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PARAMETERS USED IN THE ENVIRONMENTAL PATHWAYS AND RADIOLOGICAL DOSE MODULES OF THE PHASE I AIR PATHWAY CODE

Hanford Environmental Dose
Reconstruction Project

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PREFACE

This report is a description of work performed for the Hanford Environmental Dose Reconstruction (HEDR) Project. The HEDR Project was established to estimate radiation doses to individuals resulting from releases of radionuclides from the Hanford Site since 1944, when facilities there first began operating. An independent Technical Steering Panel directs the project, which is conducted by Battelle staff from the Pacific Northwest Laboratory.

The objective of Phase I of the HEDR Project was to demonstrate through calculation that adequate models and support data existed or could be developed to allow estimation of realistic doses to individuals from historical Hanford Site radionuclide releases. As part of Phase I work, a computer code was developed to support this objective.

The HEDR Phase I computer code was used to model the transport of iodine-131 released to the atmosphere from the Hanford Site facilities, through environmental pathways to points of human exposure. Output from the code was preliminary estimates of doses received by members of the public living in the vicinity of the Hanford Site. Later project work continues to build upon Phase I progress in order to refine dose estimates.

Final dose estimates developed by the HEDR Project are expected to be employed in a thyroid disease study being conducted by the Fred Hutchinson Cancer Research Center, Seattle, for the Centers for Disease Control, Atlanta.

SUMMARY

This report describes parameter values and statistical distributions used in the HEDR Phase I air pathway computer code. The modules of the HEDR Phase I code addressed in this document include those for environmental pathways and dose calculations, i.e., modules 2, 3, 4, 5, and 6. Phase I computer code calculations were initiated using estimates of monthly iodine-131 releases to the atmosphere from irradiated-fuel processing plants (Heeb and Morgan 1991). These estimates were input to module 1, which was used to calculate the atmospheric dispersion and deposition of iodine-131 throughout the Columbia Basin region. Modules 2 through 6 followed module 1 and were used to estimate vegetation concentrations, animal product concentrations, milk accumulation in creameries, milk distribution, and reference individual doses, respectively. Dose evaluations considered the exposure pathways of air submersion, groundshine, inhalation, and ingestion of both crops and animal products.

This letter report will assist those who wish to evaluate the input used in the HEDR Phase I code. The central values and distributions of parameters used in the environmental pathways and dose calculation modules are described and documented. Presentation of distributions is necessary because the Phase I code was partially stochastic, using distributions of input data and parameter values to produce a range of dose estimates rather than simply producing deterministic (single-value) estimates. Appendix A tabulates all parameters discussed in this document. Appendix B provides an example of how parameters were used in animal product concentration calculations.

Phase I dose estimates were finalized in July 1990 (PNL 1991b). Since then, significant changes have been made in the modeling approach and structure of the air pathway code (Ikenberry et al. 1992). Refinement of some of the model parameters discussed in this report is planned. Parameter values required for subsequent versions of the HEDR code, which may be different from those included in the Phase I modules, will be investigated. A complete description and technical basis of model parameters and parameter distributions used in updated HEDR codes will be discussed in documents to be prepared later in FY 1992 (Shipler 1992).

CONTENTS

TABLES

1.0 INTRODUCTION

Phase I of the HEDR Project was completed and preliminary results were reported in July, 1990 (PNL 1991a, 1991b). The model design and specifications for computer implementation of the Phase I air pathway code have previously been documented by Napier (Napier 1991a). However, none of these reports includes the actual parameter values used to calculate radionuclide concentrations and radiological dose.

This report documents the central values and distributions of parameters used in the environmental pathways and dose calculation modules of the air pathway code for Phase I of the HEDR Project. Central values are presented as means for normal distributions, medians for lognormal distributions, and modes for triangular distributions. No central value estimate is presented for uniform or log-uniform distributions. The parameters were used to generate the estimated dose results discussed in the Phase I Summary Report (PNL 1991a) and were presented in the Phase I Air Pathway Report (PNL 1991b). Presentation of distributions is necessary because the Phase I code was partially stochastic, using distributions of input data and parameter values to produce a range of dose estimates rather than simply producing deterministic (single-value) estimates. However, not all of the parameters were represented with distributions; for these parameters, "none (constant)" is indicated.

The objective of Phase I was to demonstrate through calculation that adequate models and support data existed, or could be developed, to estimate realistic doses to individuals from releases of radionuclides to the environment that occurred as long as 45 years ago (PNL 1991a). Because the primary objective was to demonstrate feasibility of the dose estimation process rather than to provide comprehensive results, calculations for the atmospheric exposure pathways were limited to a single radionuclide, iodine-131; to the time period from late 1944 through 1947; and to a ten-county region surrounding the Hanford Site. Iodine-131 was selected because it was estimated to be the radionuclide contributing most (approximately 90%) of the dose received by individuals in the study area (Napier 1991b). Much of the data used in Phase I was preliminary or approximate, and, therefore, the doses calculated were considered to be approximations subject to revision.

Because of the preliminary nature of the Phase I dose calculations, many of the central values of radionuclide-dependent parameters used were those generally available and used for current Hanford annual environmental dose calculations. These annual dose calculations are required by the U.S. Department of Energy (DOE) in DOE Order 5400.1 (U.S. DOE 1988c). The parameter values are site-specific for the Hanford area, and are derived from those used in the GENII computer code (Napier et al. 1988). Many of the radionuclide-independent parameters needed to reflect the time period of the Phase I calculations, such as food-ingestion rates or milk-holdup times, were investigated and developed by researchers from the Pacific Northwest Laboratory (PNL) as part of the HEDR Project (Callaway 1992; Beck et al. 1992).

Selection of a probability distribution (e.g., normal, lognormal, triangular, uniform, or log-uniform) to characterize the uncertainty of each parameter was based on the expert opinions of the model and code developers. For a very few parameters, such as the radiological half-life of iodine-131 (a physical constant), the value is well-established. For others, such as the feed intake-to-milk transfer factor, there have been enough experimental studies to establish a parameter distribution. However, for many parameters there are only a few studies that provide estimates of uncertainty. For parameters such as dose factors, calculated values are published without estimates of uncertainty.

This report documents Milestone 0703A, Letter Report: Iodine-131 Parameters and Dose Factors, Phase I. Development work continues on parameter distributions for the models to be used in future HEDR calculations. A complete description and technical basis of iodine-131 related model parameters and parameter distributions are planned for FY 1992 (Shipler 1991). Future parameter documentation will include data-quality objectives.

2.0 PARAMETER DESCRIPTIONS

The Phase I computational model for atmospheric releases prepared for the HEDR Project consisted of six modules: atmospheric transport, vegetation concentrations, animal product concentrations, milk accumulation in creameries, milk distribution, and individual exposure and dose. A description of these modules and their execution was provided in Napier (1991a). This report provides descriptions of parameters in code modules 2 through 6: those used to calculate the accumulation and transport through environmental pathways, and those used to calculate radiological dose from air submersion, groundshine, inhalation, and ingestion. The module parameters for the atmospheric transport component (module 1) were described by Ramsdell (1991) and Ramsdell and Burke (1991). Estimated monthly releases of iodine-131 used in module 1 were reported by Heeb and Morgan (1991). The information presented by Heeb and Morgan indicated the basis for selecting a triangular distribution to represent iodine-131 releases, with a central value using the 75% release factor, lower limit using a 50% release factor, and upper limit using an 85% release factor.

Descriptions of each parameter include a description of the environmental transfer process being modelled and a listing of the parameter characteristics as they were used in the HEDR Phase I code. Listings of the parameter characteristics include the parameter symbol, the parameter values and units, and its probability distribution.

2.1 PARAMETERS USED IN ALL MODULES

The single parameter that was used in all six modules of the Phase I code is the radioactive decay constant of iodine-131. This constant represents the probability that a given atom will disintegrate in a specified unit of time (NBS 1949). The physically constant nature of radioactive decay for each specific radioisotope has been empirically and theoretically verified by numerous scientific researchers. A discussion of exponential radioactive decay is found in numerous texts, including that by Turner (1986). The radioactive half-life of iodine-131 is 8.05 days. Using the exponential radioactive decay law, the radioactive decay constant of iodine-131 is equal to the natural logarithm of 2 divided by the radioactive half-life of iodine-131, or 0.693/8.05 days.

