Teenager	Adults
Inhalation dose Factor (mrem/pCi)	2.04E-7	9.62E-8	5.92E-8	5.92E-8

Age dependent breathing rates were utilized. Maximum individual breathing rates were taken as the average breathing rate of individuals in each age class. Monthly doses were calculated assuming breathing rates are uniform throughout the year; annual rates observed in literature were divided by twelve in order to obtain monthly breathing rates (USNRC 1977; NCRP 1984). Annual and monthly breathing rates are listed in Table 7.

Table 7- Maximum Individual Breathing Rates Incorporated into Monthly and Annual Dose Calculations

	Infant	Child	Teenager	Adult
Breathing rate(m^3/month)	117	308	667	667
Breathing Rate (m^3/yr)	1400	3700	8000	8000

Maximum individual monthly and annual doses due to ingestion of tritium in food were calculated assuming all food that is consumed by an individual was produced at the site boundary. Maximum individual doses from ingestion of milk were calculated according to NRC Regulatory Guide 1.109 methods:

$$\text{Dose (mrem)} = U_m C_m DF_{ing} \qquad (7)$$

where :

U_m = Age dependent maximum individual monthly or annual consumption of milk (L/month)

C_m = Annual or monthly concentration of tritium in milk (pCi/L)

Df_{ing} = Age dependent tritium ingestion dose factor (mrem/pCi)

Maximum individual consumption rates were derived from the US Department of Agriculture 1977-78 Food Consumption Survey of Southern Households (USDA 1983). Methods for determining age dependent and seasonal maximum individual consumption rates are indicated in the section entitled " Age and Season Dependent Consumption Values Utilized in Dose Calculations". Seasonal values were summed in order to obtain annual consumption rates. Methodology regarding the calculation of these values is described in the section entitled "Age and Season Dependent Consumption Values Utilized in Dose Calculations".

Age and season dependent monthly and annual maximum individual doses due to ingestion of contaminated beef were calculated based on methodology outlined in NRC Regulatory Guide 1.109:

$$\text{Dose (mrem)} = U_f C_f DF_{ing} \qquad (8)$$

where:

U_f = Age dependent maximum individual monthly or annual consumption of beef (kg/month)

C_f = Annual or monthly concentration of tritium in beef (pCi/kg)

Df_{ing} = Age dependent tritium ingestion dose factor (mrem/pCi)

Monthly and annual age dependent maximum individual doses due to ingestion of vegetation were determined by summing the doses from leafy vegetables and non-leafy vegetables, fruits, and grains:

$$\text{Dose} = (U_l C_l + U_n C_n)\, Df_{ing} \qquad (9)$$

where:

U_l = Age and season dependent maximum individual consumption of leafy vegetables (kg/month or kg/yr)

U_n = Age and season dependent maximum individual consumption of non-leafy vegetables, fruits, and grains (kg/month or kg/yr)

C_l = Monthly or annual concentration in leafy vegetables (pCi/kg)

C_n = Monthly or annual concentration in non-leafy vegetables, fruits, and grains (pCi/kg)

Df_{ing} = Age dependent tritium ingestion dose factor (mrem/pCi)

Collective Committed Dose Calculations. Collective committed inhalation and ingestion doses at 15,25, 35 and 45 mile regions from the release point were summed in order to estimate monthly and annual population doses. A region was defined as an area within the sector which extends 10 miles along a fifty mile radius surrounding the site. Annuli were defined as areas equidistant from the release.

Monthly and annual population age- dependent inhalation and ingestion doses were calculated assuming average consumption and incorporating population estimates within the west-northwest sector into dose calculations. It was assumed that infants comprise 2% of the population, children comprise 16% of the population, teenagers comprise 11% of the population, and adults comprise 71% of the population (USNRC 1977). The estimates of the number of individuals residing at differential distances from the release in the west-northwest sector were taken from the Savannah River Site 1994 Environmental Report and are as follows:

- 10-20 miles from release: 3,342
- 20-30 miles from release: 106,900
- 30-40 miles form release: 50,310
- 40-50 miles from release : 11,550

Inhalation and absorption population doses due to SRS atmospheric tritium releases in the 10-20 mile, 20-30 mile, 30-40 mile, and 40-50 mile regions of the sector were summed across all age groups. Doses for each region were them summed in order to estimate monthly and annual population inhalation and absorption doses:

$$\text{Population Inhalation and Absorption Dose (person -mrem)} = \sum_{R}\sum_{A} 1.5 * BR * P_R * f_A * \chi_R * DF_{inh\ A} \quad (10)$$

where:

BR= age dependent average breathing rate (m^3/month or m^3/yr)

P_R = Population in the sector region R

f_A = fraction of population in age group A

χ_R = Monthly or annual air concentration (pCi/m^3) in the sector region R

DF_{inhA} = age specific inhalation dose factor (mrem/pCi)

Population doses due to ingestion of each food item following H area atmospheric tritium releases were found by summing doses over age groups and regions:

$$D_{IM,Y} = \begin{cases} \sum_R \sum_A I_R * \overline{C}_{IR} * F_{IA} * DF_{ing\,A} & \text{if monthly or annual demand} <= \text{monthly or annual production} \\ \sum_R \sum_A (I_R + ((\text{Demand}-I_R)*f_c)) * \overline{C}_{IR} * F_{IA} * DF_{ing\,A} & \text{if monthly or annual demand} > \text{monthly or annual production} \end{cases} \qquad (10)$$

where:

D_{IM} = Population dose in month M or year Y due to ingestion of food item I (person- mrem)

$\overline{C}_{IR}$ = Monthly or annual average tritium concentration of food item I in region R

I_R = regional monthly or annual production of food item I

f_c = fraction of food item imported that is contaminated

F_{IA} = fraction of food item I consumed by age group A

$DF_{ing\,A}$ = Tritium ingestion dose factor for age group A (mrem/pCi)

The percentage of each food consumed by different age groups was assigned based on data from the US Department of Agriculture 1977-78 Food Consumption Survey. These percentages may be found in the parameter characterization section under "Consumption Rates". The variable $\overline{C}_{IR}$ is the regional concentration weighted by the fifty- mile monthly production of food item I. This term is calculated assuming the tritium concentration in food items is identical at all points equidistant from the release, termed an annulus. Annulus concentrations were weighted against 50 mile production to account for movement of food items outside of the annulus (i.e closer to or further from the point of release):

$$\overline{C}_{IR}\ (\text{pCi/kg}) = (\exp\text{-}(\lambda t) * C_A * I_A) / I_{50} \qquad (11)$$

where:

I_{50} = Annual or Monthly production of food item I within a fifty mile radius of release (kg)

λ = tritium decay constant (d^{-1})

t = transport time for food item I (d)

C_A = Monthly or annual concentration of tritium in food item I in annulus (equivalent to concentration in region of sector) (pCi/kg)

I_A = Monthly or annual annulus production of food item I (kg)

Monthly annulus, regional, and fifty mile productivity values were derived from annual data. The procedure for these calculations is described in the section entitled "Inclusion of Seasonal Productivity". Monthly and annual consumption demands were summed across all age groups for each region as follows:

$$Demand_{iRM,Y} = \sum_{A} P_R*F_A * U_{AiM,Y} \qquad (12)$$

where:

$Demand_{iRM}$ = Demand for food product I in region R in month M or year Y (kg)

P_R = population in region R (10-20, 20-30, 30-40, or 40-50 miles from release)

F_A = fraction of individuals in age group A

U_{AIM} = Usage of food product I by an average individual in age group A in month M or year Y (kg /month)

Average individual age and season dependent consumption rates are listed in the section entitled " Age and Season Dependent Consumption Values Utilized in Dose Calculations". Seasonal consumption rates were summed in order to obtain annual rates. Demands were compared with regional production in order to estimate the fraction of foodstuffs being imported from surrounding areas. If it was found that monthly or annual population demands were higher than regional productivity could support, regional productivity was increased by a fraction of the item which is necessarily imported from other regions within the 50 mile radius and is contaminated:

Increase in monthly or annual productivity for foodstuff I = $(\text{Demand}_{iRM,Y} - RM,Y_I) * f_c$ (13)

where:

RM,Y_I = Regional monthly or annual production of foodstuff I (kg)

f_c = fraction of imported foodstuff I which is contaminated

Monthly and annual regional and fifty mile productivity values for each food group are indicated the section entitled " Inclusion of Seasonal Productivity". The fraction of each imported foodstuff which is contaminated was calculated as the quotient of the total fifty mile annual productivity and the sum of the annual fifty mile population demands of each age group:

$$\text{Fraction of imported food group I which is contaminated} = A_I / \sum_A U_{AIY} * P_A \qquad (14)$$

where:

A_I = Annual production of food group I within 50 miles of the site (kg)

U_{AIY} = usage of food group I by an average individual in age group A on an annual basis (kg/yr)

P_A = number of individuals in age group A in the fifty mile population surrounding the site

In performing this calculation, it was assumed that the proportion of each uncontaminated food class imported from outside the fifty mile radius of the site is representative of the proportion of these food classes imported into each region of the west-northwest sector. It was also assumed that the proportion of each food group imported on an annual basis is representative of the proportion of food imported on a monthly basis. The number of individuals in each age group in the 50 mile population surrounding the site was calculated by utilizing population estimates from the 1990 census (WSRC 1995). The fractions of individuals in each age group were assigned according to methods outlined in NRC Regulatory Guide 1.109.

Age and Season Dependent Consumption Values Utilized in Dose Calculations. Values for consumption of food products were taken from the US Department of Agriculture's Survey of Food Consumption for the south in the years 1977-78 (USDA 1983). This report provided information on total household consumption for the spring, summer, winter, and fall seasons for each food group. It was assumed that the relative percentage of a particular food group consumed annually by different ages suggested by a review of the literature was representative of age-dependent consumption in the south (O'Neill et. al 1981; Rupp 1980; Hoffman and Baes 1979; Shevenell and Hoffman 1981; Hoffman et. al 1982; Baes et. al 1983; Hamby 1993; Miller and Hoffman 1982). These percentages are indicated in the parameter characterization section under "Consumption Rates". The mean annual rate of consumption of beef, milk, leafy vegetables, and non-leafy vegetables, fruits, and grains determined in the parameter characterization section of this report were multiplied by the total number of infants, children, teenager, and adults in the United States in order to determine the total amount of each food consumed in a year for each age group. Consumption among age groups was summed in order to estimate the total annual consumption foods in the United States. An estimate of the complete United States population was taken from the 1993 Demographic Yearbook (1995). The percentage of milk, beef, leafy vegetables, and non-leafy vegetables, fruits, and grains consumed by each age was determined by dividing the annual consumption in the particular age group by the total annual consumption of all age groups. These percentages were applied to seasonal household consumption data taken from the US Department of Agriculture survey in order to estimate age-dependent consumption in the south. The survey represented information gathered from 4324 households in the South, with an average household size of 2.71, yielding a total population of 11718 individuals. It was assumed that the age distribution of individuals in the south is identical to the age distribution of the U.S. (USNRC 1977).

Values taken from the survey represent items both bought and raised or grown for home use. Data representing all urbanizations were utilized, as some portions of the west-northwest sector may be metropolitan, and others may be rural. Winter was defined as the months of January, February, and March. Spring was defined as the months of April, May, and June. Summer was defined by the months of July, August, and September. Finally, fall was defined by the months of October, November, and December (US Dept. of Agriculture, 1983). Calculated seasonal values were divided by three in order to estimate monthly consumption.. These values are given in parentheses in the Tables 8 though 15. In addition, seasonal values were summed in order to determine annual consumption.

Table 8-Milk Consumption in the SRS Vicinity

	Infants	Children	Teens	Adults
Winter (L/season)	66.0 (22L/month)	47.7 (15.9 L/month)	44.2 (14.7 L/month)	22.8 (7.6 L/month)
Spring (L/season)	65.8 (21.9 L/month)	47.4 (15.8 L/month)	44.0 (14.7 L/month)	22.7 (7.6 L/month)
Summer(L/season)	64.5 (21.5 L/month)	46.5 15.5 L/month)	43.1 (14.4 L/month)	22.3 (7.4 L/month)
Fall (L/season)	64.8 (21.6 L/month)	46.7 (15.6 L/month)	43.3 (14.4 L/month)	22.4 (7.5 L/month)
Annual Consumption (L/yr)	261.1	188.4	174.6	90.2

*Milk consumption included whole, buttermilk, skim, lowfat, yogurt , and chocolate milk.

Table 9- Beef Consumption in the SRS Vicinity

	Infants	Children	Teens	Adults
Winter (L/season)	0.0012 (0.0004kg/month)	4.3 (1.4kg/month)	7.1 (2.4 kg/month)	12.20 (4.1kg/month)
Spring (L/season)	0.0014 (0.0005 kg/month)	4.8 (1.6 kg/month)	8.1 (2.7 kg/month)	13.9 (4.6 kg/month)
Summer (L/season)	0.0012 (0.0004kg/month)	4.5 (1.5 kg/month)	7.4 (2.5 kg/month)	12.8 (4.3 kg/month)
Fall (L/season)	0.0012 (0.0004kg/month)	4.4 (1.5kg/month)	7.3 (2.4 kg/month)	12.6 (4.2 kg/month)
Annual Consumption (kg/yr)	0.005	18.0	29.9	51.5

Table 10- Leafy Vegetable Consumption in the SRS Vicinity

	Infants	Children	Teens	Adults
Winter (kg/season)	0.24 (0.08 kg/month)	2.3 (0.77 kg/month)	3.6 (1.2 kg/month)	5.9 (2.0 kg/month)
Spring (kg/season)	0.26 (0.09 kg/month)	2.6 (0.87 kg/month)	3.9 (1.3 kg/month)	6.4 (2.1 kg/month)
Summer (kg/season)	0.25 (0.08 kg/month)	2.5 0.83 kg/month)	3.8 (1.3 kg/month)	6.2 (2.1 kg/month)
Fall (kg/season)	0.26 (0.09 kg/month)	2.6 (0.87 kg/month)	4.0 (1.3 kg/month)	6.6 (2.2 kg/month)
Annual Consumption (kg/yr)	1.01	10.0	15.3	25.1

*Leafy vegetables were assumed to include dark-green leafy, lettuce, and cabbage (Hamby 1991)

Non-leafy vegetables were defined as all fruits, grains, and vegetables other than leafy. Consumption of all fresh fruits was included. Flour, cereal, bread, and bakery items listed in the USDA 1977-78 consumption survey were assumed to be representative of grain consumption.

Table 11- Non-leafy Vegetables, Fruits, and Grains Consumption

	Infants	Children	Teens	Adults
Winter (kg/season)	19.5 (6.5 kg/month)	38.2 (12.7 kg/month)	42.2 (14.1 kg/month)	39.2 (13.1 kg/month)
Spring (kg/season)	22.9 (7.6 kg/month)	44.8 (14.9 kg/month)	49.4 (16.5 kg/month)	45.9 (15.3 kg/month)
Summer (kg/season)	29.0 (9.7 kg/month)	56.8 (18.9 kg/month)	62.7 (20.9 kg/month)	58.3 (19.4 kg/month)
Fall (kg/season)	19.6 (6.5 kg/month)	38.4 (12.8 kg/month)	42.3 (14.1 kg/month)	39.3 (13.1 kg/month)
Annual Consumption (kg/yr)	91.0	178.2	196.6	182.7

Maximum individual consumption rates were derived (Hamby 1991) from the variation in reported values of household consumption from the US Department of Agriculture Food Consumption Survey (1977-78). Hamby (1991) determined three standard deviations from the mean weekly values, and calculated a variability factor as:

VF = three standard deviations/ weekly consumption

The average individual seasonal consumption rates were increased by the variability factor in order to determine maximum individual consumption values. It was assumed that variability in weekly consumption is representative of seasonal variability, and that household variability factors are representative of variation in all age groups. Resulting maximum individual consumption rates are indicated in Tables 12 through 15 below. Seasonal values were divided by three in order to obtain monthly estimates of consumption. Seasonal values were summed in order to estimate maximum individual annual consumption.