Symbol: λ_r
Units: d^{-1} (inverse days)
Value: 0.086
Distribution: none (constant)

2.2 VEGETATION CONCENTRATION PARAMETERS

Module 2 of the Phase I code calculated the average monthly iodine-131 concentration in the eight different types of vegetation for each of the census divisions in the Phase I study area (Napier 1991a). This module used monthly time-integrated atmospheric concentration and month-end soil concentration output from module 1 to calculate monthly leaf, root, and total plant concentrations. Primary parameters in module 2 included biomass, interception fraction, weathering decay constant, soil surface density, soil-to-plant concentration ratio, and leaf-to-edible part translocation. These parameters and their values in the Phase I code are described below.

2.2.1 Types of Vegetation

A description and explanation of the types of vegetation included in the Phase I code is necessary even though vegetation types were not strictly defined as model parameters. The vegetation type was either directly or indirectly included in each of the environmental pathways and dose code modules.

Phase I results demonstrated that the major potential exposure pathway from Hanford atmospheric releases of iodine-131 was ingestion of contaminated foodstuffs, particularly milk, but also leafy vegetables and fruits (PNL 1991a, 1991b). A primary environmental pathway for radioiodine in milk is the forage-cow-milk pathway (Parker 1956), so dairy cow feed concentrations are particularly important.

Eight general categories of vegetation were considered in the Phase I code: leafy vegetables, other vegetables, fruit, grain, pasture, alfalfa, silage, and sagebrush. Leafy vegetables, other vegetables, fruit, and grain were assumed to be consumed by humans (Callaway 1992), while dairy cows were assumed to consume grain, pasture grass, alfalfa, and silage (Beck et al.. 1992). Sagebrush is food for neither animals nor humans, but concentrations of iodine-131 in sagebrush were estimated to compare the model's performance with historical environmental monitoring measurements of sagebrush contamination levels.

Vegetation for human consumption falls into four categories. Leafy vegetables are those vegetables that have edible, leafy parts of the plant directly exposed to, and a high collection efficiency for, airborne contamination. These vegetables include lettuce, cabbage, spinach, and parsley. Other vegetables include those in which more fleshy vegetation (e.g., fruit, tuber, root) is eaten, such as corn, beans, and tomatoes, and root crops such as carrots, beets, and potatoes. Fruits consist only of tree fruits such as apples, plums, apricots, and pears. Grains for human consumption are assumed to consist primarily of wheat, but also include other small grains such as barley. Other Phase I human food consumption data are presented in Callaway (1992).

Animal feeds fall into four categories as well, one of which is also grain. Grain for animal feed includes small grains, such as wheat and barley, as well as corn. Pasture grass is assumed to be irrigated and may be either grazed or cut for grass hay in the Phase I model. Alfalfa was harvested as feed exclusively as stored alfalfa hay. Silage was assumed to be corn silage harvested in the fall and fed after a short storage period. Additional information on animal feeding regimes is presented by Beck et al. (1992).

2.2.2 Biomass

The monthly biomass for food crop or animal feed production was defined as the useable (harvestable) dry mass of a crop that can be produced in a specified area. Biomass was calculated in Phase I as the product of three biomass sub-parameters: maximum wet biomass, plant dry weight:wet weight ratio, and available fraction of standing biomass. Maximum biomass values and available fraction of standing biomass were developed by PNL staff, who examined the scientific literature, consulted local farmers, and collected information from the Prosser Experiment Station, Prosser, Washington. Data sources acknowledged that considerable variation in the values could occur, but because of the lack of a firm technical basis, no attempt was made to estimate the spread of the distribution. The three biomass sub-parameters are described below.

Maximum Wet Biomass

Plant biomass varies over the course of a year. It is typically at a minimum during the winter months, increases during the spring and summer as the growing season progresses, and reaches a maximum shortly before harvest. After harvest or at the conclusion of the growing season, plant biomass is at a low level or decreases into the winter months. In the Phase I code, monthly biomass values for a specific vegetation type were calculated using the maximum biomass value and multiplying by a month-specific available fraction. These values were for useable standing biomass, such as leaves, fruit, or edible stalk. Non-edible woody parts, such as fruit tree branches, were not included.

Symbol:	Y	
Units:	kg (wet)/m^2	
Values:	leafy vegetables	2.0
	other vegetables	2.0
	grain	0.8
	fruit	3.0
	alfalfa	1.0
	pasture grass	1.5
	silage	1.5
	sagebrush	0.08
Distribution:	none (constant)	

Plant Dry Weight:Wet Weight Ratio

Vegetation biomass values were used in the Phase I code on the basis of both wet biomass and dry biomass. For example, the mass of food crops ingested by humans was based on wet biomass, whereas the calculation of the vegetation interception fraction was based on dry biomass. The ratio of plant dry weight:wet weight biomass is necessary to make conversion between wet and dry weights. Vegetation types that have a large water content, such as leafy vegetables and fruits, have a smaller dry:wet ratio than vegetation that has less water or is more woody, such as forage or sagebrush. The constant values chosen were default values used in the GENII computer code (Napier et al. 1988).

Symbol:	f_d	
Units:	unitless	
Values:	leafy vegetables	0.10
	other vegetables	0.25
	grain	0.18
	fruit	0.18
	alfalfa	0.20
	pasture grass	0.20
	silage	0.20
	sagebrush	0.50
Distribution:	none (constant)	

Available Fraction of Maximum Wet Biomass

Over the course of a year the amount of non-woody crop vegetation (leaves or fruit) on crops changes considerably. This non-woody vegetation can be consumed by animals or humans. The values in Table 2.1 indicate the fraction of the maximum wet non-woody biomass that is estimated to be present during the indicated month. For example, the amount of pasture grass available for animal consumption in the month of September is 0.8 (80%) of the maximum pasture wet biomass amount listed earlier. As another example, leafy vegetables are not grown in the Columbia Basin during February, so there is no maximum wet biomass available for human consumption in February.

Symbol:	f_s
Units:	unitless
Values:	see Table 2.1
Distribution:	none (constant)

TABLE 2.1. Monthly Available Fraction of Maximum Standing Biomass for Animal or Human Consumption for Nine Vegetation Types

Month	Leafy Veget.	Other Veget.	Grain	Orchard Fruit	Alfalfa	Pasture	Silage	Sage-brush
January	0	0	0	0.5	0	0.1	0	0.25
February	0	0	0	0.5	0	0.1	0	0.5
March	0	0	0.1	0.5	0.25	0.2	0	0.75
April	0.2	0.1	0.2	0.6	0.5	0.5	0.1	1.0
May	0.5	0.5	0.4	0.7	0.75	0.9	0.3	1.0
June	1.0	0.8	0.6	1.0	0.75	0.9	0.5	1.0
July	1.0	1.0	0.8	1.0	0.75	0.9	0.7	0.25
August	1.0	1.0	1.0	1.0	0.75	0.9	1.0	0.25
September	0.8	0.8	0.5	0.8	0.75	0.8	0.5	0.25
October	0.5	0.5	0	0.6	0	0.5	0	0.25
November	0	0	0	0.5	0	0.2	0	0.25
December	0	0	0	0.5	0	0.1	0	0.25

2.2.3 Vegetation Interception Fraction

The interception of airborne radionuclides by vegetation was calculated by using an equation based on a model proposed by Chamberlain (1970) and shown in Napier (1991a). This is an equation that contains two independent variables as exponents: Y_m, the monthly plant biomass (dry) discussed above, and k, an empirically determined proportionality constant. Vegetative interception is directly proportional to both of these parameters, increasing as the biomass and proportionality constant increase. Values of the parameter k taken from Pinder et al. (1988) were selected to represent generalized non-grass and grass categories. No distribution was defined because data were not available to support any particular distribution selection at the time the Phase I model was developed.

Subsequent literature searches have revealed compilations of data showing values of k ranging from 1.0 to 4.0 for forage grasses, and 1.25 to 17.4 for non-grass species (Miller 1979). These ranges are generally consistent with equations in Pinder et al. (1988) used to calculate plant interception.

The values for k used in the Phase I calculations are considered to be representative of the range of observed values, although no distribution was included.