Table 12-Maximum Individual Consumption of Milk

	Infants	Children	Teens	Adults
Variability Factor	0.89	0.89	0.89	0.89
Winter (L/season)	124.7 (41.6 L/month)	90.2 (30.1 L/month)	83.5 (27.8 L/month)	43.1 (14.4 L/month)
Spring (L/season)	124.4 (41.5 L/month)	89.8 (29.9 L/month)	83.2 (27.7 L/month)	42.9 (14.3 L/month)
Summer (L/season)	121.9 (40.6 L/month)	87.9 (29.3 L/month)	81.5 (27.2 L/month)	42.1 (14.0 L/month)
Fall (L/season)	122.5 (40.8 L/month)	88.3 (29.4 L/month)	81.8 (27.3 L/month)	42.3 (14.1 L/month)
Annual Consumption (L/yr)	493.5	356.2	330.0	170.4

Table 13-Maximum Individual Consumption of Beef

	Infants	Children	Teens	Adults
Variability Factor	0.88	0.88	0.88	0.88
Winter (kg/season)	0.0023 (0.0008 kg/month)	8.1 (2.7 kg/month)	13.3 (4.4 kg/month)	22.9 (7.6 kg/month)
Spring (kg/season)	0.0026 (0.0009 kg/month)	9.0 (3.0 kg/month)	15.2 (5.1 kg/month)	26.1 (8.7 kg/month)
Summer (kg/season)	0.0023 (0.0008 kg/month)	8.5 (2.8 kg/month)	13.9 (4.6 kg/month)	24.1 (8.0 kg/month)
Fall (kg/season)	0.0023 (0.0008 kg/month)	8.3 (2.8 kg/month)	13.7 (4.6 kg/month)	23.7 (7.9 kg/month)
Annual Consumption (kg/yr)	0.0095	33.9	56.1	96.8

Table 14-Maximum Individual Consumption of Leafy Vegetables

	Infants	Children	Teens	Adults
Variability Factor	1.03	1.03	1.03	1.03
Winter (kg/season)	0.48 (0.16 kg/month)	4.7 (1.6 kg/month)	7.3 (2.4 kg/month)	12.0 (4.0 kg/month)
Spring (kg/season)	0.53 (0.18 kg/month)	5.3 (1.8 kg/month)	7.9 (2.6 kg/month)	13.0 (4.3 kg/month)
Summer (kg/season)	0.51 (0.17 kg/month)	5.1 (1.7 kg/month)	7.7 (2.6 kg/month)	12.6 (4.2 kg/month)
Fall (kg/season)	0.53 (0.18 kg/month)	5.3 (1.8 kg/month)	8.1 (2.7 kg/month)	13.4 (4.5 kg/month)
Annual Consumption (kg/yr)	2.05	20.4	31	51

Table 15-Maximum Individual Consumption of Non-Leafy Vegetables, Fruits, and Grains

	Infants	Children	Teens	Adults
Variability Factor	0.73	0.73	0.73	0.73
Winter (kg/season)	33.7 (11.2 kg/month)	66.1 (22.0 kg/month)	73.0 (24.3 kg/month)	67.8 (22.6 kg/month)
Spring (kg/season)	39.6 (13.2 kg/month)	77.5 (25.8 kg/month)	85.5 (28.5 kg/month)	79.4 (26.5 kg/month)
Summer (kg/season)	50.2 (16.7 kg/month)	98.3 (32.8 kg/month)	108.5 (36.2 kg/month)	100.9 (33.6 kg/month)
Fall (kg/season)	33.9 (11.3 kg/month)	66.4 (22.1 kg/month)	73.2 (24.4 kg/month)	67.9 (22.6 kg/month)
Annual Consumption (kg/yr)	157.4	308.3	340.2	316.0

Inclusion of Seasonal Productivity. Fifty mile radius, regional sector, and annulus milk, beef, and vegetation production data were utilized in calculating collective committed doses in the west-northwest sector. Annual data from 1994 were applied to all months for milk, meat, and vegetation production (WSRC 1995). Annual data from 1991 for leafy vegetables were applied (Hamby 1991). These annual values were utilized in yearly dose calculations. Given that beef and milk are produced year round, beef and milk seasonal productivity were accounted for by simply apportioning annual production equally among the seasons (Hamby 1991,1992). Production of leafy vegetables and vegetation, which includes vegetables other than leafy, fruits, and grains, occurs in the site vicinity in the months of March until November. Accordingly, winter months were each assigned one ninth of the vegetation production, spring and summer months were each assigned one third of the total annual production, and winter months were each assigned two ninths of the annual production. Precise monthly values were not calculated, as it is assumed some variation in the growing season exists, especially in the case of leafy vegetables (Hamby 1993). Seasonal values were, therefore, equally divided among the months in each season. These monthly values are indicated in parentheses in Tables 16 through 23. Regional production values, defined as production in differential 10 mile areas of the west-northwest sector, are listed in Tables 16 through 18. Annulus production values, defined as production of food stuffs in areas equidistant from the site center, are listed in Tables 19 through 22. Finally, 50 mile production values, defined as production within a fifty mile radius of the site center, are listed in Table 23.

Table 16- Seasonal Regional Production of Milk and Beef in the West-Northwest Sector

	10-20 Mile Region	20-30 Mile Region	30-40 Mile Region	40-50 Mile Region
Milk (L/season)	5.75E4 (1.92E4 L/month)	2.75E5 (9.17E4 L/month)	3.00E5 (1.00E5 L/month)	5.00E5 (1.67E5 L/month)
Beef (kg/season)	1.20E4 (4.0E3 kg/month)	1.55E4 (5.17E3kg/month)	3.25E4 (1.08E4 kg/month)	7.25E4 (2.42E4 kg/month)
Annual Beef Production (kg/yr)	4.8E4	6.2E4	1.3E5	2.9E5
Annual Milk Production (L/yr)	2.3E5	1.10E6	1.2E6	2.0E6

Table 17- Regional Vegetation Production in the West-Northwest Sector

	10-20 Mile Region	20-30 Mile Region	30-40 Mile Region	40-50 Mile Region
Winter	2.89E4 (9.63E3)	4.22E3 (1.41E3)	6.89E3 (2.30E3)	1.22E5 (4.07E4)
Spring	8.67E4 (2.89E4)	1.27E4 (4.22E3)	2.07E4 (6.89E3)	3.67E5 (1.22E5)
Summer	8.67E4 (2.89E4)	1.27E4 (4.22E3)	2.07E4 (6.89E3)	3.67E5 (1.22E5)
Fall	5.78E4 (1.93E4)	8.44E3 (2.81E3)	1.38E4 (4.59E3)	2.44E5 (8.13E4)
Annual Production (kg/yr)	2.6E5	3.8E4	6.2E4	1.1E6

Table 18- Regional Production of Leafy Vegetables in the West-Northwest Sector

	10-20 Mile Region	20-30 Mile Region	30-40 Mile Region	40-50 Mile Region
Winter (kg/season)	1.33E3 (4.44E2 kg/month)	1.56E1 (5.19 kg/month)	2.11E3 (7.04E2 kg/month)	5.56E3 (1.85E3 kg/month)
Spring (kg/season)	4.0E3 (1.33E3 kg/month)	4.67E1 (1.56E1 kg/month)	6.33E3 (2.11E3 kg/month)	1.67E4 (5.56E3 kg/month)
Summer (kg/season)	4.0E3 (1.33E3 kg/month)	4.67E1 (1.56E1 kg/month)	6.33E3 (2.11E3 kg/month)	1.67E4 (5.56E3 kg/month)
Fall (kg/season)	2.67E3 (8.89E2 kg/month)	3.11E1 (1.04E1 kg/month)	4.22 E3 (1.41E3 kg/month)	1.11E4 (3.70E3 kg/month)
Annual Production (kg/yr)	1.2E4	1.4E2	1.9E4	5.0E4

Table 19- Annulus Milk Production Values Utilized in Dose Calculations

	10-20 Miles	20-30 Miles	30-40 Miles	40-50 Miles
Winter (L/season)	1.41E6 (4.7E5 L/month)	4.45E6 (1.48E6L/month)	9.89E6 (3.30E6 L/month)	1.22E7 (4.07E6 L/month)
Spring (L/season)	1.41E6 (4.7E5 L/month)	4.45E6 (1.48E6L/month)	9.89E6 (3.30E6 L/month)	1.22E7 (4.07E6 L/month)
Summer (L/season)	1.41E6 (4.7E5L/month)	4.45E6 (1.48E6L/month)	9.89E6 (3.30 E6 L/month)	1.22E7 (4.07E6 L/month)
Fall (L/season)	1.41E6 (4.7E5 L/month)	4.45E6 (1.48E6L/month)	9.89E6 (3.30 E6L/month)	1.22E7 (4.07E6 L/month)
Annual Production (L/yr)	5.60E6	1.78E7	3.95E7	4.89E7

Table 20-Annulus Beef Production Utilized in Dose Calculations

	10-20 Miles	20-30 Miles	30-40 Miles	40-50 Miles
Winter (kg/season)	3.12E5 (1.04E5 kg/month)	5.79E5 (1.93E5 kg/month)	1.07E6 (3.57E5 kg/month)	1.68E6 (5.60E5 kg/month)
Spring (kg/season)	3.12E5 (1.04E5 kg/month)	5.79E5 (1.93E5 kg/month)	1.07E6 (3.57E5 kg/month)	1.68E6 (5.6E5 kg/month)
Summer (kg/season)	3.12E5 (1.04E5 kg/month)	5.79E5 (1.93E5 kg/month)	1.07E6 (3.57E5 kg/month)	1.68E6 (5.6E5 kg/month)
Fall (kg/season)	3.12E5 (1.04E5 kg/month)	5.79E5 (1.93E5 kg/month)	1.07E6 (3.57E5 kg/month)	1.68E6 (5.6E5 kg/month)
Annual Production (kg)	1.25E6	2.316E6	4.28E6	6.730E6

Table 21- Annulus Leafy Vegetable Production Utilized in Dose Calculations

	10-20 Miles	20-30 Miles	30-40 Miles	40-50 Miles
Winter (kg/season)	3.95E4 (1.32E4 kg/month)	7.46E4 (2.49E4 kg/month)	8.95E4 (2.98E4 kg/month)	8.22E4 (2.74E4 kg/month)
Spring (kg/season)	1.8E5 (3.94E4 kg/month)	2.24E5 (7.47E4 kg/month)	2.68E5 (8.93E4 kg/month)	2.47E5 (8.23E4 kg/month)
Summer (kg/season)	1.18E5 (3.94E4 kg/month)	2.24E5 (7.47E4 kg/month)	2.68E5 (8.93E4 kg/month)	2.47E5 (8.23E4 kg/month)
Fall (kg/season)	7.89E4 (2.63E4 kg/month)	1.49E5 (4.97E4 kg/month)	1.79E5 (5.97E4 kg/month)	1.64E5 (5.47E4 kg/month)
Annual production (kg/yr)	3.55E5	6.72E5	8.05E5	7.40E5

Table 22- Annulus Vegetation Production Utilized In Dose Calculations

	10-20 Miles	20-30 Miles	30-40 Miles	40-50 Miles
Winter (kg/season)	8.29E5 (2.76E5 kg/month)	1.61E6 (5.37E5 kg/month)	1.79E6 (5.97E5 kg/month)	1.37E6 (4.56E5 kg/month)
Spring (kg/season)	2.49E6 (8.30E5 kg/month)	4.83E6 (1.61E6 kg/month)	5.38E6 (1.79E6 kg/month)	4.11E6 (1.37 E6kg/month)
Summer (kg/season)	2.49E6 (8.30E5 kg/month)	4.83E6 (1.61E6 kg/month)	5.38E6 (1.79E6 kg/month)	4.11E6 (1.37E6 kg/month)
Fall (kg/season)	1.66E6 (5.53E5 kg/month)	3.22E6 (1.07E6 kg/month)	3.59E6 (1.20E6 kg/month)	2.74 E6 (9.13E5 kg/month)
Annual Production (kg/yr)	7.46E6	1.45E7	1.61E7	1.23E7

Table 23- 50 Mile Production Utilized in Dose Calculations

	Milk (L)	Beef (kg)	Leafy Vegetables (kg)	Vegetation (kg)
Winter	2.78E7 (9.27E6L/month)	3.64E6 (1.21E6 kg/month)	2.9E5 (9.70E4 kg/month)	5.60E6 (1.87E6 kg/month)
Spring	2.78E7 (9.27E6 L/month)	3.64E6 (1.21E6kg/month)	8.73E5 (2.91E5 kg/month)	1.68E7 (5.60E6 kg/month)
Summer	2.78E7 (9.27E6 L/month)	3.64E6 (1.21E6 kg/month)	8.73E5 (2.91E5 kg/month)	1.68E7 (5.60E6 kg/month)
Fall	2.78E7 (9.27E6 L/month)	3.64E6 (1.21E6 kg/month)	5.82E5 (1.94E5 kg/month)	1.12E7 (3.73E6 kg/month)
Annual Production	1.11E8	1.46E7	2.62E6	5.04E7

CHARACTERIZATION OF MODEL PARAMETERS AND DETERMINATION OF DOSE DISTRIBUTIONS

Currently used models in regulatory assessment are deterministic. However, a deterministic approach fails to indicate the possible variability in the predicted dose (O'Neill et. al 1981). The range in reported doses was estimated through utilization of the simulation software Crystal Ball. Parameter characteristics utilized in estimating dose distributions were based on previously published analyses. Only distributions of parameters involved in the dose calculation methodology, as outlined in NRC Regulatory Guide 1.109, were considered. Variables were characterized by distributions depicted below. In addition, a sensitivity analysis was conducted using Crystal Ball in order to determine the effect of parameter uncertainty on maximum adult dose forecasts. Sensitivity values were taken as the coefficient of variation introduced to the maximum adult dose distribution due to independent parameter variability. This method of sensitivity determination is well established and its accurate performance has been confirmed (Hamby 1993; Hamby 1995).

Dose distributions were determined for the population and maximum infant, child, teenager, and adult total doses in each month as well as annually. Distributions were assigned using Latin Hypercube sampling due to added precision in estimates over a simple Monte Carlo approach (Hamby 1993). One thousand dose estimates were calculated using the Gaussian atmospheric tritium dose model; Hamby (1993) indicated that the statistics of the dose distribution are not significantly improved by increasing the number of trials above 1,000. It was assumed that all parameters are independent. Iterations of the model provided frequency distributions of total dose.