Symbol: k

Units: m^2/kg

Pasture grass, leafy vegetables, alfalfa, silage, grain

Value: 2.9

Other vegetables, fruits, sagebrush

Value: 3.6

Distribution: (none) constant

2.2.4 Weathering Rate Constant

Weathering is the process whereby contamination deposited on the outer surfaces of plants is removed by natural elements such as wind, rain, and irrigation water. Weathering was modeled as a continuous process in which contamination is removed as an exponential loss function and transferred to the soil surface. This loss may be described in terms of a weathering half time, W_T, defined as the time during which one-half of the surface-deposited contamination is removed, or in terms of a weathering rate constant. The Phase I model used a weathering rate constant, defined as the natural logarithm of 2 divided by the weathering half time, $0.693/W_T$. A common default value for W_T is 14 days (NCRP 1985). A value of 14 days was used by Baker et al. (1976) in the FOOD model, and is the default value in the NRC's Regulatory Guide 1.109 (U.S. NRC 1977). Lengemann (1966) cited four sources for an observed radionuclide weathering half time of 14 days. Miller and Hoffman (1979) examined the results of a number of different studies on weathering half times of iodine-131 on pasture forage. They reported a range of 6.5 to 13 days, and indicated that an assumption of a lognormal distribution was reasonable. However, in the opinion of the model developers, a distribution centered around the established weathering half time was most appropriate for the Phase I calculations. Therefore, a triangular distribution centered around a half time of 14 days (rate constant of 0.05 d^{-1}) was selected.

Symbol: λ_w

Units: d^{-1} (inverse days)

Value:	central	0.050	(14-day half time)
	upper limit	0.035	(20-day half time)
	lower limit	0.087	(8-day half time)
Distribution:	triangular		

2.2.5 Soil Surface Density

The soil surface density, or soil areal density, is a parameter that incorporates the soil bulk density and a soil depth typical of the plant root zone and describes them in terms of soil surface area. The parameter for soil surface density describes the mass of dry soil found in a 1-meter by 1-meter plot to a depth of 0.15 meters (15 cm). This value was used to determine the concentration of iodine-131 available to plant roots. All iodine-131 deposited on the soil's surface was assumed to be uniformly mixed with the soil to a depth of 15 cm.

The 15-cm depth was used as the tillage depth and effective rooting zone depth of crops and vegetation in the HEDR Phase I study area (U.S. NRC 1977; Baker et al. 1976; Napier et al. 1988). The variance in the soil density was believed to be very small, so a constant value, used by the U.S. Nuclear Regulatory Commission (U.S. NRC 1977), was chosen. A similar value, 224 kg (dry)/m^2 was used in the FOOD model (Baker et al. 1976).

Symbol:	P
Units:	kg (dry)/m^2
Value:	240
Distribution:	none (constant)

2.2.6 Soil-to-Plant Concentration Ratio

Contaminated soil provides a source of iodine-131 for uptake by the roots of vegetation. The soil-to-plant concentration ratio is an empirically-determined ratio between radioactivity in soil and in plants. It was measured under the assumption of equilibrium conditions between soil and plant. The central value was taken from Napier et al. (1988). The range of values and a log-triangular distribution (i.e., a triangular distribution on a logarithmic scale) were selected based on the expert opinions of the model developers for application in the mid-Columbia area. These values are representative of the central portion of the range of values presented by Ng et al. (1982) in a compilation of literature values. The reported ratios varied from 0.015 to 1.9.

Symbol:	B_v	
Units:	unitless	(Ci/kg_{soil} per Ci/kg_{plant})
Value:	central	0.1
	upper limit	0.2
	lower limit	0.05
Distribution:	log-triangular	

2.2.7 Plant Translocation Factors

The translocation factor describes the fraction of activity moved from the outer vegetative surfaces (leaves) to the inner, edible portion of the crop. The edible fraction of some crops (e.g., lettuce, alfalfa) is exposed directly to the atmosphere. The radioactivity deposited on these crops is equivalent to the activity on the consumed portions of the plant; i.e., the translocation factor is 1.0. Other crops (e.g., corn, cereal grains, carrots) have an edible portion sheltered from atmospheric deposition. Radioactivity deposited on the vegetative portions of these crops may be translocated to the inner edible parts. Foliar-adsorbed iodine is reported to be relatively immobile (Cougherty et al. 1985). Baker et al. (1976) proposed translocation factors of 1.0 for leafy vegetables and fresh produce and 0.1 for all other produce. These values were subsequently recommended by the NCRP (NCRP 1985). Previously, Hungate et al. (1963) had investigated foliar sorption of iodine-131 by plants and found no greater than 5% translocated from leaves to other plant parts within 3 days. Cline et al. (1965) reported on a study at Hanford by Selders and Hungate (1956) during which it was observed that only 2% of a single leaf exposure was translocated to the roots, and 6% to roots from a whole plant exposure.

The translocation factor for leafy vegetables and fresh forage was used as a constant in the Phase I code, because any loss from the exposed plant parts would be encompassed by the weathering loss. The range of values and the log-uniform distribution of the other vegetation categories were selected by the model developers to include the empirical observations of the earlier researchers as well as the recommended values of Baker et al. (1976) and the values in NCRP (1985).

Symbol: T_p

Units: unitless

Pasture, leafy vegetables, alfalfa, silage, sagebrush

Value: 1.0

Distribution: none (constant)

Other vegetables, grain, fruit

Value: upper limit 0.1

lower limit 0.01

Distribution: log-uniform

2.2.8 Alfalfa Harvest Dates

Average alfalfa harvest dates were varied for each of the U.S. Census subdivisions (the smallest geographic subdivision evaluated) within the Phase I study area. Historically, three alfalfa harvests typically occurred during the alfalfa growing season (Beck et al. 1992). The dates of harvest, listed by census subdivision in Beck et al. (1992), were assumed to be in early June, late July, and early September. Geographic differences in the mean harvest date were based on the average date of the last spring frost. In addition, both 1946 and 1947 were warmer years than 1945. To account for these annual temperature differences, four days were subtracted from the mean harvest dates of 1946 and seven days were subtracted from the mean harvest dates of 1947. Furthermore, the actual harvest date was assumed to occur with an uncertainty of ± 7 days from the weather-adjusted harvest date, allowing for differences among individual farms.

As an example, in census division WA1 (Walla Walla County) the average date of the first alfalfa cutting was established as day 161 (June 10). In 1945 this was the average harvest date, but in 1946 it was day 157 (-4) and in 1947 it was day 153 (-7). The actual harvest for each year could vary ±7 days on either side of the harvest date for that year. Appendix B, section 4.3.1 provides an additional example of the alfalfa harvest date calculation.

Symbol: ALF_CUT_DAY

Units: Julian day

Value: see Beck et al. (1992)

Distribution: Triangular

2.3 ANIMAL PRODUCT CONCENTRATION PARAMETERS

The animal products concentration module (module 3) calculated the concentration of iodine-131 in milk for each census division in the Phase I study area (Napier 1991a). The module has the capability to calculate the radionuclide concentrations in a variety of animal products, but only milk was included in the Phase I calculations (PNL 1991a, 1991b). The location-specific iodine-131 concentrations in various animal feed types, calculated in module 2, were used to estimate iodine-131 concentrations in milk. Major parameters of this module were the feed intake-to-milk transfer factor and the type and quantity of feed eaten.

2.3.1 Feed Intake-to-Milk Transfer Factor

This term describes the fraction of iodine-131 activity ingested in a specific time period (day) that is transferred to a unit volume (liter) of cow's milk. Ng et al. (1977) compiled literature values for these factors ranging from 0.0014 to 0.018, with a recommended value of 0.0099. The data compiled by Ng was examined by Hoffman (1979), who determined that the range of values was best described by a lognormal distribution. Hoffman did not include the studies from underground weapons test fallout, because the physicochemical form of the iodine-131 released from the tests could result in significantly lower transfer factor values than forms of iodine-131 released from nuclear facilities.

The central value used in the Phase I code was a median converted from the mean value of 0.012 used in the GENII code (Napier et al. 1988). The lognormal distribution was based on information from Hoffman (1979), with a geometric standard deviation (geom. std. dev.) to encompass all but the lowest of the range of values presented by Ng et al. (1977) and to incorporate values observed after the Chernobyl accident (Bertilsson et al. 1988).