CHARACTERIZATION OF PARAMETERS ASSOCIATED WITH CALCULATION OF INHALATION DOSE

Breathing Rate. Given the wide range in ventilation rates cited in literature, it is necessary to incorporate age dependent breathing rates into dose calculations. The difference in the range of breathing rates between infants and adults is a factor of 13, while this difference between children and adults is less than a factor of 2 (NCRP 1984). Hoffman and Baes characterized breathing rates for infants, children, teens, and adults. The values reported by Hoffman and Baes were based on reviews of surveys, interviews, metabolic studies, and personal communication. These data do not reflect time averaging, and are lognormally distributed. Breathing rate values found in literature are listed in Tables 24 through 27.

Deterministic values recommended in NRC Regulatory Guide 1.109 were utilized in dose calculations. These values are: 1400 m^3/yr for infants, 3700 m^3/yr for children, and 8000 m^3/yr for teenagers and adults. Arithmatic means were taken of values reported under resting, light activity, active, and maximum work physical states. A weighted average of these values based on the amount of time spent in each state was determined. This weighted value was averaged with mean values cited in literature to obtain final mean breathing rates. It was assumed that infants spend 8 hours resting, 12 hours in light activity, and 4 hours active. It was assumed that children spend 8 hours resting, 12 hours in light activity, 3 hours active, and 1 hour at maximum work. It was assumed that teenagers spend 8 hours resting, 15 hours active, and 1 hour at maximum work. The assumption of 15 hours of activity is conservative and was chosen due to an absence of light activity data. Finally, it was assumed that adults spend 8 hours resting, 14 hours in light activity, 1 hour active, and 1 hour at maximum work. Annual means and standard deviations were divided by twelve in order to obtain monthly values. A review of the literature indicates that infant and teenage breathing rates are lognormally distributed. Based on this observation, it was assumed for this report that breathing rates of all age groups are lognormally distributed.

For infants, the final mean was determined as 1510 m^3/yr. In addition, the geometric standard deviation of 757 and lognormal distribution type reported in NCRP (1984) were utilized. The range utilized was 463-2210 m^3/yr, and is indicative of the minimum and maximum values for all physical activity states in the literature.

For dose distribution purposes, a range of 2700m^3/yr -37300m^3/yr for child breathing rates represents the variation in all values found in literature. In determining the distribution in child doses, the infant standard deviation was assumed to apply. A final mean final child mean value of 4740m^3/yr was determined.

In determining the dose distribution, a range of 3490m^3/yr - 59400m^3/yr in teenage breathing rates represents the range in all values reported at all physical states. A final mean of 10300m^3/yr was calculated. The adult geometric standard deviation of 1700 m^3/yr was assumed to apply to teenage breathing rate data.

Finally, in the case of adults, a range of 1840m^3/yr - 68300m^3/yr represents the variation in all reported values and was used for dose distribution purposes. A mean of 8500m^3/yr and standard deviation of 1700m^3/yr, based on the work of Hamby (1993) and confirmed by the weighted mean value calculated in this report, are the values utilized in dose distribution estimations in the present report.

Deterministic values taken from NRC Regulatory Guide 1.109 were assumed to be representative representative of persons living around the Savannah River Site.

Table 24 Data on Infant Breathing Rates

Source	Study Type	Distribution Type	Value Reported (m^3/yr)	Standard Deviation
NCRP 1984	Literature Review, minimum value reported		463	
NCRP 1984	Literature Review, average of resting values reported		639	
NCRP 1984	Literature Review, average of resting values. Based on three time the resting ventilation		1900	
NCRP 1984	Literature Review		1390	
USNRC 1977			1390	
Hoffman and Baes 1979	Literature Review, average rate		1390	
ICRP 1975	Resting value, up to 1 year of age		788	
ICRP 1975	light activity up to 1 year of age		2210	
NCRP 1984	Literature Review	Lognormal	700(geometric)	1.44
Anspaugh et. al 1973			1830	

Table 25 Data on Child Breathing Rates

Source	Study Type	Value Reported (m^3/yr)
NCRP 1984	Literature Review, average of values listed for resting	2700
NCRP 1984	Literature Review, active value based on three time the resting value	9130
USNRC 1977		3650 (specific for 4 yrs. of age)
Hoffman and Baes 1979	Literature Review	3700
ICRP 1975	Light activity value	6830
Hoffman and Baes 1979	Literature review, average inhalation rate	1470
ICRP 1975	Maximum work value	37300

Table 26 Data on Teenage Breathing Rates

Source	Study Type	Distribution Type	Value Reported (m^3/yr)
NCRP 1984	Literature review, average of boys and girls resting values		3490
NCRP 1984	Literature review, average of boys and girls active value taken		14400
USNRC 1977			8030
Hoffman and Baes 1979	Literature Review		8000
ICRP 1975	Resting value		2730
ICRP 1975	Maximum work value		59400
NCRP 1984	Literature review, light to moderate activity	Lognormal	geometric mean 4310

Table 27 Data on Adult Breathing Rates

Source	Study Type	Value Reported (m^3/yr)	Standard Deviation
NCRP 1984	Literature review, average of men and women's resting values reported	4050	
NCRP 1984	Literature review, average of men's and women's active values reported	14400	
NCRP 1984	Average of men's and women's maximum work values reported	60200	
ICRP 1975	Average of men's and women's values reported	8030	
Hoffman and Baes 1979; Baes et. al 1983	Average value for adults listed	8030	
Hoffman and Baes 1979	Literature review	8000	
NCRP 1984	Literature review, light exercise	1840	
NCRP 1984	Literature review, maximum work	68300	
NCRP 1984; Hamby 1993	Literature review, resting	3940	690 (average of men and women)
NCRP 1984; Hamby 1993	Literature review, light exercise	10500	
NCRP 1984	Literature review. maximum work	53200	
ICRP 1975	average of men's and women's resting values	3130	
ICRP 1975	Average of men's and women's light activity values	11800	
ICRP 1975	Average of men's and women's maximum work values	52800	
Anspaugh et, al 1973		7300	
NCRP 1984	Literature review, average of men's and women's geometric means	60200	694 (average of men and women)
Hamby 1993	Assuming rest for 1/2 of year, heavy exercise for 5hr/wk.	8500	1700

PARAMETERS UTILIZED IN THE CALCULATION OF THE CONCENTRATION OF ^{3}H IN VEGETATION

Various models, such as the Multimedia Environmental Pollutant System, rank vegetable consumption as the predominant pathway in determining health risks (Shevenell and Hoffman 1993).

Humidity. Several studies have been conducted in order to characterize humidity data. Ethnier (1980) calculated the absolute humidity at 218 points across the United States based on annual average temperature and relative humidity data from the 1977 summary of US Climatological Data. The range of absolute humidity values for western South Carolina in this study was reported as 7.6-9.5 g/m^3. In a review of the SITE database, Baes et. al. (1983) reported a range of absolute humidity data in western South Carolina as 6-8 g/m^3. In a site-specific review of weekly average absolute humidity measurements between June 1987 and June 1989, Hamby and Jumper (1990) found that the mean absolute humidity at the Savannah River Site was 11.4 g/m^3, ranging from 3.5g/m^3 to 25g/m^3. Additionally, Hamby (1993) characterized absolute humidity as a normal distribution with a mean of 11.3 g/m^3 and a standard deviation of 0.53 g/m^3.

Based on the above reports , the range in absolute humidity measurements to be used in the uncertainty analysis will be 3.0- 25.6 g/m^3, accounting for the uncertainty of 5% in the measurement instrument utilized by Hamby and Jumper (1990). The parameter was assumed to have a normal distribution with a mean of 11.3 g/m^3 and a standard deviation of 0.53. This value of the standard deviation was chosen over the standard deviation in weekly averages reported by Hamby and Jumper (1990) because the deviation reported in this report was based on weekly measurements, which would be expected to demonstrate more deviation than measurements analyzed on an annual basis. Specific seasonal humidity values were assumed to represent monthly means.

Vegetation to Air Concentration Ratio. The uncertainty in the vegetation-to-air concentration ratio of atmospheric tritium (R) is particularly important to characterize when we consider that errors in estimating the magnitude of this parameter effect milk and meat concentration estimates (Hamby 1994).

Murphy (1984) indicates that the specific activity ratio for atmospheric releases may vary greatly depending on the relative humidity and temperature conditions. Murphy reported ratio values from 0.44 to 1.5 based on environmental monitoring data at the Savannah River Site. Examination of Murphy's data by Hamby (1993) indicated a triangular distribution of the parameter with a range of 0.4 to 1.2.

Later work by Hamby and Bauer (1994) characterized the site specific vegetation-to-air concentration ratio for tritium. Their research was based on measured environmental tritium concentrations in air and vegetation at the site on a nine year basis. This work parameterized seasonal mean ratios of R by a lognormal distribution with a mean of 0.54 and a geometric standard deviation of 0.10. This work suggested a range in R of 0.3 to 0.8 based on site environmental data. This measured value (0.54) was utilized in dose calculations rather than the NRC default value of 0.50. Further, ranges of 0.17 to 0.49 (Belot et. al 1979; Anspaugh et. al 1973) have been reported.

Based on the above observations, R in this report was characterized by a lognormal distribution with a mean of 0.54 and a geometric standard deviation of 0.10. The geometric mean was utilized in dose calculations. The average of the minimum reported values is 0.33, while the average of the maximum reported values is 1.00 . Therefore, the variation utilized in estimating the dose distribution was 0.33 to 1.00.

Time Between Harvest and Consumption.

Uncertainty in the transport time for vegetables and other foods is assumed to be insignificant based on the relatively long half life of tritium. Baes et. al. (1983) indicated that the mean time between harvest and consumption for leafy vegetables and produce is 336 hours. Based on this analysis, the mean value for the time between harvest and consumption for fruits, vegetables, and grains was assumed to be 336 hours. The range in values was assumed to be 1 to 20 days (Hamby 1994, Hamby 1991). For produce, the time between harvest and consumption is estimated at 60 days (USNRC 1977). The range in this value was arbitrarily assigned as 0-100 days. The distribution type of this parameter was assumed to be lognormal, based on the finding of Hamby (1993) that meat and milk transport times are lognormal. The standard deviation determined for milk and beef transport time (0.39 days) was assumed to apply to this parameter. Deterministic values were assumed to represent means. The deterministic values for maximum and average individuals, as outlined in NRC Regulatory Guide 1.109, were utilized in dose calculations. These determinations are 24 hours for the transport time for leafy vegetables to the maximum individual, 60 days for transportation of all other produce to the maximum individual, and a 14 day transport time to the general population.

Feed Storage Time. O'Neill et. al (1981) indicated that this parameter has a triangular distribution with a mean value of 90 days. Baes et. al (1983) confirmed this mean value.

Based on the above analysis, the feed storage time was assumed to have a triangular distribution with a mean of 90 days. Feed storage times around the Savannah River Site range from 1 month to 1 year (Hamby 1992), and these conditions deem the NRC stored feed default value of 90 days appropriate for the site. The range in values noted at the Savannah River Site was used as the parameter range. The NRC default value was utilized in all dose calculations.

Fraction of Water in vegetation. Hamby (1993) estimated a distribution in this parameter to account for the different types of vegetation being consumed in the southeast. Based on a review of the literature, Hamby assigned a triangular distribution to the parameter with a mean of 0.86, and upper and lower bounds on the parameter of 0.77 to 0.95, respectively. This information was used in dose distribution estimates. The deterministic value listed in NRC Regulatory Guide 1.109 is 0.75, and this value was utilized in all dose calculations.

PARAMETERS UTILIZED IN THE CALCULATION OF ^{3}H CONCENTRATION IN MILK

It was assumed that all feed consumed by beef and dairy cows is contaminated (Shevenell and Hoffman 1993).

Fraction of Feed Taken From Pasture (f_s).

A review of the literature indicates that this parameter is normally distributed (O'Neill et. al 1981; Hoffman and Baes 1979). In addition, the literature is in agreement that the mean value for the fraction of feed taken from the pasture is 0.43, with a standard deviation of 0.13 (O'Neill et. al 1981;

Hoffman and Baes 1979; Baes et. al 1983). Hoffman and Baes (1983) indicated a range in the variable from 0.1 to 0.8.

Based on the above findings, the fraction of feed taken from pasture was assumed to be normally distributed with a mean of 0.43 and a standard deviation of 0.13 for both milk and beef cows. The site specific values of 0.56 for milk cows and 0.75 for beef cows, as determined by Hamby (1992) were utilized in dose calculations. Based on the work of Hoffman and Baes (1979), a range in the variables from .1 to 0.8 was assumed.

Fraction of Time on Pasture(f_p). The literature is in agreement that this parameter is normally distributed (O'Neill et. al 1981; Hoffman and Baes 1979). In addition, reviewed reports consistently report a mean value of 0.40 for the parameter (O'Neill et, al 1981; Hoffman and Baes 1979; Baes et, al 1983). The most commonly quoted standard deviation for the parameter is 0.22 (O' Neill et. al 1981; Hoffman and Baes 1979; Baes et, al 1983). However, Little and Miller (1979) report a standard deviation of 0.41. Further, Hoffman and Baes (1979) indicate a range in the parameter from 0.1 to 1.0.

Based on the above analysis, the fraction of time spent on pasture for all cow types was assumed to be normally distributed with a mean of 0.40 for dose distribution purposes. A mean of the reported standard deviations was taken to obtain a deviation of 0.27 to be utilized in dose distribution estimations. The range was assumed to be 0.1- to 1.0 based on the work of Hoffman and Baes (1979). A site specific value of 1.0 rather than the NRC default value of 0.75, was used in dose calculations (Hamby 1992).

Feed Consumption Rate. A review of the literature yielded the information in Table 28.

Table 28 Data for Dairy Cow Feed Consumption Rate

Source	Study Type	Distribution Type	Mean (kg/day)	Standard Deviation (kg/d)	Range (kg/d)
Hoffman and Baes (1979)	Literature Review from Dairy Herd Improvement Association	Normal	16 (dry)	2.6 (dry)	6-25 (dry)
O'Neill et. al (1981)	Literature Review	Normal	16 (dry)	2.6	
Shevenell and Hoffman (1993)	Literature Review	Normal Triangular	11 (dry)	2.6	4-25
Hoffman et. al (1982)	Literature Review*	Normal	11 (dry) (geometric)	2.6	4-25
Ng. et. al (1977)			50 (wet)		
Hamby (1993)	Literature Review	Normal	13.1(dry)	2.9	
Little and Miller (1979)				0.12	

*This data is taken from the National Dairy Herd Improvement Association, which collects data for 11% of the entire US dairy population. Values were averaged for herds, not individual cows.

Based on the above information, the dairy cow feed consumption rate was assumed to be normally distributed. The arithmatic means of the listed mean and standard deviation values were taken to obtain a mean of 53 kg/day (wet) and a standard deviation of 8.9 (wet) to be utilized in dose distribution estimations. The range in the parameter was estimated from the ranges reported in literature, and was found to be 16-100 kg/day (wet). A site specific value of 52 kg/d (wet), rather than the default value recommended by the NRC, was utilized in dose estimations (Hamby 1993).

Transport time for milk. O'Neill et. al (1981) suggest that this parameter has a triangular distribution. However, Hamby (1993) indicates that the parameter is lognormally distributed. Hamby (1993) reports a mean value for the parameter of 3.1 days, while Hoffman and Baes (1979) suggest that the mean value is 1 day. Hamby (1993) recommends a geometric standard deviation of 0.39 days.

A lognormal distribution was assumed for this parameter, as it was not clear how the triangular distribution reported by O'Neill et. al was determined. The arithmatic mean of the values reported by Hamby (1993) and Hoffman and Baes (1979) was taken to obtain a mean value of 2.05 days. The geometric standard deviation reported by Hamby (0.39) was utilized in dose distribution estimations. The range was assumed to span an order of magnitude from 1 to 10 days based on area-specific data for milk processing (Hamby 1993; Hamby 1991). The lower bound on this range was extended to zero in order to account for maximum individual exposure. The site specific value of 3 days reported by Hamby (1992) was used in dose calculations rather than the default value of 4 days suggested by the NRC.

Transfer Coefficient For Milk. Much uncertainty exists in estimating the transfer coefficient, F_m. Transfer coefficient data is often based on experiments that were designed for purposes other than the evaluation of transfer factors (Ng, 1982). In addition, in many estimations of transfer coefficients, assumptions must be made regarding the milk secretion rate, the kilograms of feed ingested by the cow, or the total activity expected to be secreted beyond the duration of an experiment (Ng, 1982). A review of the literature indicated the parameter characters listed in Table 29.

Table 29 Data for the Tritium Milk Transfer Coefficient

Source	Study Type	Distribution Type	Mean (d/L)	Range (d/L)
Ng (1982)	Literature Review [1]		1.0E-2	
Hoffman and Baes (1979)	Literature Review	Lognormal		
Ng et.al. (1977)			1.3E-3[2]	
Ng. et. al (1977)			1.1E-2[3]	
Ng. et. al. (1977)			1.4E-2	
Ng. et. al (1968)			2.00E-2[5]	
Ng. et. al. (1978)			1.4E-2	
Hamby (1992)	Literature Review	Uniform	0.01d/L	0.002-0.02
Ng. et. al (1977)			2.4E-2[4]	

[1] reported values are unweighted means of mean values reported in literature, F_m is based on the recovery of a single administered dose of a radioisotope.
[2]This value is derived from data on oral administration of tritiated water
[3]This value is derived from oral; administration of THO
[4]This value is derived from studies where animals were fed THO for 40 and 150 days.
[5]This value is the estimated maximum value

The parameter distribution for the feed-to-milk transfer coefficient was assumed to have a uniform distribution, as the lognormal distribution suggested by Hoffman and Baes (1979) is based on radionuclides other than tritium, and a lack of data exists for the characterization the transfer coefficient for tritium. Therefore, the uniform value reported by Hamby (0.01d/L) was utilized in dose distribution estimations. The range in the parameter reported by Hamby (1993), based on an assumption of an order of magnitude range, was 0.002 to 0.02 d/L, and was utilized in dose distribution calculations. The default value suggested by the NRC is 0.01d/L, and was utilized in all dose calculations.

PARAMETERS UTILIZED IN THE CALCULATION OF ^3H CONCENTRATION IN BEEF

Transfer Coefficient for Beef. Beef transfer coefficients reported in Regulatory Guide 1.109 are based on the average concentration in meat divided by 50 times the average concentration in food derived from plants (Ng 1982). In general, the variability in the beef transfer coefficient derived from stable element concentrations in unassociated meat and vegetation is characterized by geometric standard deviations ranging from 1.3d/kg to 3.8 d/kg with a mean of 0.012d/kg (Ng 1982). Hoffman and Baes (1979) suggested a lognormal distribution for the parameter. Finally, Tandy and Thompson (1978) suggested a mean value for the parameter of 0.018 d/kg. Given the uncertainty in the parameter data, a uniform distribution was assumed for the tritium meat transfer coefficient, centered around the default value of 0.012 d/kg suggested by the NRC. This default value was utilized in dose calculations. In addition, the order- of- magnitude range suggested by Hamby (0.002-0.02 d/kg) was assumed.

Feed Consumption Rate. Hamby (1993) suggested that the feed consumption rate by beef cows is normally distributed with a mean of 18.9 kg/day and a standard deviation of 4.0 kg/day. Shevenell and Hoffman (1993) confirmed the normality of the parameter, but suggested a mean value of 8.3 kg/day and a standard deviation of 2.0 kg/day. Further, Shevenell and Hoffman (1993) indicated a range in the parameter of 1.6 kg/day - 18 kg/day.

A review of the above analysis indicated that this parameters is normally distributed. The mean utilized in dose distribution estimations was calculated by taking the arithmatic average of the mean values reported. This value was determined to be 13.6 kg/d. Similarly, the standard deviation in the parameter was determined as the mean of the two reported values, or 3.0 kg/d. The range in the parameter was the range indicated by Shevenell and Hoffman (1993) with the upper bound increased to include the mean value reported by Hamby (1993). This range is 1.6 to 18.9 kg/d. The site specific value of 36 kg/d reported by Hamby (1992) was utilized in all dose calculations.

Time Between Slaughter and Consumption. Hamby (1993) indicated that this parameter is lognormally distributed with a mean of 153 hours and a standard deviation of 8.6 hours. The range in this parameter reported by Hamby (1993) was arbitrarily chosen to span an order of magnitude from 48 to 480 hours. Hoffman and Baes (1979) indicated a mean value of 300 hours for the parameter.

Based on the above review, this parameter was assumed to be lognormally distributed. The mean value to be utilized in dose distribution estimations was calculated as the arithmatic average of the mean values reported. This value was calculated as 227 hours. The geometric standard deviation of the parameter was taken from the work of Hamby (1993) and was assigned a value of 8.6 hrs. The range for maximum individuals was arbitrarily chosen as zero to 10 days. A site specific value of 6 days was utilized in dose calculations rather than the default value of 480 hours recommended by the NRC.

CONSUMPTION RATES

Values taken from Rupp (1980), although from a review of the literature, were predominantly based on values from the USDA survey of 1965. Mean values indicated in this section were utilized in determining the percentage of food groups consumed by different age groups; these values were not utilized in dose calculations or dose distribution estimations.

Age and season dependent consumption rates for maximum individuals utilized in dose calculations and distribution estimates are listed in the section of this report entitled “Age and Season Dependent Consumption Values Utilized on Dose Calculations”. In estimating maximum individual dose distributions, maximum individual consumption values obtained from the USDA 1978 Food Consumption Survey were assumed to represent mean values. The standard deviation in these values was determined from the work of Hamby (1991). The variability factors listed in the maximum individual consumption tables represent 3 standard deviations divided by consumption rate (Hamby 1991). Minimum and maximum individual consumption rates were assumed to span 3 standard deviations. Distribution types for average individuals were assumed to be representative for maximum individuals.

Milk. A review of the literature pertaining to milk consumption rates for infants and children yielded the characterizations indicated in Tables 30 and 31, respectively. This literature review indicates that milk consumption by infants and children is lognormally distributed. An arithmatic average of all mean values reported was taken to yield a mean of 281L/yr for infants and 203L/yr for children. No distinction was made for infants of different ages, as any individual under the age of 1 year was considered an infant in the present study.

Rupp (1980) suggested a mean annual milk consumption by teenagers from age 11 to age 18 of 177L/yr, while Hoffman and Baes (1979) suggest 200L/yr as the mean value for teenage milk consumption. The distribution of milk consumption in teenagers was expected to be represented by milk consumption in other age groups. Therefore, a lognormal distribution was assumed. The mean, calculated as the arithmatic average of values reported in literature, was assigned a value of 189 L/yr.

Review of the literature regarding adult milk consumption yielded the data listed in Table 32. Based on the this review, adult milk consumption was assumed to be lognormally distributed. The mean, estimated from the averages of the reported values, was determined to be 97.4L/yr.

It was estimated that infants consume 4.4% of milk in the South, children consume 25.4 % of milk, teenagers consume 16.2% of milk, and adults consume 54.0% of milk .

Table 30 Data on Infant Milk Consumption

Source	Study Type	Distribution Type	Mean (L/yr)
O'Neill et. al (1981)	Literature Review	Lognormal	305
Rupp (1980) (up to 4 mo.)	Literature Review		273
Rupp (1980) (4-6 mo.)	Literature Review		292
Hoffman and Baes (1979) (4-6 mo.)	Literature Review	Lognormal	305 (54%) Median:299 Mode: 287 (42%)
Hoffman and Baes (1979) (6-12 mo.)	Literature Review	Lognormal	276 (54%) Most Probable:259 (42%) Median:270 (50%)
Hoffman and Baes (1979) (0-12 mo.)	Literature Review	Lognormal	273(55%) Median:270 (50%) Most Probable:266 (45%)
Hoffman and Baes (1979)(0-4 mo.)	Literature Review	Lognormal	273 (52%) Median:270 Most probable:226
Rupp (1980) (1 year of age)	Literature Review		254*

*This mean value is the average milk consumption for all infants less than one year of age

Table 31 Data on Child Milk Consumption

Source	Study Type	Distribution Type	Mean (L/yr)
Rupp (1980) (1-11 yrs)	Literature Review		198
Hoffman and Baes (1979)	Literature Review		170
Hoffman and Baes 91979) (12-18 mo.)	Literature Review	Lognormal	223 (52%) Most Probable:218 (45%) Median:221 (50%)
Hoffman and Baes (1979) (12-24 mo.)	Literature Review	Lognormal	222(51%) Most Probable:220 (47%) Median:221 (50%)

Table 32 Data on Adult Milk Consumption

Source	Study Type	Distribution Type	Mean (L/yr)
Rupp (1980) (>18 yrs)	Literature Review		95.3
Shevenell and Hoffman (1993)*	Literature Review	Lognormal	95.0
Hoffman et. al (1982)*[1]	Literature Review	Lognormal	95
Baes et. al (1983)			112
Hamby (1993)	review of Dept. of Agriculture Data	Lognormal	77
Hoffman and Baes (1979)	Literature Review		110

*Any consumption rate without an age specified was assumed to be an adult rate
[1]Minimum and maximum values in this report were indicated as 4 times the observed range. This was an arbitrary decision.

Beef. Beef consumption was assumed to be lognormally distributed for all age groups (Hoffman and Baes 1979; Shevenell and Hoffman 1993; Hamby 1993).

Rupp (1980) reported mean values for infant, child, and teenage beef consumption of 0.007 kg/yr, 13.9 kg/yr, and 24.1 kg/yr. Hoffman and Baes (1979) indicated that these mean values are 0.05 kg/yr (meat and poultry), 37 kg/yr, and 59 kg/yr, respectively. The mean given by Rupp (1980) was utilized for infant beef consumption, as the mean indicated by Hoffman and Baes includes poultry.

The means for children and teenagers, determined as the arithmatic average of values reported in literature, were found to be 25.4 kg/yr and 41.5 kg/yr, respectively.

A review of the literature indicated the parameter characterizations for adult beef consumption listed in Table 33. The mean, determined as the average of reported values, was assigned a value of 70.9 kg/yr.

It was estimated that infants consume 0.00024% of beef in the South, children consume 6.8% of beef, teenagers consume 7.7% of beef, and adults consume 85.5% of beef.

Table 33 Data on Adult Beef Consumption

Source	Study Type	Distribution Type	Mean (kg/yr)	Standard Deviation (kg/yr)
Rupp (1980)	Literature Review		31.39	
Shevenell and Hoffman (1993)*	Literature Review	Lognormal	94	1.65
Miller and Hoffman (1982)	Literature Review		94	1.65
Baes et. al (1983)			32	
Hamby (1993)	Review of Dept. Agriculture Data	Lognormal	79	0.68
Hoffman and Baes (1979)	Literature Review		95	

* Any adult consumption rate without an age specified was assumed to be an adult consumption rate

Vegetables (Leafy). Leafy Vegetable consumption was assigned a lognormal distribution for all age groups(Hoffman and Baes 1979).

Rupp (1980) reported the following mean values for leafy vegetable consumption : 0.73 kg/yr for infants, 7.3 kg/yr for children, and 10.0 kg/yr for teenagers. Hoffman and Baes suggest these mean value are 0.70 kg/yr, 7.0 kg/yr, and 11.0 kg/yr, respectively. The means were calculated as the average of the two reported values, and were assigned values of 0.72 kg/yr, 7.2 kg/yr, and 10.9 kg/yr, respectively.

A review of the literature yielded the adult leafy vegetable characterizations listed in Table 34. The mean, calculated as the average of all reported values, was determined to be 18.04 kg/yr.

It was found that infants consume 0.09% of leafy vegetables, children consume 7.6% of leafy vegetables, teenagers consume 8% of leafy vegetables, and adults consume 84% of leafy vegetables

Table 34 Data on Adult Leafy Vegetable Consumption

Source	Study Type	Distribution Type	Mean (kg/yr)
Rupp (1980) (>18yrs.)	Literature Review		18.25
Shevenell and Hoffman (1993)*	Literature Review	Logtriangular	18
Hoffman et, al. (1982)*[1]	Literature Review	Lognormal	18 (geometric)
Hoffman and Baes (1979)	Literature review	Lognormal	18
Baes et, al. (1982)			18
Hamby (1993)	Review of Dept. of Agriculture Data	Lognormal	47
Miller and Hoffman (1982)	Literature Review	Lognormal	18 (geometric)

* Any consumption rate without an age specified was assumed to be an adult consumption rate
[1]Minimum and maximum values in this report were determined as 4 times the observed range. This was an arbitrary decision

Non-Leafy Vegetables, Fruits, and Grains. Infant, child, and teenage non-leafy vegetable, fruits, and grains consumption rates were assumed to be lognormally distributed based on the observation that consumption rates of other food items by these age groups were lognormally distributed. Adult consumption of these food items was assumed to be lognormally distributed based on the work of Hoffman et. al (1982).

A review of the literature indicated the parameter characterizations for infants, children, teenagers, and adults listed in Tables 35 through 38, respectively. For every age group, the average of reported values for the categories of non-leafy vegetables, fruits, and grains were found. These average values were summed and then averaged with the fruits, vegetables, and grains rate reported by Hoffman and Baes (1979) in order to determine a mean non-leafy vegetable, fruits, and grains consumption rate. This procedure gave mean consumption rates for infants, children, teenagers, and adults of 109 kg/yr, 206 kg/yr, 226 kg/yr, and 211 kg/yr, respectively.

It was found that infants consume 1% of food in this category, children consume 15.7% of food in this category, teenagers consume 11.9% of food in this category, and adults consume 71.4% of food in this category.