Symbol:	FM
Units:	days/liter (Ci/L_{milk} per $Ci_{ingested}$/day)
Value:	median 0.0092
	geom. std. dev. 2.1
Distribution:	lognormal

2.3.2 Type and Quantity of Feed Eaten

The quantity of a particular feed type that a dairy cow consumed varied by location (census division), month (season), and feeding regime. The total quantity of feed consumed per day was the sum of the quantities of each particular type of feed consumed per day. Types of constituent feeds considered included grains, alfalfa hay, pasture, silage, and grass hay. The total quantity of feed consumed was constrained to fall within certain limits, shown in Table 2.2, which are consistent with those reported by Comar (1966). Beck et al. (1992) provide a complete discussion of the dairy cow feeding-regime parameter values, particularly those for constituent feeds, which are too voluminous to reproduce here.

Symbol: QF (for each constituent feed in a regime)
Units: kg/day (dry)
Values: see Beck et al. (1992) for constituent feed types
Distribution: triangular

TABLE 2.2. Total Quantity Consumed for Dairy Cow Feeding Regimes

Feeding Regime (constituent)	Lower Limit	Upper Limit
1. (grain, alfalfa hay, pasture, silage)	8	20
2. (grain, alfalfa hay, pasture)	8	20
3. (grain, alfalfa hay)	7	15
4. (grain, grass hay)	7	15

2.4 PARAMETERS FOR MILK CONCENTRATION AT CONSUMPTION

Two modules of the Phase I code calculated the concentration of iodine-131 in milk at the time of consumption. Module 4 was used to calculate the distribution of iodine-131 concentrations in milk accumulated and pooled at various creameries (milk-bottling plants) from output calculated in module 3. Module 3 was used to estimate the iodine-131 concentration in milk supplied to the creameries from various dairies throughout the Phase I study area. Module 5 was the milk-distribution module. It used the pooled milk iodine-131 concentrations from module 4 to calculate the iodine-131 concentration in milk distributed to urban and rural grocery stores throughout the study area.

A third type of milk source is the so-called backyard or family cow. This source was not considered in modules 4 or 5 because the milk was assumed to be supplied directly to the family owning the cow. In this case, milk concentration output from module 3 was used directly by module 6 (individual dose calculations, discussed in section 2.4) to calculate dose from ingestion of milk from the family cow. Additional information on milk accumulation and distribution was presented in Beck et al. (1992).

For the purposes of environmental pathways and dose calculations, the major parameter for milk accumulation and distribution was the fresh milk hold-up time. A related parameter is whether the milk was consumed as fresh milk or as a stored milk product. Fresh milk products included liquid milk and ice cream. Stored milk products included dry powdered milk (not reconstituted), cheese, cottage cheese, cream cheeses, processed cheese spread, imitation cheeses, and soups.

The time between milk collection and consumption, the "hold-up time," varied according to the dairy source and type of milk product. A longer hold-up time yielded more radioactive decay of iodine-131, decreasing the radioactivity in the milk product prior to consumption. Hold-up time is important for iodine-131 because of its short radioactive half-life of 8.05 days. The hold-up times were determined by inspection of available information regarding marketing practices and shelf-life of milk products in the late 1940s. By consensus of the expert opinions of the model and code developers, it is believed that a greater quantity of shorter shelf-lived stored milk products were consumed by the HEDR study population. The lognormal distribution of the hold-up times for stored milk reflect this.

Symbol: th_1, backyard cow milk (fresh)
th_2, creamery milk (fresh)
th_3, grocery milk (fresh)
th_s, grocery milk products (stored)

Units: days

Fresh Milk:

Values:	backyard cow milk	1
	creamery milk, grocery milk	4
Distribution:	none (constant)	

Stored Milk:

Value:	grocery milk products (stored)	
	median	30
	geom. std. dev.	2
Distribution:	lognormal	

2.5 DOSE CALCULATION PARAMETERS

The final code module, module 6, used the output of the prior modules to estimate the dose received by an individual from external radiation via the air submersion and groundshine exposure pathways, and from internal radiation via the inhalation and ingestion pathways. The results were dose distributions to reference individuals in each of the study area census divisions for each of the exposure pathways. Results of these calculations were presented in the Phase I Air Pathway Report (PNL 1991b).

The majority of parameters in module 6 are dose factors (DFs). DFs indicate the dose-per-unit intake or dose-per-unit concentration in a given environmental medium. All DFs were assumed to be lognormally distributed. Dunning and Schwartz (1981) provided evidence that internal DFs for iodine-131 are lognormally distributed. The external exposure DFs in module 6 were also assumed to be lognormally distributed.

2.5.1 Reference Individual Categories

Categories of individuals were established to provide a basis for "reference individual" doses within the Phase I study area. The reference categories were age (infant < 1 year or adults > 20 year), sex (male or female), and lifestyle (urban or rural), for a specific census division and the 1944-1947 time period addressed in Phase I. Two age categories for reference individuals were necessary because the level of physical development is relevant to differences in the types and the quantities of food consumed and to physical and metabolic differences that affect how radiation dose is received and calculated (Stather and Greenhalgh 1983). An adult and infant consuming the same quantity of iodine-131 would receive different radiation doses. Similarly, physical and metabolic differences between male and female adults were addressed by considering the two sexes in different categories. Urban and rural lifestyles were separated to address differences in the source of milk consumed. For example, individuals with rural lifestyles were assumed to be more likely to consume milk produced by a family-owned backyard cow.

2.5.2 Submersion Dose Factors

The submersion dose factor describes the external dose that an individual receives from living in a cloud of iodine-131-contaminated air. Dose was calculated from exposure to a semi-infinite cloud, with no consideration for age, sex, or lifestyle differences. A semi-infinite cloud is a plume of airborne iodine-131 bounded by the ground surface. No shielding factors were included. Phase I submersion dose results were presented as absorbed dose to the thyroid (in rad), rather than as dose equivalent (rem). This difference is mainly semantic for iodine-131 (and other pure beta-gamma emitters) because absorbed dose and dose equivalent are essentially the same (Till and Meyer 1983). Dose factors were based upon those presented in DOE (1988a) with unit conversions made.

Symbol:	DF_s
Units:	rem/mo per Ci/m^3
Value:	median: 1.6×10^5
	geom. std. dev.: 1.3
Distribution:	lognormal

2.5.3 Groundshine Dose Factors

The groundshine dose factor describes the external dose an individual receives from living on a surface—the surface of the earth—contaminated with iodine-131. The dose was calculated as dose from an infinite plane source with no consideration of age, sex, or lifestyle differences. No shielding factors were included. As noted above for submersion dose, Phase I groundshine dose results were presented as dose to the thyroid (in rad), rather than as dose equivalent (rem). Dose factors were based upon those presented in U.S. DOE (1988a) with unit conversions made.

Symbol:	DF_G
Units:	rem/mo per Ci/m^2
Value:	median: 3.6×10^3
	geom. std. dev.: 1.3
Distribution:	lognormal

2.5.4 Inhalation Dose Factors

Inhalation dose factors were used to calculate the 50-year committed dose equivalent to specific organs per unit of activity inhaled. For iodine-131, the thyroid gland is the organ of specific interest and was the only organ for which dose calculations were made. Distinction was made between age categories but not for sex or lifestyle differences. Committed dose equivalent factors for inhalation by adults were based upon those provided in U.S. DOE (1988b); these values are consistent with those published by the International Commission on Radiological Protection (ICRP 1979) and the U.S. Environmental Protection Agency (U.S. EPA 1988). Inhalation doses in Phase I were calculated for two age groups: infants (<1 year) and adults (>20 years). Committed dose equivalent factors for inhalation by infants were derived from those presented in Johnson (1982). Phase I results were presented as committed dose to the thyroid (in rad), rather than committed dose equivalent (rem). This difference is mainly semantic for iodine-131 (and other pure beta-gamma emitters) because committed dose and committed dose equivalent are essentially the same.

Symbol:	DF_H	
Units:	$rem/Ci_{inhaled}$	
Values:	<1 year old	median: 7.7×10^6
		geom. std. dev.: 2
	>20 years old	median: 1.1×10^6
		geom. std. dev.: 2
Distribution:	lognormal	

2.5.5 Breathing Rates

Breathing rates were used in the same equation with the inhalation dose factors to calculate dose from inhalation. The quantity of air inhaled was directly proportional to the inhalation dose received. Breathing rates differed according to age group and, in adults, according to sex. There were no lifestyle differences. The average breathing rates used for each group were taken from the reference values listed in ICRP Publication 23 (1975).