Table 35 Data on Infant Non-Leafy Vegetable, Fruits, and Grain Consumption

Source	Non-leafy Vegetables, Fruits, or Grains	Study Type	Distribution Type	Mean (kg/y)
Rupp (1980) (<1 yrs)	Non-leafy Vegetables	Literature Review		12
Rupp (1980) (1-11yrs), Hoffman and Baes (1979)	Citrus fruit	Literature Review	Lognormal	23
Rupp (1980) (<1 yrs)	Other Fruit	Literature Review		112
Rupp (1980) (<1yrs)	Grains	Literature Review		21
Hoffman and Baes (1979)	Fruits, vegetables, grains	Literature Review	Normal	88
Baes et. al (1983)	Grains			35
Baes et. al (1983)	Other Vegetables			45
Baes et. al (1983)	Below ground vegetables			28
Rupp (1980) (<1 yrs)	Other Vegetables	Literature Review		50

Table 36 Data on Child Non-Leafy Vegetable, Fruits, and Grain Consumption

Source	Non-leafy Vegetables, Fruits, or Grains	Study Type	Mean (kg/y)
Rupp (1980) (1-11 yrs)	Non-leafy Vegetables	Literature Review	7
Rupp (1980) (1-11 yrs)	Citrus fruit	Literature Review	74
Rupp (1980) (1-11 yrs)	Other Fruit	Literature Review	112
Rupp (1980) (1-11yrs)	Grains	Literature Review	87
Hoffman and Baes (1979)	Fruits, vegetables, grains	Literature Review	200
Rupp (1980) (1-11 yrs)	Other Vegetables	Literature Review	58

Table 37 Data on Teenage Non-Leafy Vegetable, Fruits, and Grain Consumption

Source	Non-leafy Vegetables, Fruits, or Grains	Study Type	Distribution Type	Mean (kg/y)
Rupp (1980) (>11-18 yrs)	Non-leafy Vegetables	Literature Review		7
Rupp (1980) (>11-18 yrs)	Citrus fruit	Literature Review		93
Rupp (1980) (>11-18 yrs)	Other Fruit	Literature Review		116
Rupp (1980)(>11-18yrs)	Grains	Literature Review		113
Hoffman and Baes (1979)	Fruits, vegetables, grains	Literature Review		240,185
Rupp (1980) (11-18 yrs)	Other Vegetables	Literature Review		82

Table 38 Data on Adult Non-Leafy Vegetable, Fruits, and Grain Consumption

Source	Non-leafy Vegetables, Fruits, or Grains	Study Type	Distribution Type	Mean (kg/y)
Hoffman et. al (1982)*[1]	Non-leafy Vegetables	Literature Review	Lognormal	45
Rupp (1980) (>18 yrs)	Non-leafy Vegetables	Literature Review		8
Rupp (1980)	Citrus fruit	Literature Review		99
Rupp (1980)	Other Fruit	Literature Review		87
Rupp (1980)	Grains	Literature Review		97
Miller and Hoffman (1982)	Non-Leafy Vegetables	Literature Review		45
Hoffman and Baes (1979)	Fruits, vegetables, grains	Literature Review		190,176
Rupp (1980)	Other Vegetables	Literature Review		99

* Any consumption rate not age specific was assumed to be an adult rate. This value assumes 25% of non-leafy vegetables are home-grown.
[1]Minimum and maximum values in this report were determined as 4 times the observed range. This was an arbitrary decision.

TRITIUM DOSE FACTORS

Shevenell and Hoffman (1993) report that the ingestion dose factor for tritium is lognormally distributed. Based on this work, both the ingestion and inhalation dose factors were assigned lognormal distributions. Values utilized in dose calculations were assumed to be mean values, and are listed in the dose calculation methodology section. Maximum and minimum values were estimated as differing from the mean by a factor of ten (Hoffman and Miller 1983). The maximum values were assumed to represent 3 standard deviations.

Further investigations of this parameter involved estimation of the parameter range through Crystal Ball simulation.

The tritium dose factor is given by:

$$DF = \frac{0.592\ Q\ E\ f\ T_e}{\ln(2)\ M} \qquad (15)$$

where:

Q = The quality factor for tritium

E= The energy emitted per nuclear transition

f = fraction of energy being deposited in the organ of interest

M = soft tissue mass

T_e = Biological half life of tritium

All variables other than the soft tissue mass and the biological half-life of tritium were held constant. Both the soft tissue mass and the biological half-life were assigned lognormal distributions (Hamby 1993). The biological half life was assigned a range of 8 to 12 days, with a geometric mean of 8.7 days and a geometric standard deviation of 0.27 (Hamby 1993). The soft tissue mass was assigned a geometric mean value of 70 kg with a geometric standard deviation of 0.14. The range in this variable was assigned as 50 kg to 95 kg (Hamby 1993). A simulation forecasting the range in the dose factor indicated a range in the dose factor of a factor of 2 rather than a factor of 100, as indicated by Hoffman and Miller (1993). The range utilized in dose distribution calculations was found to be very conservative.

RESULTS

Comparison of Doses Based on Five Year and Monthly Meteorological Data. The doses to maximum individuals in each age group and the population in the west-northwest sector via inhalation and absorption of tritium through the skin, milk, beef, and vegetation pathways are listed by month and year in Appendix B. Monthly doses for each pathway were summed and compared to annual averaged values in order to determine the difference between annual average values based on a five year meteorological database versus monthly estimates.

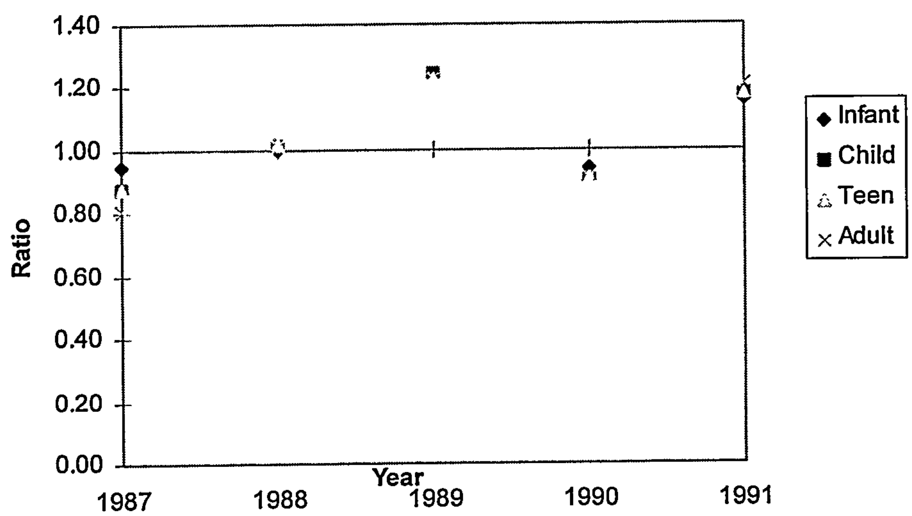
Plots of the ratio of maximum individual annual averaged dose to monthly summed dose for each pathway are indicated in Figures 2 through 6. It is evident that maximum individual dose is not consistently over or under estimated by annual averaged values for any pathway. However, the average ratio of annual averaged to summed monthly values over five years indicates an overestimate in each case. The magnitude of these overestimations is indicated in Table 39. The trend of discrepancies noted is consistent in every pathway. This is expected; the accuracy of using averaged meteorological data to represent monthly conditions is reflected in all pathways. In addition, discrepancies in monthly summed versus annual averaged values are consistent for all age groups. This finding is an artifact of identical dose equations utilized in the calculation of doses to each age group.

Table 39 Average Ratios of Annual Averaged to Monthly Summed Doses Over Five Years

Pathway	Average Overestimate for Maximum Individuals	Average Overestimate for Population	Mean Overall Overestimate
Total Dose	4%	6%	5%
Inhalation and Absorption through Skin	6%	6%	6%
Milk	2%	3%	2%
Beef	2%	6%	3%

Discrepancies in monthly summed versus annual averaged doses were found to originate in misrepresentations of monthly meteorological data by 5 year averaged frequency distributions. These discrepancies are reflected in divergent air concentrations. For example, the summed population total dose in 1990 differs from the annual averaged value by 6%, while the 1991 comparison indicated a difference of 26%. This difference in the ability of 5 year averaged data to represent monthly doses is depicted in differences in air concentrations resulting from assumed meteorological conditions; in 1990 the average difference in air concentrations in sector regions was 6.6%, while in 1991 this average difference was 28.2%. The 1990 population dose is better represented by the 5 year data because the meteorological conditions during this year more closely parallel conditions represented by the 5 year meteorological data set; in 1990, the average percent difference in annual averaged and monthly wind speeds was 8.9%, and the percent difference in frequency estimations was 52.9%. This may be contrasted with percent differences in 1991 of 10.5% and 76.1%, respectively.

Figure 2
Ratio of Annual Average to Monthly Summed Total Dose
Estimates for Maximum Individuals



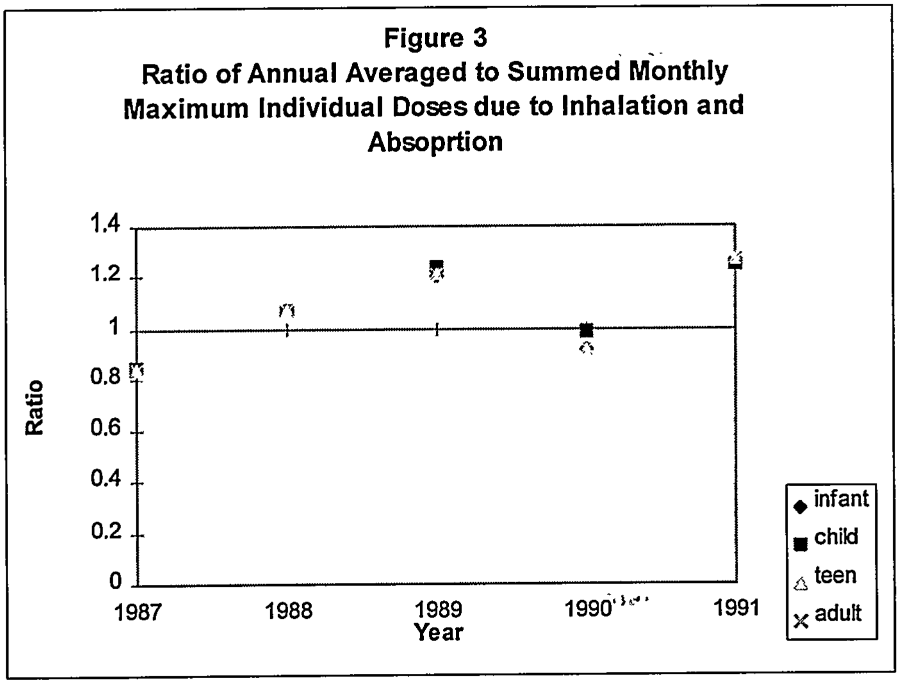


Figure 3
Ratio of Annual Averaged to Summed Monthly Maximum Individual Doses due to Inhalation and Absoprtion
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Ratio
1987
1988
1989
1990
1991
Year
infant
child
teen
adult

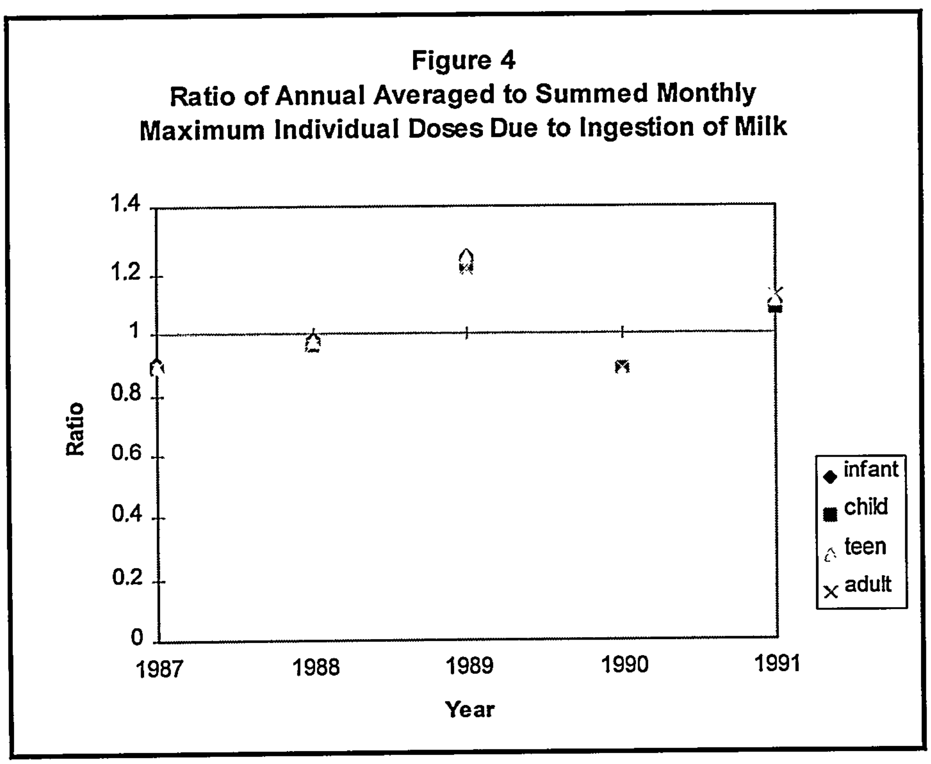


Figure 4
Ratio of Annual Averaged to Summed Monthly Maximum Individual Doses Due to Ingestion of Milk
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Ratio
1987
1988
1989
1990
1991
Year
infant
child
teen
adult

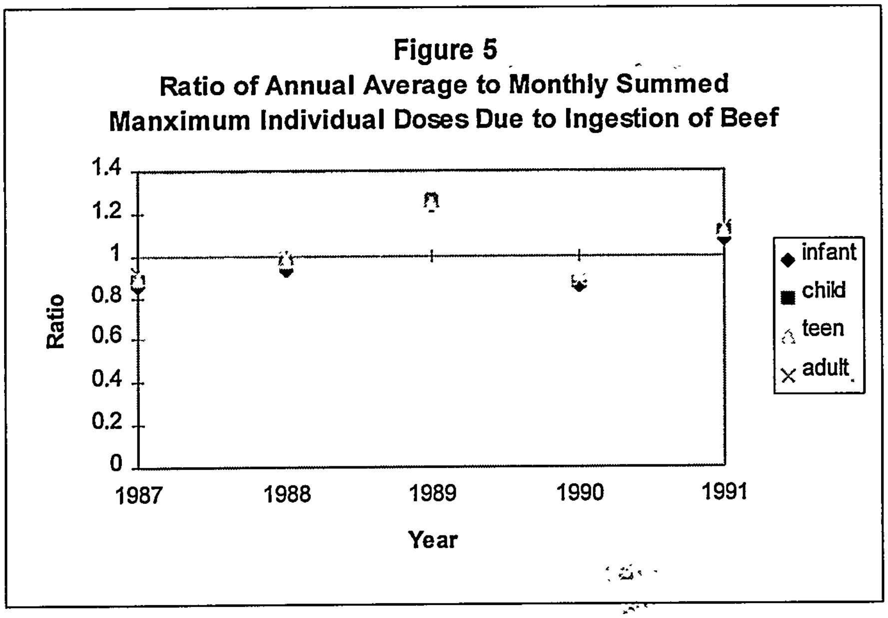


Figure 5
Ratio of Annual Average to Monthly Summed
Manximum Individual Doses Due to Ingestion of Beef
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Ratio
1987
1988
1989
1990
1991
Year
infant
child
teen
adult