Symbol: BR

Units: m^3/d

Values:

< 1 year median: 3.8
geom. std. dev.: 2

> 20 years

females	median:	20
	geom. std. dev.:	1.5
males	median:	23
	geom. std. dev.:	1.5

Distribution: lognormal

2.5.6 Ingestion Dose Factors

Ingestion dose factors were used to calculate the 50-year committed dose equivalent to specific organs per unit of activity ingested. No distinction was required between the different types of food ingested, since ingestion dose depends only upon the quantity of radionuclides ingested. For iodine-131, the thyroid gland is the organ of specific interest and was the only organ for which dose estimates were made (PNL 1991b). Distinction was made between age categories but not for sex or lifestyle differences. Committed dose equivalent factors for ingestion by adults were based upon those provided in U.S. DOE (1988b), which are consistent with those published by the ICRP (1979) and the U.S. EPA (1988). Committed dose equivalent factors for ingestion by infants were derived from those in Johnson (1982). Phase I results were presented as committed dose to the thyroid (in rad), rather than committed dose equivalent (rem). This difference is mainly semantic for iodine-131 (and other pure beta-gamma emitters) because committed dose and committed dose equivalent are essentially the same.

Symbol:	DF		
Units:	$rem/Ci_{ingested}$		
Values:	< 1 year	median:	1.5×10^7
		geom. std. dev.:	2.0
	> 20 years	median:	1.8×10^6
		geom. std. dev.:	2.0
Distribution:	lognormal		

2.5.7 Fresh Fraction of Food Ingested

The fresh-food fraction of food ingested, as compared with the fraction that is stored or store-bought, is important to the total dose received from iodine-131. Food that is eaten fresh has potentially much greater activities than stored or store-bought food. Because of the relatively short radioactive half-life of iodine-131, a significant amount of radioactivity can radiologically decay away during transport, handling, and storage and thereby be present in lesser quantities at the time of ingestion. The fraction of fresh food ingested was considered for milk and vegetables in the Phase I code. Several months were designated as the months during which fresh vegetation was eaten by individuals; these months are listed in Table 2.3. During other months it was assumed that the food crops consumed did not contain any iodine-131. A constant value, no distribution, was chosen by parameter definition.

Symbol:	ff (vegetation only)
Units:	unitless
Value:	1.0 during fresh harvest months
	0 for other months
Distribution:	none (constant)

TABLE 2.3. Months of Fresh Harvest of Vegetation Consumed by Individuals (Minimum time between harvest and consumption is 0 days.)

Vegetation Category	Months when Fresh Produce Harvested
Leafy vegetables	June - September
Other vegetables	June - September
Fruits	June - October
Grains	July - September

2.5.8 Ingestion Rates

An ingestion dose is also proportional to the quantity of food ingested. Quantities of the different food types ingested by reference individuals for the HEDR Phase I code were taken from Callaway (1992). The reader is referred to that report for parameter values. The Callaway (1992) report indicated a normal distribution for this parameter. The normal distributions describing these values were truncated by setting negative values to zero, to eliminate the evaluation of impossible, negative consumption rates.

Symbol: R
Units: kg/month (wet)
Value: see Callaway (1992)
Distribution: truncated normal (values less than zero were set to zero)

3.0 CONCLUSION

The dose estimates resulting from the use of the HEDR Phase I code and parameter values were presented in July 1990 (PNL 1991a, 1991b). Future work will refine the Phase I efforts as a result of Phase I critiques and a rigorous investigation of sensitive parameter values. Updated code and parameter values will be reported in future documentation.

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APPENDIX A

PARAMETERS USED IN THE PHASE I AIR PATHWAY CODE

PARAMETERS USED IN ALL MODULES

Parameter	Units	Central Value	Distribution	Minimum (lower limit)	Maximum (upper limit)
Radiological decay	day^{-1}	0.086	None	None	None

MODULE 2. VEGETATION CONCENTRATIONS

Parameter	Units	Central Value	Distribution	Minimum (lower limit)	Maximum (upper limit)
Maximum wet biomass	kg (wet)/m^2		None	None	None
Leafy vegetables		2.0			
Other vegetables		2.0			
Grain		0.8			
Fruit		3.0			
Alfalfa		1.0			
Pasture grass		1.5			
Silage		1.5			
Sagebrush		0.08			
Dry:wet ratios	None		None	None	None
Leafy vegetables		0.10			
Other vegetables		0.25			
Grain		0.18			
Fruit		0.18			
Alfalfa		0.20			
Pasture grass		0.20			
Silage		0.20			
Sagebrush		0.50			
Monthly fraction of maximum available biomass					see Table 2.1

MODULE 2 (contd)

Parameter	Units	Central Value	Distribution	Minimum (lower limit)	Maximum (upper limit)
Vegetation interception fraction	m^2/kg		None	None	None
• Other Vegetables, Fruit		3.6			
• Pasture, Leafy vegetables, Alfalfa, Ensilage, Sagebrush, Grain		2.9			
Weathering rate	$days^{-1}$	0.05	Triangular	0.087	0.035
Soil surface density	kg $(dry)/m^2$	240	None	None	None
Soil-to-plant concentration factors	None	0.1	Log-triangular	0.05	0.2
Plant translocation factors	None			None	None
• Leafy vegetables		1.0	None		
• Other vegetables, Fruit, Grain			Log-uniform	0.01	0.1
Alfalfa harvest date (three per year)	Julian day	set in Beck et al. (1992)	Triangular	-7	+7

MODULE 3. ANIMAL PRODUCT CONCENTRATIONS

Parameter	Units	Central Value	Distribution	Minimum (lower limit)	Maximum (upper limit)
Intake-to-milk transfer factor	days/liter	0.0092	Lognormal	geom* std. dev. = 2.1	geom. std. dev. = 2.1
Feed quantities in dairy cow feeding regimes			see Table 2.2 and Beck et al. (1992).		

MODULES 4 and 5. MILK CONCENTRATION AT CONSUMPTION

Parameter	Units	Central Value	Distribution	Minimum (lower limit)	Maximum (upper limit)
Fresh milk hold-up times • Backyard cow • Creamery, Grocery	days	 1 4	none	none	none
Stored milk hold-up times Grocery milk products	days	30	Lognormal	geom. std. dev. = 2.0	geom. std. dev. = 2.0

* geom. std. dev. = geometric standard deviation of lognormal distribution.

APPENDIX B

EXAMPLE CALCULATION FOR ANIMAL PRODUCT IODINE-131 CONCENTRATION

W. V DeMier, December 18, 1989

APPENDIX B

EXAMPLE CALCULATION FOR ANIMAL PRODUCT IODINE-131 CONCENTRATION

CONTENT

1.0 INTRODUCTION

The primary expression to be evaluated in module 3 (GS03) includes a term "QF," representing the feed rate (kg/day) of feed type "t," fed to an animal at location "l" during month "m."

Although QF values are based on values read from tables, the procedures for selecting and adjusting these values are rather involved, and differ in detail for each feed type. This appendix attempts to clarify, by use of specific examples, the processes whereby the QF term is obtained.

2.0 EXAMPLES

In the examples that follow:

- The following feed types are considered:
  Pasture
  Alfalfa Hay
  Grass Hay
  Grain
  Silage
- Not every "plant type" in module 2 (GS02) has a corresponding "feed type" in GS03. The relationship between GS02 plant types and GS03 feed types is:

GS03 Feed Type	Feed Name	GS02 Plant Type
1	grain	3
2	alfalfa hay	5
3	grass hay	(see example 3)
4	pasture	6
5	silage	7

- Feed month and feed location will be varied as required to provide meaningful examples.
- It is assumed that feed fed in a given location was harvested in that location.

2.1 BASE QF VALUES

The base values of QF are obtained from one or more of five "Seasonal Feeding" files:

WINTER_FEEDING.ORIG
SPRING_FEEDING.ORIG
SUMMER_FEEDING.ORIG
EARLY_FALL_FEEDING.ORIG
LATE_FALL_FEEDING.ORIG

Each file provides a triangular distribution of values (central, maximum, minimum) for each feed type, and for each of four different feeding regimes. Since the total of all feed fed is constrained, the base value distributions for all feed types are sampled together for a given regime and season so that we can assure that the total is in the allowable range. For a given feed month "m," base QF values from more than one file will be required if parts of the month fall into different feeding seasons.

Subroutine CONTRI samples the distributions and assures that the total is within the allowable range.

3.0 EXAMPLE 1

In this example QF is obtained for:

- Feed location: No. 46 (KI08)
- Feed month: No. 21 (September 1946)
- Feed types: all applicable to this feed month and location.

3.1 BASE QF VALUES

Assume that sampling of the seasonal feeding files via subroutine CONTRI provides the following set of base QF values (kg/day). (Values for Winter and Spring feeding also would be sampled at this time, but are omitted here because they will not be required for the example.)

SUMMER					EARLY FALL				
Regime =	1	2	3	4	Regime =	1	2	3	4
Grain	4.13	2.39	2.86	1.51	Grain	3.82	3.59	1.19	1.76
Alfalfa	0.62	3.87	6.47	0.00	Alfalfa	6.12	4.05	12.96	0.00
Grass	0.00	0.00	0.00	12.05	Grass	0.00	0.00	0.00	8.24
Pasture	10.77	8.22	0.00	0.00	Pasture	3.64	1.43	0.00	0.00
Silage	0.00	0.00	0.00	0.00	Silage	0.00	0.00	0.00	0.00
Total	15.52	14.48	9.33	13.56	Total	13.58	9.07	14.15	10.00

LATE FALL

Regime =	1	2	3	4
Grain	5.08	1.67	1.64	5.02
Alfalfa	7.72	8.00	13.19	0.00
Grass	0.00	0.00	0.00	8.37
Pasture	0.00	0.00	0.00	0.00
Silage	7.20	0.00	0.00	0.00
Total	20.00	9.67	14.83	13.39

3.2 PASTURE FEEDING

3.2.1 Determining Pasture Season Dates

The base QF values will be adjusted according to such factors as feed month and pasture season dates. Pasture season dates depend upon the census division and upon a "weather adjustment" for the year of interest.

FEED MONTH is an input value = 21

CENSUS DIVISION is an input value = 46

Month 21 falls in 1946. The weather-adjusted pasture season dates for 1946 are obtained by adding:
minus 8 days to beginning of season
and minus 3 days to end of season.

For census division #46, the distribution for pasture season dates is:

Beginning day for	Spring	Late Fall
Mean	130	270
Min	120	250
Max	140	290

Assume that sampling of the above distribution returns day 120 as the (unadjusted) beginning of Spring. The weather adjustment (-8 days) produces a beginning date of 112 days.

Since by definition Spring lasts 14 days, the last day of Spring will be day number 125.

The first day of early Fall is determined as follows:

> Assume that sampling of the above distribution returns day 270 as the unadjusted beginning day for late Fall. In 1946 the weather adjustment for beginning of late Fall is -3, giving an adjusted late Fall beginning day of 267. Early Fall runs for the 14 days preceding late Fall, i.e. from day 253 through day 266.

In summary, the seasons are:

Day 1 through 111 : Winter
Day 112 through 125 : Spring
Day 126 through 252 : Summer
Day 253 through 266 : Early Fall
Day 267 through 365 : Late Fall

3.2.2 Seasonal Adjustment Factors

The example month of September includes days 244 through 273 of the year:

Days 244 through 252 in SUMMER feeding season (9 days)
Days 253 through 266 in EARLY FALL feeding season (14 days)
Days 267 through 273 in LATE FALL feeding season (7 days)

During September the seasonal adjustments to be applied to the daily feed rates from the seasonal feeding files are:

9/30 * values from SUMMER_FEEDING.ORIG,
14/30 * values from EARLY_FALL_FEEDING.ORIG, and
7/30 * values from LATE_FALL_FEEDING.ORIG.

For the example case, the dailv feed rates for pasture feeding under the four different feeding regimes during September are:

		REGIME 1	REGIME 2	REGIME 3	REGIME 4	
Summer	(9 days)	10.77	8.22	0.0	0.0	kg/day
Early Fall	(14 days)	3.64	1.43	0.0	0.0	kg/day
Late Fall	(7 days)	0.00	0.00	0.0	0.0	kg/day

Multiplying the above daily feed rates by the seasonal adjustment factors (9/30 for Summer, 14/30 for early Fall, and 7/30 for late Fall) and adding them together produces the following average feed rate for pasture feeding in September 1946.

REGIME 1	REGIME 2	REGIME 3	REGIME 4	
4.93	3.13	0.0	0.0	kg/day

3.2.3 Feeding-Regime Practices

The binary file CENSUS_FEED_REGIMES.BIN contains data showing, for each census division, the fraction of milk cows that were fed under each of the four feeding regimes in each census division. The distribution for census division KI08 is:

FRACTION OF COWS FED UNDER REGIME				
Regime =	1	2	3	4
Mean	0.45	0.45	0.10	0.0
Min	0.20	0.20	0.0	0.0
Max	0.65	0.65	0.15	0.0

Assume that sampling of the above distribution produces fractions 0.65, 0.25, 0.10, and 0.0 for regimes 1, 2, 3, and 4, respectively.

Applying these fractions to the current values of pasture feeding rates of 4.93, 3.13, 0.0, and 0.0 for regimes 1, 2, 3, and 4 produces daily feed rates of:

0.65 * 4.93 = 3.20 kg/day under regime 1
0.25 * 3.13 = 0.78 kg/day under regime 2
0.10 * 0.0 = 0.00 kg/day under regime 3
0.00 * 0.0 = 0.00 kg/day under regime 4

Final value of QF(t) 3.98 kg/day pasture feed rate of cows in census division KI08 in Sept of 1946.

3.3 ALFALFA HAY FEEDING

It is assumed that the base QF values have already been obtained via subroutine CONTRI. (See section 3.1)

3.3.1 Alfalfa Hay Cutting Dates

File [GS02.DAT]CUTTING.DAT contains the mean values for alfalfa hay cutting date (days since January 1) for each of three cuttings made during the year, in each census division. Range on the values is plus or minus 7 days.

For census division KI08, mean cutting dates as read from file [GS02.DAT]CUTTING.DAT for 1st, 2nd, and 3rd cuttings are: 176, 221, and 266. (Range is + or - 7.)

For the example year (1946), the adjustment to be added is -4.

Thus WEATHER-ADJUSTED MEAN CUTTING DATES are 172, 217, and 262.

Applying the range (+ or - 7) to the above produces the following triangular distribution for cutting dates:

Cutting date (days since Jan 1)			
	1st cut	2nd cut	3rd cut
Mean	172	217	262
Min	165	210	255
Max	179	224	269

Assume that sampling of the above distribution gives WEATHER-ADJUSTED CUTTING DATES of:

1st cutting: day 175 (month 18)
2nd cutting: day 219 (month 20)
3rd cutting: day 260 (month 21)

3.3.2 Effect of Multiple Cutting on Alfalfa Hay Feed Mixture

For the example month (days 244 through 273), cows will be fed the following mixes of alfalfa hay cut in 1946:

FEED DAYS	MIXTURE
244 through 259	50% 1st + 50% 2nd cutting
260 through 273	33.33% 1st + 33.33% 2nd + 33.33% 3rd

for a composite of:

(16/30 * 50.0%) + (14/30 * 33.33%) = 42.22% first cutting
(16/30 * 50.0%) + (14/30 * 33.33%) = 42.22% second cutting
(14/30 * 33.33%) = 15.56% third cutting

3.3.3 Seasonal Adjustment

Seasonal adjustment factors have been determined in 3.2.2 above. They are:

Summer 9/30 Early Fall 14/30 Late Fall 7/30

The already-sampled (see 3.1) distribution from the seasonal feeding files has produced:

ALFALFA HAY FEEDING RATE (kg/day)					
Regime =		1	2	3	4
Summer	(9 days)	0.62	3.87	6.47	0.0
Early Fall	(14 days)	6.12	4.05	12.96	0.0
Late Fall	(7 days)	7.72	8.00	13.19	0.0

Multiplying by seasonal adjustment factors and adding the products, we obtain the average alfalfa hay feed rate in each regime during the month:

REGIME 1	REGIME 2	REGIME 3	REGIME 4
9/30 * 0.62 = 0.19	9/30 * 3.27 = 1.16	9/30 * 6.47 = 1.94	0.0
14/30 * 6.12 = 2.86	14/30 * 4.05 = 1.89	14/30 * 12.96 = 6.05	0.0
7/30 * 7.72 = 1.80	7/30 * 8.00 = 1.87	7/30 * 13.19 = 3.08	0.0
Month Avg: 4.85	4.92	11.07	0.0

3.3.4 Feeding-Regime Practices

The fraction of cows fed under each of the four feeding regimes, as was determined in 3.2.3, is 0.65, 0.25, 0.10, and 0.0 for regimes 1, 2, 3, and 4, respectively.