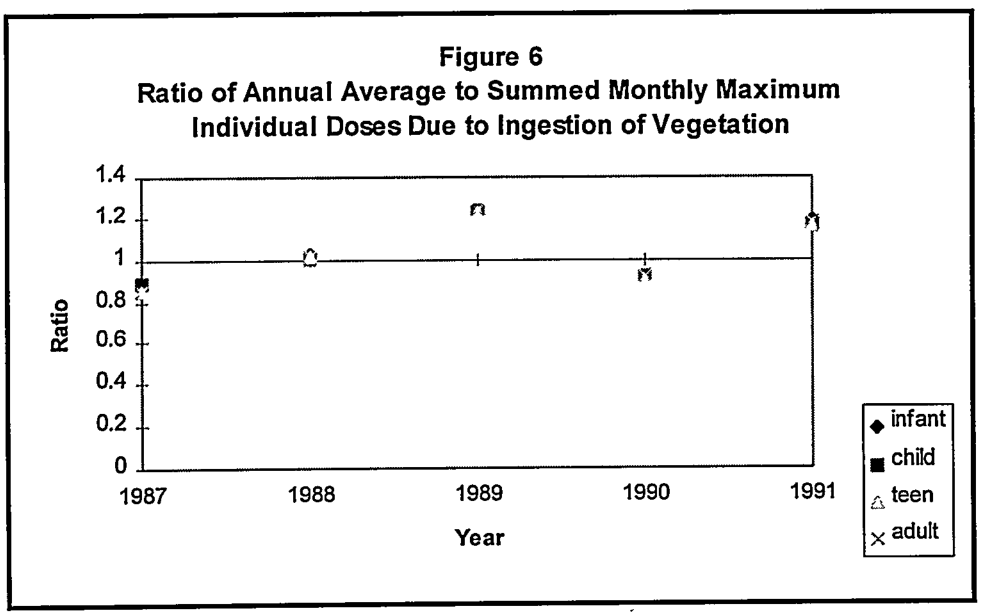
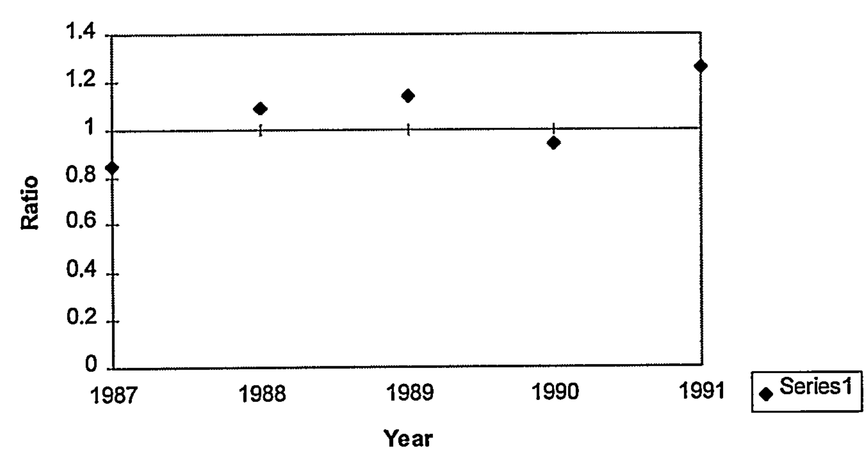


Figure 6
Ratio of Annual Average to Summed Monthly Maximum
Individual Doses Due to Ingestion of Vegetation
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Ratio
1987
1988
1989
1990
1991
Year
infant
child
teen
adult

Ratios of annual averaged to monthly summed population doses for each pathway are represented in Figures 7 through 11. As expected, population dose discrepancies in all pathways follow the trends noted for maximum individuals. This finding is due to the fact that discrepancies in doses stem from differences in air concentrations. Discrepancies in any given month are reflected in concentration calculations for maximum individuals and the population equally. However, slight differences in ratios between maximum individual and population doses (within 10%) were noted due to averaging of age group and distance discrepancies in population calculations. Population total doses are not consistently over or under estimated by averaged data. However, the mean of annual averaged to monthly summed ratios over 5 years is greater than 1.00 for every pathway, indicating an average overestimate of monthly doses by averaged meteorological data over a five year period. Differences in overestimates between population and individual doses are slight; therefore, population and maximum individual doses are equally overestimated in each pathway. Overall discrepancies in each pathway are indicated in Table 39.

Figure 7
Ratio of Annual Average to Monthly Summed Total Dose Estimates for the Population



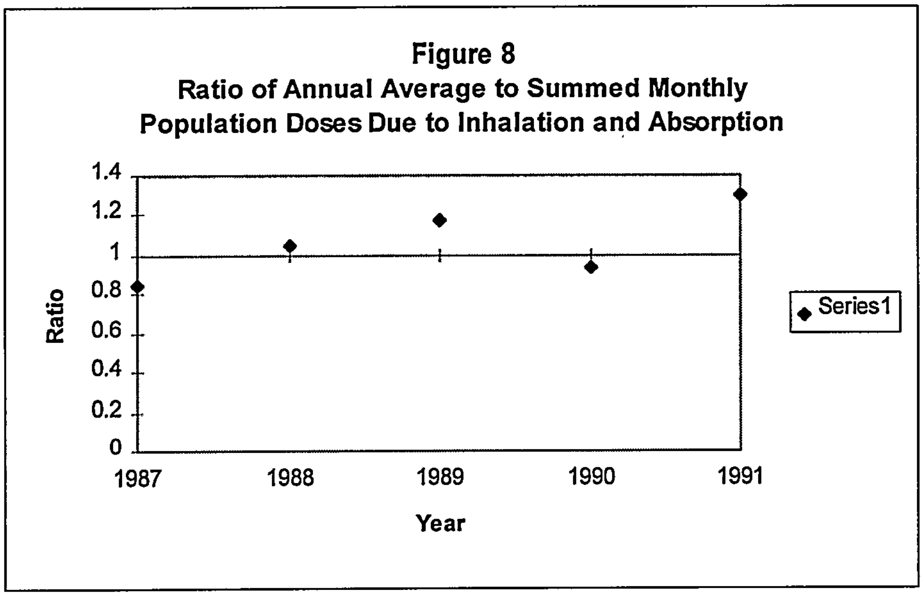


Figure 8
Ratio of Annual Average to Summed Monthly Population Doses Due to Inhalation and Absorption
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Ratio
1987
1988
1989
1990
1991
Year
Series1

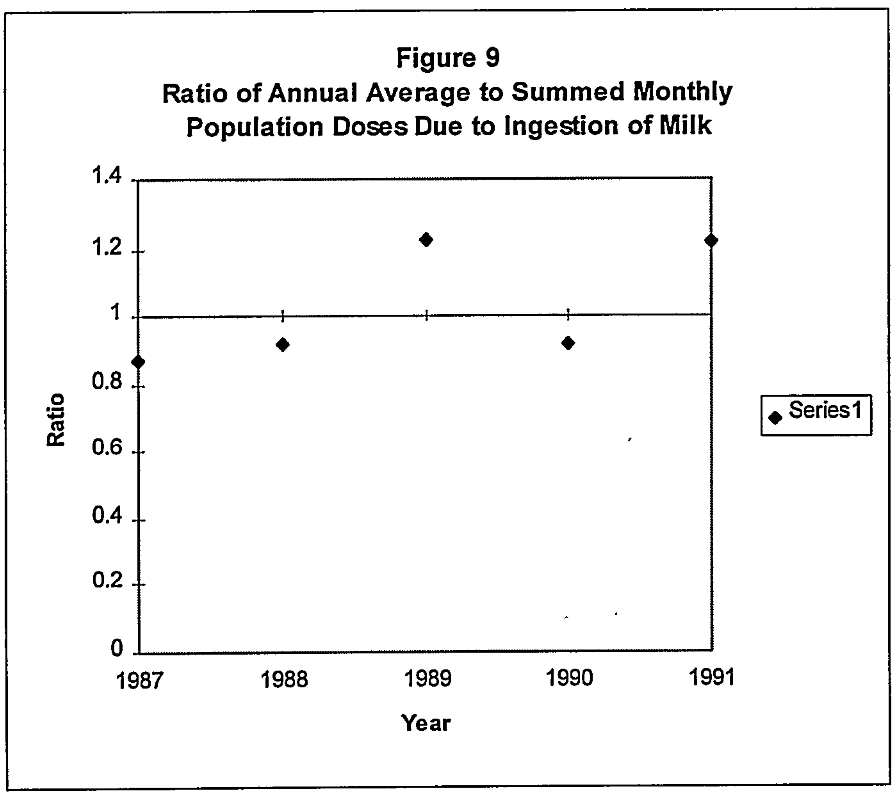
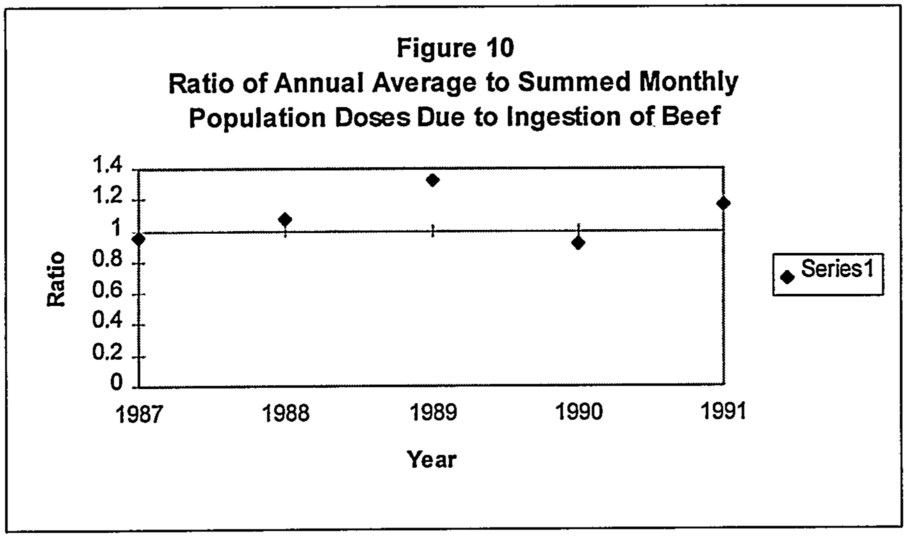
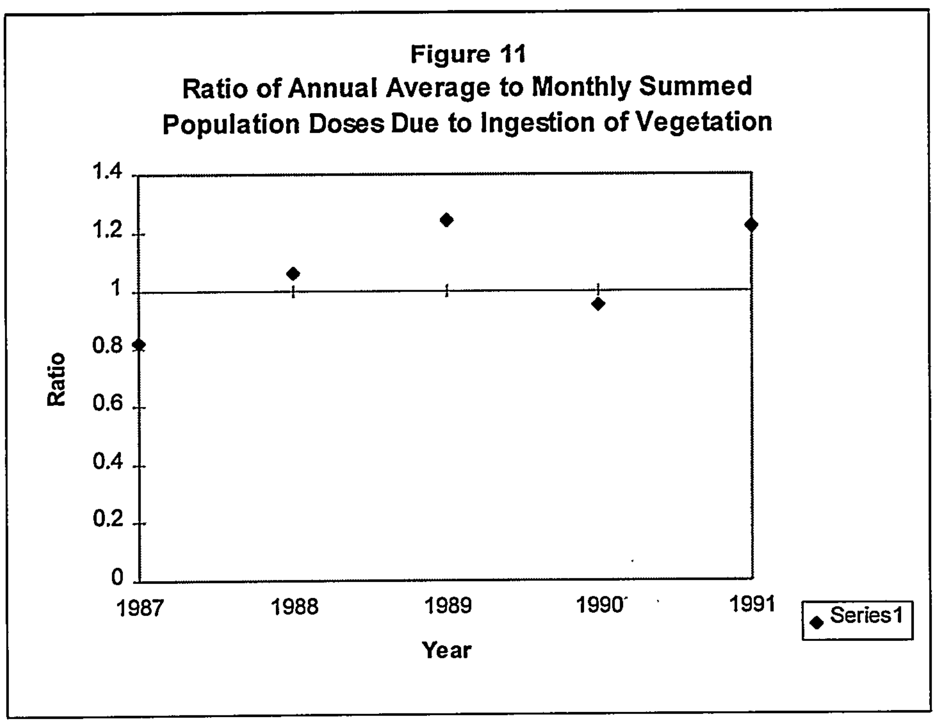


Figure 9
Ratio of Annual Average to Summed Monthly Population Doses Due to Ingestion of Milk
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Ratio
1987
1988
1989
1990
1991
Year
Series1





Some differences in the accuracy of averaged data in predicting doses due to ingestion of foods in comparison with inhalation doses were noted. For example, in 1990, annual averaged maximum individual inhalation doses differed from monthly summed doses by 6%. The percent difference between annual averaged and monthly summed maximum individual milk doses in this year, however, was 12.5%. This difference may be attributed to the relative effect of air concentration discrepancies on inhalation and ingestion doses. Specifically, differences in air concentrations are directly reflected in inhalation and absorption doses, while differences in ingestion doses are indirectly influenced through concentrations in foodstuffs. For example, an averaged air concentration which is higher than a monthly concentration may be negated by a monthly humidity value which is lower than the annual average humidity value utilized. In addition, the slightly less extreme overestimates noted for the milk and beef pathways in comparison to vegetation ratios may be attributed to the relatively constant consumption of milk and beef through the seasons.

In summary, a comparison of monthly summed and annual averaged environmental doses indicates a slight overestimation of annual doses in using averaged meteorological data. This overestimate is not consistent, however. The relative degree to which averaged five year data is representative of monthly conditions in each year is consistent between athways. Slight differences between ratios in inhalation and ingestion pathways were noted because monthly humidity values which are higher or lower than the annual average value may accentuate or diminish air concentration discrepancies. The slightly lower overestimates noted for the milk and beef pathways in comparison to vegetation ratios may be attributed to the relatively constant consumption of milk and beef through the seasons. However, it was found that in comparison to monthly summed estimates, annual estimates overestimate doses in every pathway considered.

Relative Doses Among Age Groups. In terms of inhalation and absorption doses, the following hierarchy was observed in all months and years:

infant< child< teenager = adult

Teenager and adult inhalation doses are equivalent due to identical breathing rates and inhalation dose factors. Although the infant inhalation dose factor is larger than the child inhalation dose factor, infant inhalation and absorption doses are less than child doses due to a drastically lower breathing rate (a factor of 0.38 less). Similarly, child inhalation and absorption doses are less than those observed for teenagers and adults due to a child breathing rate that is a factor of 0.46 less than the adult breathing rate.

In all months, the pattern of doses among age groups due to the ingestion of milk is as follows:

infant>child>teenager>adult

This pattern is a result of the greater milk consumption rates and ingestion dose factors for infants and children over teenagers and adults. Teenage doses due to the ingestion of milk are higher than doses noted for adults because they consume a factor of 1.9 more milk than adults, on average.

In all months, the pattern of doses due to ingestion of beef is as follows:

infant<child< teenager<adult

This pattern is a result of low beef consumption rates by children and infants in relation to teenagers and adults. Although ingestion dose factors are higher for infants in comparison with teenagers and adults, infant consumption of beef is an average of a factor of 0.0002 less than teenage consumption rates and a factor of 0.0001 less than adult consumption rates. Likewise, child beef consumption is a factor of 0.60 less than teenage beef consumption and a factor of 0.35 less than adult consumption.

In all months, the relative pattern of vegetation doses among age groups is as follows:

infant>child> teenager> adult

Infant and child vegetation doses are higher than teenage and adult doses due to a higher ingestion dose factor applied. Teenage vegetation doses are higher than doses observed for adults due to a slightly higher teenage consumption rate.

These patterns combine to yield a pattern of total doses among age groups as follows:

infants> children>teens>adults

This hierarchy is understood through examination of usage and dose factors for the different age groups. Although infant beef and inhalation doses are less than doses in other age groups due to lower usage factors, infant vegetation and milk doses are larger than comparative doses in other age groups. Infant milk doses are relatively high due to greater consumption of milk by infants relative to other age groups. Infant vegetation doses are relatively high due to the larger dose factor applied. For example, the infant ingestion dose factor is 3.4 times higher than the adult dose factor, and infant consumption of milk is an average of 2.9 times higher than adult consumption. When multiplied to obtain the dose due to milk ingestion , these differences combine to produce an infant milk dose that is a factor of 9.8 higher than adult doses. In addition, although infants, on average, consume less vegetation than adults (a factor of 0.43

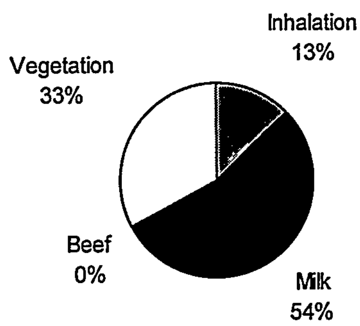
less), the large difference in the recommended dose factor results in an increased vegetation dose. Similarly, child total doses are next highest due to their increased consumption of milk over other age groups and the large dose factor applied. Finally, although an identical dose factor is applied in the case of teenagers and adults, the increase consumption of milk by teenagers over adults results in an increased teenage total dose. Moreover, although infant beef and inhalation doses are lower than doses calculated for other age groups, increased infant milk consumption rates and a larger ingestion dose factor results in a high infant dose relative to other age groups.

Pathway Contributions to Total Dose. Relative contributions of exposure pathways to total dose for different age groups have their basis in differences in the concentrations of tritium in food items and differences in consumption rates. Representation of pathway contributions to total dose are given for 1987 below. These results are assumed to be applicable to all years.

One indication of the importance of a pathway exposure to total dose is the concentration of tritium in the food item of interest. For a given air concentration, the concentration of tritium in vegetation is highest among food groups. This finding is due to model assumptions that 54% of tritium in atmospheric water vapor is directly transported to water in vegetation , while for beef and milk, only approximately 1.2% of the daily tritium ingested appears in the animal per kg of muscle or liter of milk under steady state conditions. Secondly, milk concentrations for a given air concentration are higher than beef concentrations. Factors contributing to this finding are a greater feed consumption rate for dairy cows and a shorter transport time from milking to consumption than from slaughter to consumption. Pathway contributions are evident when these considerations are taken into account.

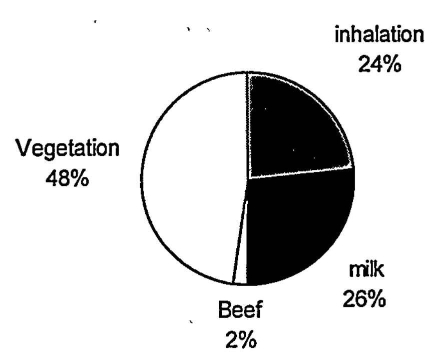
Pathway contributions to total infant dose in the year 1987 are indicated in Figure 12. The major contributor to infant tritium ingestion dose is milk consumption. Although vegetation concentrations are higher than milk concentrations at a given air concentration by approximately a factor of 1.9, infants consume approximately 3.1 times more milk than vegetation. The next primary contributor to infant dose is vegetation. This is due to the high concentrations noted in this food item relative to other foods. Third and fourth contributors to infant dose are inhalation and absorption of tritium through the skin and beef ingestion, respectively. The low percentage of total dose attributed to beef consumption for infants has a basis in a very low consumption rate of beef by infants.

Figure 12
Pathway Contributions to Maximum Infant Dose in 1987



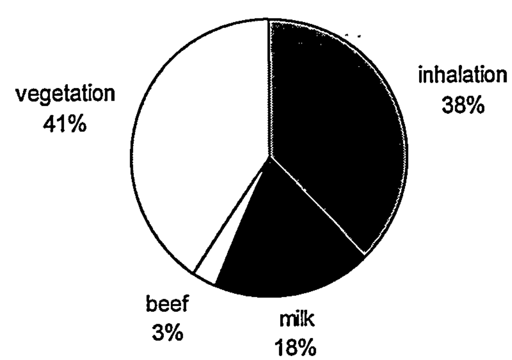
Pathway contributions to child total dose in 1987 are illustrated in Figure 13. The major contributor to child total dose is the ingestion of vegetation. Milk consumption rates by children are not significant enough to deem milk ingestion the primary contributor; however, child milk consumption is high enough (10% higher) to make milk ingestion the second highest contributor to child total dose. As in the case of infants, inhalation and absorption of tritium and beef ingestion are the third and fourth contributors to total dose, respectively. Beef ingestion is an insignificant contributor to child total dose due to the low consumption of beef by children.

Figure 13
Pathway Contributions to Maximum Child Dose in 1987



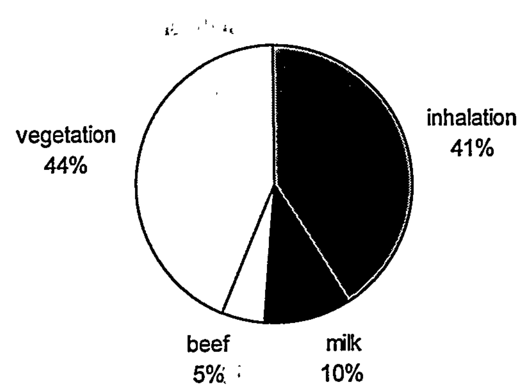
Pathway contributions to teenage total dose in the year of 1987 are indicated in Figure 14. Due to the relatively large concentration of tritium in vegetation relative to other food items and the fact that teenagers consume mostly vegetation, this pathway contributes the highest percentage to total teenage dose. Inhalation and absorption of tritium through the skin is the second largest contributor; this is a result of relatively higher breathing rates in comparison with milk consumption by teenagers. Beef consumption is the least significant contributor to teenage dose due to relatively low beef tritium concentrations and teenage consumption of beef.

Figure 14
Pathway Contributions to Maximum Teenager Dose in 1987



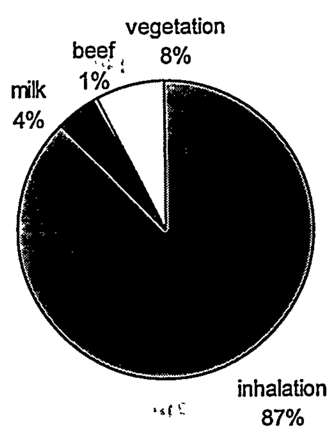
Pathway contributions to adult total dose in 1987 are represented in Figure 15. Adult contributions closely parallel teenage contributions due to similar consumption rates. Vegetation ingestion is the primary contributor to adult total dose due to relatively high vegetation concentrations at a given air concentration relative to other food items and the fact that the majority of the adult diet is comprised of vegetation. Inhalation and absorption of tritium through the skin is the secondary contributor to total dose due to larger adult breathing rates in comparison to milk ingestion. Finally, beef consumption is the least significant contributor to adult total dose due to relatively low beef tritium concentrations in comparison to concentrations in other foods and the fact that the smallest part of the adult diet is comprised of beef.

Figure 15
Pathway Contributions to Maximum Adult Dose in 1987



Pathway contributions to population dose were also examined. A representation of pathway contributions to the population dose in 1987 is indicated in Figure 16. Inhalation and absorption of tritium through the skin is the primary contributor to population dose. This is attributed to population demands for food items being larger than local production can supply. Further, of the food imported into the region, only a fraction is assumed to be contaminated. This may be contrasted with the assumptions that all food consumed is contaminated and all food demanded is supplied in the calculation of maximum individual doses. Other factors contributing to this result are the large fraction of the population that are adults (71%) coupled with the significance of inhalation and absorption as modes of exposure for the adult population.

Figure 16
Pathway Contributions to Population Dose in 1987



Finally, pathway contributions to total dose for the different age groups throughout the year were investigated. The hierarchy of pathway contributions for infants noted above is consistent throughout the year. Pathway contributions for infants are constant due to the large contribution to total dose from milk ingestion coupled with constant infant milk consumption rates through the seasons. In the case of children, pathway contribution are as indicated above in all months except June, July, August, and

September. In these months, inhalation and absorption are the secondary contributors, while milk ingestion becomes the tertiary contributor. The change in pathway contributions for these months is attributable to higher monthly humidity values at this time of year, and a resulting lower concentration in pasture grass and vegetation. For adults and teenagers, pathway contributions also deviate from above observations in the months of June through September. In these months, inhalation and absorption are the primary contributors to dose, while vegetation is the secondary contributor Again, this deviation is the result of higher humidity values in these months.

Sensitivity Analysis. The results of the sensitivity analysis are found in Table 40. The most sensitive parameters are the inhalation and ingestion dose factors, indicating that addressing the uncertainty in these variables is of primary importance. The next most sensitive parameters are the vegetation to air concentration ratio and the breathing rate, followed by the milk transfer coefficient. The dose model is not sensitive to transport times due to the relatively long half life of tritium (Hamby 1993). The importance of dose conversion factors has previously been suggested (Hoffman and Baes 1979).

Table 40 Parameter Sensitivity

Variable	Sensitivity[1]
Inhalation Dose Factor	95
Ingestion Dose Factor	53
Vegetation to Air Concentration Ratio	10.6
Breathing Rate	8.23
Milk Transfer Coefficient	6.11
Humidity	5.8
Milk Consumption	2.91
Fraction of Vegetation that is Water	2.7
Beef Transfer Coefficient	2.43
Dairy Cattle Consumption of Forage	1.78
Leafy Vegetable Consumption	1.36
Beef Consumption	1.36
Beef Cattle Consumption of Forage	0.39
Feed Storage Time	0.065
Fraction of Year Animals Graze	0.028
Fraction of Daily Feed that is Pasture Grass	0.0087
Transport Time for Produce	0.0021
Transport Time for Milk	0.00057
Transport Time for Leafy Vegetables	0.00031
Time from Slaughter to Consumption	0

[1]Defined as the ratio of the maximum adult dose distribution's standard deviation to its mean, multiplied by 100.

Dose Distributions. The distribution in total dose for maximum individuals and the population as well as the percentiles for each distribution for the period of 1987 to 1991 may be reviewed in Appendix C. A representative distribution is indicated in Figure 17. The figure indicates a lognormal dose distribution. The range in infant distributions was on the order of a factor of 200, and was generally higher than the range noted for adult distributions, which ranged approximately a factor of 80. Means and standard deviations of each distribution are listed in Tables 41 through 46 . A review of the data indicates that means of adult dose distributions are higher than calculated deterministic doses. This finding is the result of a large maximum adult breathing rate and a larger proportion of values located from the mean to maximum rate than is observed for other age groups. Therefore, although calculated adult doses are lowest among age groups, the mean values of adult distributions are high relative to other ages. This finding is especially accentuated in population dose means due to the large proportion of the population that are adults.

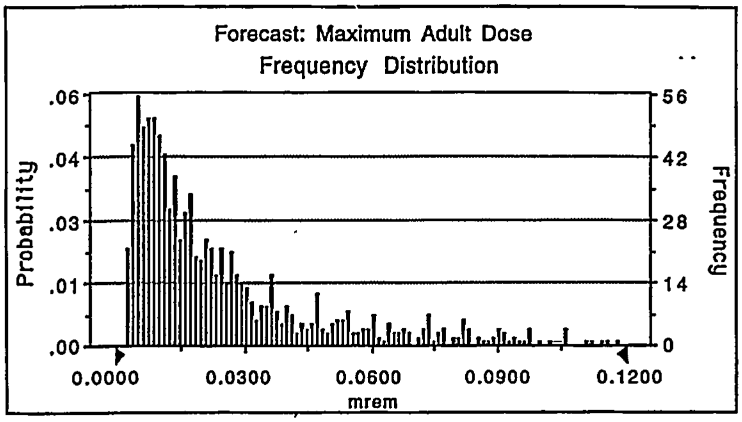


Figure 17 Maximum Adult Dose Distribution in January 1987

Table 41 Means and Standard Deviations of Dose Distributions in 1987

	Mean*	Standard Deviation*		Mean*	Standard Deviation*
JANUARY			JULY		
infant	0.020	0.017	infant	0.22	0.25
child	0.0013	0.0013	child	0.15	0.14
teen	0.0011	0.0011	teen	0.12	0.12
adult	0.0024	0.0026	adult	0.27	0.24
population	567.52	554.15	population	5738.6	5475.4
FEBRUARY			AUGUST		
infant	0.0011	0.0020	infant	0.013	0.014
Child	0.0013	0.0013	child	0.010	0.010
teen	0.0011	0.0011	teen	0.008	0.008
adult	0.0026	0.0024	adult	0.019	0.017
population	64.1	63.8	population	307.7	385.6
MARCH			SEPTEMBER		
infant	0.035	0.038	infant	0.052	0.059
child	0.025	0.024	child	0.038	0.036
teen	0.019	0.018	teen	0.030	0.031
adult	0.049	0.046	adult	0.073	0.067
population	1079.9	1085.5	population	1459.1	1377.5
APRIL			OCTOBER		
infant	0.0044	0.0048	infant	0.028	0.031
child	0.0032	0.0031	child	0.019	0.018
teen	0.0026	0.0026	teen	0.016	0.015
adult	0.0060	0.0050	adult	0.040	0.039
population	129.2	123.7	population	911.5	898.2
MAY			NOVEMBER		
infant	0.062	0.067	infant	0.088	0.095
child	0.045	0.043	child	0.060	0.054
teen	0.036	0.034	teen	0.050	0.048
adult	0.086	0.078	adult	0.13	0.12
population	1936.9	1945.2	population	3075.8	2979.3
JUNE			DECEMBER		
infant	0.023	0.025	infant	0.063	0.072
child	0.016	0.016	child	0.041	0.039
teen	0.013	0.013	teen	0.035	0.034
adult	0.032	0.029	adult	0.087	0.080
population	682.2	686.7	population	1981.3	1925.5

****Means are in units of mrem for individuals and person-mrem for population doses. Meand and standrad deviations are arithmatic.***

Table 42 Means and Standard Deviations of Dose Distributions in 1988

	Mean*	Standard Deviation*		Mean*	Standard Deviation*
JANUARY			JULY		
infant	0.025	0.029	infant	0.024	0.027
child	0.018	0.017	child	0.017	0.016
teen	0.015	0.014	teen	0.014	0.013
adult	0.036	0.035	adult	0.033	0.030
population	752.3	710.43	population	661.7	644.8
FEBRUARY			AUGUST		
infant	0.0084	0.0093	infant	0.041	0.045
child	0.0060	0.0058	child	0.029	0.026
teen	0.0047	0.0044	teen	0.023	0.022
adult	0.012	0.011	adult	0.054	0.050
population	261.2	265.3	population	1174.5	1179.3
MARCH			SEPTEMBER		
infant	0.054	0.061	infant	0.012	0.013
child	0.037	0.035	child	0.0090	0.0090
teen	0.029	0.028	teen	0.0080	0.0080
adult	0.073	0.067	adult	0.018	0.017
population	1600.2	1556.2	population	351.9	343.0
APRIL			OCTOBER		
infant	0.020	0.025	infant	0.024	0.027
child	0.015	0.014	child	0.018	0.018
teen	0.012	0.011	teen	0.014	0.014
adult	0.030	0.028	adult	0.036	0.035
population	651.4	644.2	population	827.8	816.3
MAY			NOVEMBER		
infant	0.0043	0.0047	infant	0.0087	0.0094
child	0.0030	0.0030	child	0.0060	0.0056
teen	0.0020	0.0020	teen	0.0049	0.0047
adult	0.0060	0.0050	adult	0.012	0.011
population	125.2	119.8	population	288.6	307.5
JUNE			DECEMBER		
infant	0.019	0.020	infant	0.018	0.019
child	0.015	0.015	child	0.013	0.013
teen	0.012	0.011	teen	0.011	0.010
adult	0.030	0.029	adult	0.026	0.026
population	641.3	627.2	population	596.7	620.2

Means are in units of mrem for individuals and person-mrem for population doses.