Applying these fractions to the current values of alfalfa hay feeding rates of 4.85, 4.92, 11.07, and 0.0 for regimes 1,2,3, and 4 produces daily feed rates of:

0.65 * 4.85 = 3.15 kg/day under regime 1
0.25 * 4.82 = 1.23 kg/day under regime 2
0.10 * 11.07 = 1.11 kg/day under regime 3
0.00 * 0.00 = 0.00 kg/day under regime 4

Final value of QF(t) = 5.49 kg/day alfalfa hay feed rate of cows in census division K108 in August of 1946.

Of this amount, 0.4222 * 5.49 = 2.32 kg/day was first-cutting alfalfa, harvested in month 18.

0.4222 * 5.49 = 2.32 kg/day was second-cutting alfalfa, harvested in month 20.

and 0.1533 * 5.49 = 0.85 kg/day was third-cutting alfalfa, harvested in month 21 (current month).

3.4 GRASS HAY FEEDING

Grass hay is fed under feed regime 4 only. The CENSUS_FEED_REGIMES file indicates that, in census division KI08, no cows are fed under regime 4, so grass hay fed in KI08 is zero.

3.5 GRAIN FEEDING

3.5.1 Grain Harvest Dates

Grain harvest date is assumed to be 14 days after the grass hay cutting date for the year as determined from values in file [GS02.DAT]CUTTING.DAT. (Grain is harvested only once during the year.) In census division KI08 the MEAN CUTTING DATE for grass hay is day 210.

The weather adjustment for the 1946 grain harvest is -4, giving a weather-adjusted mean cutting date of 206.

Applying the range (+ or - 7) to the mean gives a cutting date distribution of:

Mean day 206
Min day 199
Max day 213

Assume that sampling of the above distribution gives a weather-adjusted cutting date of 210. Applying the 14-day offset between grass hay cutting day and grain harvest day gives:

GRAIN HARVEST DATE = day 224, month 20 (Aug 1946)

The entire feed month (days 244 through 273) comes after the harvest date, so all grain fed during the month will be from the August 1946 harvest.

3.5.2 Seasonal Adjustment

Grain-feeding rate has the same distribution throughout the year for all four regimes; however, since the constrained joint sampling routine CONTRI will in general, for regimes 1 and 2, return a different grain-feeding rate for each season, we will use those values in the same manner as we treated pasture grass and alfalfa hay. That is, we will multiply them by the appropriate seasonal adjustment fractions for the month to obtain an average grain feed rate for the month for each regime.

The already-sampled (see 3.1) distribution from the seasonal feeding files has produced:

		GRAIN FEEDING RATE			
		REGIME 1	REGIME 2	REGIME 3	REGIME 4
Summer	(9 days)	4.13	2.39	2.86	1.51
Early Fall	(14 days)	3.82	3.59	1.19	1.76
Late Fall	(7 days)	5.08	1.67	1.64	5.02

Multiplying by seasonal adjustment factors as in 3.2.3 we get the average grain feed rate in each regime during the month:

	REGIME 1	REGIME 2	REGIME 3	REGIME 4
9 days	1.239	0.717	0.858	0.453
14 days	1.783	1.675	0.555	0.821
7 days	1.185	0.390	0.383	1.171
Month Avg:	4.207	2.782	1.796	2.445

3.5.3 Feeding-Regime Effects

The fraction of cows fed under each of the four feeding regimes as was determined in 3.2.3 is: 0.65, 0.25, 0.1, and 0.0 for regimes 1, 2, 3, and 4, respectively.

Applying these fractions to the current values of grain-feeding rates produces daily feed rates of:

0.65 * 0.207 = 2.735 kg/day under regime 1
0.25 * 2.782 = 0.696 kg/day under regime 2
0.10 * 1.796 = 0.180 kg/day under regime 3
0.00 * 2.445 = 0.0 kg/day under regime 4

Final value of QF(t) = 3.611 kg/day grain feed rate of cows in census division KI08 in September of 1946.

3.6 SILAGE FEEDING

3.6.1 Silage Harvest Dates

Silage feeding starts at the end of the pasture season. Harvest occurs 14 days before that. Thus, harvest date coincides with the beginning of early Fall, or day 253 as shown in 3.2.1 above. As with grain, we assume that the silage fed to animals is that from the most recent harvest.

3.6.2 Seasonal Adjustment

The example month of September (days 244 through 273) includes all or part of three seasons:

Days 244 through 252 = 9 days in Summer
Days 253 through 266 = 14 days in Early Fall
Days 267 through 273 = 7 days in Late Fall

Day 253 is also the harvest date. Since September includes this date, we will assume that the silage fed in September 1946 was also harvested in that same month.

The already-sampled distributions (see 3.1 above) from seasonal feeding files for silage feeding are:

		SILAGE-FEEDING RATE DURING THE FEED MONTH				
		REGIME 1	REGIME 2	REGIME 3	REGIME 4	
Summer	(9 days)	0.0	0.00	0.00	0.00	kg/day
Early Fall	(14 days)	0.0	0.00	0.00	0.00	kg/day
Late Fall	(7 days)	7.20	0.00	0.00	0.00	kg/day

Multiplying the above rates by the seasonal adjustment factors and adding the products as in 3.2.3, we get the average silage-feed rate in each regime during the month:

AVG SILAGE FEEDING RATE DURING FEED MONTH				
REGIME 1	REGIME 2	REGIME 3	REGIME 4	
1.68	0.00	0.00	0.00	kg/day

3.6.3 Feeding-Regime Practices in Current Census Division

The fraction of cows fed under each of the four feeding regimes as determined in 3.2.3 is: 0.65, 0.25, 0.1, and 0.0 for regimes 1, 2, 3, and 4, respectively.

Applying these fractions to the current values of silage-feeding rates produces:

0.65 * 1.68 = 1.09 kg/day under regime 1
0.25 * 0.0 = 0.0 kg/day under regime 2
0.10 * 0.0 = 0.0 kg/day under regime 3
0.0 * 0.0 = 0.0 kg/day under regime 4

Final value of QF(t) = 1.09 kg/day silage feed rate of cows in census division KI08 in September of 1946.

3.7 SUMMARY OF FEED-FED ANIMALS IN KI08 DURING SEPTEMBER 1946

Feed Type	kg/day	Total kg
Grain	3.61	108.3
Alfalfa Hay	5.49	164.7
Grass Hay	0.00	0.0
Pasture	3.98	119.4
Silage	1.09	32.7

4.0 EXAMPLE 7

In this example QF is obtained for:

- Feed location: No. I (AD01)
- Feed month: No. 18 (June 1946)
- Feed types: all applicable feeds for this month and location

4.1 BASE QF VALUES

Data in the CENSUS_FEED_REGIME file show that feeding in census division AD01 follows regimes 3 and 4 only. Data in the seasonal feeding files show that, in regimes 3 and 4, the distributions of base QF for a given feed type do not vary from season to season. Thus, for this example we can sample from any one of the seasonal feeding files.

Assume that the following base QF values are returned by subroutine CONTRI for regimes 3 and 4:

	Base QF Values			
	REGIME 1	REGIME 2	REGIME 3	REGIME 4
Grain	---	---	2.86	1.51
Alfalfa	---	---	6.47	0.00
Grass	---	---	0.00	12.05
Pasture	---	---	0.00	0.00
Silage	---	---	0.00	0.00
Total			9.33	13.56

4.2 PASTURE FEEDING

From file PASTURE_SEASONS.BIN, pasture season dates for census division AD01 are zero, indicating that no pasture feeding occurs in AD01.

4.3 ALFALFA HAY FEEDING

4.3.1 Alfalfa Hay Cutting Dates

File [GS02.DAT]CUTTING.DAT contains the mean values for alfalfa hay cutting date (days since January 1) for each of three cuttings made during the year, in each census division. Range on the values is plus or minus 7 days. For census division AD01, mean cutting dates as read from the file are: 166, 211, and 256.