Table 43 Means and Standard Deviations of Dose Distributions in 1989

	Mean*	Standard Deviation*		Mean*	Standard Deviation*
JANUARY			JULY		
infant	0.010	0.010	infant	0.0080	0.0088
child	0.007	0.006	child	0.021	0.020
teen	0.006	0.005	teen	0.018	0.018
adult	0.015	0.013	adult	0.042	0.039
population	343.2	337.1	population	865.7	844.2
FEBRUARY			AUGUST		
infant	0.010	0.012	infant	0.027	0.030
child	0.007	0.006	child	0.021	0.020
teen	0.006	0.006	teen	0.016	0.016
adult	0.0014	0.0013	adult	0.037	0.034
population	319.1	320.9	population	791.0	777.24
MARCH			SEPTEMBER		
infant	0.006	0.006	infant	0.018	0.020
child	0.004	0.003	child	0.013	0.013
teen	0.003	0.003	teen	0.010	0.010
adult	0.008	0.008	adult	0.025	0.023
population	180.9	182.2	population	517.9	499.3
APRIL			OCTOBER		
infant	0.011	0.013	infant	0.012	0.014
child	0.0080	0.0070	child	0.0090	0.0084
teen	0.0060	0.0050	teen	0.0074	0.0070
adult	0.015	0.014	adult	0.019	0.018
population	353.3	362.5	population	542.5	519.4
MAY			NOVEMBER		
infant	0.0098	0.011	infant	0.0081	0.0087
child	0.0070	0.0070	child	0.0056	0.0052
teen	0.0060	0.0050	teen	0.0047	0.0043
adult	0.014	0.013	adult	0.012	0.011
population	303.9	312.4	population	263.7	267.1
JUNE			DECEMBER		
infant	0.0094	0.010	infant	0.0023	0.0027
child	0.0070	0.0070	child	0.0016	0.0015
teen	0.0050	0.0050	teen	0.0013	0.0013
adult	0.013	0.011	adult	0.0032	0.0030
population	302.6	314.7	population	81.4	82.6

***Means are in units of mrem for individuals and person-mrem for population doses.**

Table 44 Means and Standard Deviations of Dose Distributions in 1990

	Mean*	Standard Deviation*		Mean*	Standard Deviation*
JANUARY			JULY		
infant	0.0056	0.0062	infant	0.0080	0.0080
child	0.0040	0.0038	child	0.0060	0.0050
teen	0.0032	0.0029	teen	0.0040	0.0040
adult	0.0080	0.0073	adult	0.011	0.010
population	186.6	184.9	population	220.87	217.21
FEBRUARY			AUGUST		
infant	0.0063	0.0070	infant	0.0099	0.011
child	0.0044	0.0041	child	0.0074	0.0071
teen	0.0035	0.0032	teen	0.0058	0.00555
adult	0.0090	0.0086	adult	0.013	0.012
population	208.5	213.5	population	281.1	275.4
MARCH			SEPTEMBER		
infant	0.0093	0.010	infant	0.015	0.016
child	0.0060	0.0050	child	0.010	0.010
teen	0.0050	0.0040	teen	0.0090	0.0087
adult	0.013	0.012	adult	0.022	0.020
population	274.5	265.9	population	465.3	457.7
APRIL			OCTOBER		
infant	0.0092	0.0096	infant	0.013	0.015
child	0.0060	0.0060	child	0.0085	0.0080
teen	0.0050	0.0050	teen	0.0072	0.0068
adult	0.013	0.012	adult	0.017	0.016
population	317.3	317.8	population	404.3	400.2
MAY			NOVEMBER		
infant	0.0061	0.0067	infant	0.011	0.012
child	0.0050	0.0040	child	0.0076	0.0070
teen	0.0040	0.0030	teen	0.0063	0.0057
adult	0.0090	0.0080	adult	0.016	0.015
population	194.4	197.1	population	361.0	364.4
JUNE			DECEMBER		
infant	0.013	0.015	infant	0.0073	0.0079
child	0.0090	0.0090	child	0.0050	0.0046
teen	0.0080	0.0070	teen	0.0041	0.0038
adult	0.019	0.018	adult	0.010	0.0096
population	405.3	415.2	population	235.4	239.4

**Means are in units of mrem for individuals and person-mrem for population doses.*

Table 45 Means and Standard Deviations of Dose Distributions in 1991

	Mean*	Standard Deviation*		Mean*	Standard Deviation*
JANUARY			JULY		
infant	0.0027	0.0030	infant	0.0030	0.0040
child	0.0019	0.0017	child	0.0020	0.0020
teen	0.0015	0.0013	teen	0.0020	0.0020
adult	0.0038	0.0035	adult	0.0040	0.0040
population	82.2	79.9	population	80.9	78.3
FEBRUARY			AUGUST		
infant	0.0022	0.0025	infant	0.0050	0.0060
child	0.0015	0.0015	child	0.0040	0.0040
teen	0.0012	0.0012	teen	0.0040	0.0040
adult	0.0031	0.0031	adult	0.0030	0.0030
population	64.3	63.4	population	143.4	139.1
MARCH			SEPTEMBER		
infant	0.0086	0.0097	infant	0.0029	0.0031
child	0.0055	0.0052	child	0.0020	0.0020
teen	0.0046	0.0044	teen	0.0020	0.0020
adult	0.012	0.011	adult	0.0030	0.0030
population	266.6	272.3	population	84.3	79.9
APRIL			OCTOBER		
infant	0.014	0.016	infant	0.00098	0.00109
child	0.0099	0.0090	child	0.00070	0.00060
teen	0.0081	0.0075	teen	0.00060	0.00050
adult	0.029	0.025	adult	0.0014	0.0014
population	456.4	454.1	population	31.9	31.7
MAY			NOVEMBER		
infant	0.0031	0.0033	infant	0.0055	0.0059
child	0.0020	0.0020	child	0.0018	0.0017
teen	0.0020	0.0020	teen	0.0016	0.0015
adult	0.0040	0.0040	adult	0.0037	0.0033
population	100.8	99.0	population	181.7	179.1
JUNE			DECEMBER		
infant	0.0030	0.0030	infant	0.0023	0.0026
child	0.0020	0.0020	child	0.0015	0.0014
teen	0.0020	0.0020	teen	0.0012	0.0012
adult	0.0040	0.0040	adult	0.0031	0.0029
population	93.6	91.7	population	71.2	70.4

**Means are in units of mrem for individuals and person-mrem for population doses.*

Table 46 Means and Standard Deviations of Annual Dose Distributions

	Mean*	Standard Deviation
1987		
infant	0.50	0.57
child	0.33	0.33
teen	0.26	0.25
adult	0.67	0.65
population	13326.6	14376.8
1988		
infant	0.27	0.29
child	0.18	0.13
teen	0.14	0.13
adult	0.37	0.34
population	7355.8	7749.4
1989		
infant	0.17	0.19
child	0.13	0.13
teen	0.095	0.094
adult	0.25	0.23
population	4991.9	5351.6
1990		
infant	0.10	0.11
child	0.070	0.068
teen	0.055	0.054
adult	0.15	0.14
population	3116.6	3177.7
1991		
infant	0.063	0.068
child	0.046	0.047
teen	0.034	0.033
adult	0.089	0.081
population	1933.0	1915.1

**Means are in units of mrem for individuals and person-mrem for population doses.*

DISCUSSION

This study has provided a comparison of monthly and annual averaged environmental dose estimates. However, a definitive statement of which method is more accurate can not be deduced. It is evident from the results reported in this study that, in comparing monthly and annual estimates, averaged meteorological data overestimate environmental tritium doses over a five year period, although not consistently. The magnitude of this overestimation, however, is less than 10%. However, measured air concentrations are necessary to confirm that monthly estimates are more accurate. Subsequently, the need for monthly dose estimations for purposes of dose reconstruction may be evaluated on a site to site basis; whether it is cost effective and necessary for the protection of public health to evaluate monthly doses is a subjective decision.

The pathway contributions to total dose evaluated in this report may guide researchers and site operators in efforts to reduce environmental tritium doses due to site operations. Indications that milk is the primary pathway of atmospheric tritium dose to infants suggests that future research focus on this pathway. In addition, the importance of vegetation doses to all age groups suggests this pathway should be completely characterized. It is prudent of site managers to be aware of the major pathways contributing to population dose due to site operations and to recognize the relative magnitude of these contributions throughout the year. Future research may address methods to reduce dose to individuals through control of primary pathway exposure routes through the seasons.

The dose distributions generated for maximum individual and population doses for each month more realistically represent the doses calculated in comparison to deterministic values. Adult distribution means for total dose were higher than infant distribution means, although the deterministic total doses calculated for infants were higher than deterministic adult total doses. In addition, population mean doses were much higher than calculated deterministic values. Finally, the observation that the model is most sensitive to the dose factor utilized, the vegetation-to- air concentration ratio, and breathing rates suggests that these parameters and their variability must be thoroughly researched. These findings illustrate clearly the need for addressing the uncertainty in parameter values.

Although the variables of breathing rate and the vegetation-to-air concentration ratio were completely characterized through a review of the literature, a discrepancy in the range of values for the tritium dose factor was noted. Further investigation revealed that the range of a factor of 100 noted by Hoffman and Miller (1993) was estimated using data for a variety of radionuclides. The range of a factor of 2 estimated using Latin Hypercube sampling, therefore, more accurately characterizes the parameter. This iterative method has been widely employed in characterizing dose factors for cesium and iodine (Dunning and Schwarz 1981; Schwarz and Dunning 1982; Kocher et. al 1980), and is therefore the recommended method for parameter characterization. The sensitivity of the model to the dose conversion factor suggests that subsequent work more precisely characterize values for the total body mass and biological half-life of tritium. Latin Hypercube sampling forecasting the tritium dose factor may follow in depth investigation into the characteristics of these variables.

Although the results of this study provide a general view of discrepancies in dose estimations when averaged meteorological data are utilized, several additional uncertainties exist in the model which were not considered in this report. Some uncertainties specific to the estimation of environmental doses due to atmospheric tritium releases which were not considered are the quantities of chemical forms of tritium present in the air, uncertainties in release rates, and uncertainties in wind speeds. In performing an uncertainty analysis, it was assumed that all parameters are independent, the Gaussian model being utilized was not biased, and parameter values and their relative distributions were representative of the population surrounding the Savannah River Site (Miller et. al 1982).

Uncertainties in the estimated air concentration and source term were not investigated. It has been demonstrated that air concentration values do not contribute significantly to uncertainty in relation to variables such as the dose conversion factor utilized (Hoffman and Baes 1979). However, future research efforts in this area may attempt to confirm the role of air concentration estimates in introducing error in dose estimates. Miller and Hoffman (1982) reported a range of the ratio of predicted values associated with the Gaussian model to observed air concentrations for flat terrain 10-150 km downwind as 0.25-4. Little and Miller (1979) reported that monthly and seasonal averages using the Gaussian model up to 100 km away can be predicted within a factor of 4, and the ratio of observed to predicted air concentrations ranges from 0.25-4. In addition, Crawford (1978) reported that monthly and seasonal air concentration calculations are accurate to within a factor of 4.

In addition, the adequacy of models utilized at the Savannah River Site for environmental dose predictions has been scrutinized. Draxler (1980) reported that the Gaussain model consistently over-predicted seasonal and annual long term krypton-85 predictions by a factor of four at the site due to averaging of wind speeds and assumptions of constant stability from the release point to the receptor. Further, although sufficient correlation between predicted and measured air concentrations while implementing the Gaussain model at 40 km has been observed , the correlations at the site boundary and at 80 km are not as promising (Murphy et. al 1992). Murphy (1992) attributes this divergence to estimation of the vertical dispersion of the plume. This observation is supported with previous work recommending the use of data other than Pasquill-Gifford curves in estimating plume dispersion (Miller and Little 1980). More specifically, Miller and Cotter (1988) suggested that dispersion parameters based on measurements near Julich, Federal Republic of Germany, yield the best comparisons between observed and expected air concentrations. Future investigations of site modeling procedures should investigate the possibility of utilizing various data sources in calculating dispersion coefficients.

It is outside the scope of this research to address every uncertainty present in atmospheric modeling procedures. The objectives of this research were aimed at investigating uncertainties and differences in monthly and annual dose estimates. This report has provided future opportunities for further investigation into other aspects of dose construction procedures and their uncertainties.

CONCLUSION

This research investigated the differences in monthly and annual averaged environmental dose estimates for purposes of dose reconstruction. The sum of monthly doses in the west-northwest sector based on time-specific meteorological data was compared to annual averaged doses in this sector determined from a five year meteorological database. It was found that averaged data overestimate environmental dose estimates for every age group and exposure pathway by 2% to 6% when evaluated on a five year basis. However, annual examination of the data does not indicate a consistent overestimate. The basis of differences in monthly and averaged dose estimates was observed to stem from basic misrepresentations of monthly meteorological data by the five year database, resulting in divergent air concentration estimates. Discrepancies from expected air concentrations were represented in all pathways, although some differences in the degree of dissimilarity were noted between inhalation and absorption pathways and ingestion. This finding was a result of the ability of monthly humidity values to accentuate or de-emphasize differences noted in monthly versus annual air concentrations with regard to vegetation and pasture grass. The implications of these discrepancies must be evaluated on a site-to-site basis in light of site specific public health and cost considerations.

The relative contributions of exposure pathways were evaluated. It was found that milk is the primary contributor to infant dose, while vegetation is the major contributor to total dose in other age groups. In addition, pathway contributions over time were investigated. Results indicate that pathway contributions to infant dose remain constant over a year, while the relative importance of inhalation and absorption of tritium through the skin for other age groups increases in importance in the months of June through September due to increased humidity values and a resulting decrease in vegetation tritium concentrations.

In examining the uncertainties associated with deterministic doses, it was found that the model utilized was most sensitive to dose factors, the ratio of the specific activity of tritium oxide in vegetation to the specific activity of atmospheric tritium oxide, and breathing rates. Further, it was found that adult distribution means were higher than infant distribution means, and that the range in infant doses was approximately a factor of 200, while the range in adult distributions was estimated as a factor of 90.

RECOMMENDATIONS

Although it is evident that averaged meteorological data overestimate dose estimates over a five year period, whether detailed monthly estimates are necessary and cost-effective is a subjective decision to be evaluated on a site by site basis.

It is recognized that not every uncertainty in the dose model employed was considered. Future researchers are encouraged to investigate further the effects of air concentration and source term uncertainty on environmental dose estimates. In addition, the appropriateness of the Gaussian model and method of stability class determination at the Savannah River Site may be evaluated in the future.

This research has provided the field of health physics more assurance in our protection of the public from radiological hazards and compliance with regulatory standards. The investigation of the adequacy of using averaged data for atmospheric tritium concentrations may aid in conducting future dose reconstructions efficiently. The extent to which site specific parameters provide more meaningful population dose estimates informs scientists with regard to their need for the use of specific models. Finally, addressing the uncertainties in present input parameters and their effect on final dose estimates has formed the basis for future work in increasing confidence in variable estimates.

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