For the example year (1946), the weather adjustment to be added is -4 so the adjusted mean values are: 162, 207, and 252.

Applying the range (+ or - 7) to the above produces the following triangular distribution for cutting dates:

	Cutting date (days since Jan 1)		
	1st cut	2nd cut	3rd cut
mean	162	207	252
min	155	200	245
max	169	214	259

Assume that sampling of the above distribution gives WEATHER-ADJUSTED CUTTING DATES of:

1st cutting: day 160 (month 6)
2nd cutting: day 210 (month 7)
3rd cutting: day 250 (month 9)

4.3.2 Effect of Multiple Cutting on Alfalfa Hay Feed Mixture

For the example month (days 152 through 181), cows will be fed the following mixes:

FEED DAYS	MIXTURE (% of indicated cutting)
152 through 159	33.33% 1st + 33.33% 2nd + 33.33% 3rd (1945 cutting)
160 through 181	100% 1st (1946 cutting)

The first alfalfa hay cutting for 1946 occurs during the feed month; thus, cuttings from 1945 are fed during the first part of the month. During the latter part of June (after the first cutting of 1946), first-cutting alfalfa from year 1946 is fed. The alfalfa hay composite is, therefore:

8/30 X 33.33% = 8.889% (1945 1st cut, month 6)
8/30 X 33.33% = 8.889% (1945 2nd cut, month 7)
8/30 X 33.33% = 8.889% (1945 3rd cut, month 9)
(22/30 X 100.0% = 73.33% (1946 1st cut, month 18)

4.3.3 Seasonal Adjustment

No seasonal adjustment is made to alfalfa hay feeding in AD01. (See 4.1 above.)

4.3.4 Feeding-Regime Practices

The binary file CENSUS_FEED_REGIMES.BIN contains data showing, for each census division, the fraction of milk cows that were fed under each of the four feeding regimes in each census division. The distribution for census division AD01 is:

FRACTION OF COWS FED UNDER REGIME				
Regime =	1	2	3	4
mean	0.00	0.00	0.05	0.95
min	0.00	0.00	0.00	0.90
max	0.00	0.00	0.10	1.00

Assume that sampling of the above distribution produces fractions 0.0, 0.0, 0.07, and 0.93 for regimes 1, 2, 3, and 4, respectively. (Only regimes 3 and 4 are applicable to the example census division.)

Applying these fractions to the current alfalfa hay feeding rates of 0.0, 0.0, 6.47, and 0.0 for regimes 1, 2, 3, and 4 produces daily feed rates of:

0.00 * 0.00 = 0.00 kg/day from regime 1
0.00 * 0.00 = 0.00 kg/day from regime 2
0.07 * 6.47 = 0.45 kg/day from regime 3
0.93 * 6.47 = 0.00 kg/day from regime 4

0.45 kg/day alfalfa hay fed to cows in census division AD01 in June 1946.

Of this amount:

0.08889 X 0.45 = 0.04 kg/day was 1945 first cut, month 6.
0.08889 X 0.45 = 0.04 kg/day was 1945 second cut, month 7.
0.08889 X 0.45 = 0.04 kg/day was 1945 third cut, month 9.
0.73333 X 0.451 = 0.33 kg/day was 1946 first cut, month 18.

4.4 GRASS HAY FEEDING

4.4.1 Grass Hay Cutting Dates

File [GS02.DAT]CUTTING.DAT contains the mean values for grass hay cutting date (days since January 1). Range on the values is plus or minus 7 days. Grass hay is cut only once during the year.

In census division AD01 the mean cutting date for grass hay is day 200. For 1946 the weather adjustment is -4.

Thus, the WEATHER-ADJUSTED mean cutting date is 196.

Applying the range (+ or - 7) to the above cutting date gives a cutting date triangular distribution of:

mean day 196

min day 189
max day 203

Assume that sampling of the above distribution gives a WEATHER-ADJUSTED CUTTING DATE of day 200. This date falls later than the end of the current feeding month; therefore, all grass hay fed in June 1946 was harvested in 1945. The 1945 weather adjustment of -7 days, together with the uncertainty range of + or - 7 days, gives a triangular distribution of 1945 cutting dates:

mean 193
min 186
max 200

which will be sampled to select a value for use in calculating radioactive decay at feeding time (see 4.4.4), and for determining the grain harvest date (see 4.5.1).

Assume that sampling of the above distribution produces 195 as the alfalfa hay cutting date.

4.4.2 Seasonal Adjustment

No seasonal adjustment is made to grass hay feeding in AD01 (See 4.1).

4.4.3 Feeding-Regime Practices

The fraction of milk cows that were fed under each regime has been determined in 4.3.4 to be 0.0, 0.0, 0.07, and 0.93 for regimes 1, 2, 3, and 4, respectively.

Applying these fractions to the current values of grass hay feeding rates of 0.0, 0.0, 0.0, and 12.05 for regimes 1, 2, 3, and 4 produces daily feed rates of:

0.00 X 0.0 = 0.00 kg/day from regime 1
0.00 X 0.0 = 0.00 kg/day from regime 2
0.07 X 0.0 = 0.00 kg/day from regime 3
0.93 X 12.05 = 11.21 kg/day from regime 4

Final value of QF(t) = 11.21 kg/day grass hay feed rate of cows in census division AD01 in June of 1946.

4.4.4 Elapsed Time Between Cutting and Feeding

While the elapsed time between cutting day and feed date for grass hay does not affect the amount of hay fed, it will affect the level of radioactivity in the hay. Nuclide concentration in the hay at time of cutting is assumed to be that of pasture grass at the same time. At feeding time the nuclide concentration in the hay is a function of the nuclide half-life and the elapsed time since cutting.

4.5 GRAIN FEEDING

4.5.1 Grain Harvest Dates

Grain is harvested only once during the year. Grain harvest date is assumed to be 14 days after the GRASS HAY cutting date for the year as determined from values in file [GS02.DAT]CUTTING.DAT.

In census division AD01 the mean cutting date for grass hay is day 200.

The weather adjustment for the 1946 grain harvest is -4, giving a weather-adjusted mean cutting date of 196.

Applying the range (+ or - 7) to the mean gives a cutting date distribution of:

mean	day 196
min	day 189
max	day 203

Assume that sampling of the above distribution gives a weather-adjusted cutting date of 200. Finally, applying the 14-day offset between grass hay cutting day and grain harvest day gives:

1946 GRAIN HARVEST DATE = day 224.

The entire feed month (days 152 through 181) is before the harvest date, so all grain fed during the month will be from the previous year's harvest (1945), and we must determine that date.

Grass harvest date for 1945 has been determined (4.4.1) to be day 195. Applying the 14-day offset between grass hay cutting day and grain harvest day gives:

1945 GRAIN HARVEST DATE = 195 + 14 = day 209

4.5.2 Seasonal Adjustment

No seasonal adjustment is made to the base QF values of grain-feeding rates determined in 4.1 above. They are:

	GRAIN-FEEDING RATE			
REGIME =	1	2	3	4
	0.0	0.0	2.86	1.51 kg/day

4.5.3 Feeding-Regime Effects

The fraction of cows fed under each of the four feeding regimes has been determined (4.4.3) to be 0.07 and 0.93 for regimes 3 and 4, respectively.

Applying these fractions to the current values of grain-feeding rates of 2.86 and 4.51 for regimes 3 and 4 produces daily feed-fed rates of:

0.07 X 2.46 = 0.20 kg/day under regime 3
0.93 X 1.51 = 1.40 kg/day under regime 4
Final value of QF(t) = 1.60 kg/day grain feed rate of cows in census division AD01 in June of 1946.

4.6 SILAGE FEEDING

The seasonal feeding files (WINTER_FEEDING.ORIG, etc.) show that silage is fed under feed regime 1 only. As noted in 4.1, feed regime 1 is not used in the example census division. Therefore, no silage feeding occurs in census division AD01.

4.7 SUMMARY OF FEED-FED ANIMALS IN AD01 DURING JUNE 1946

Feed type	kg/day	Total kg
Grain	1.60	48.1
Alfalfa	0.45	13.5
Grass hay	11.21	336.3
Pasture	0.00	0.0
Silage	0.00	0.0

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