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SCOPING CALCULATION FOR COMPONENTS
OF THE COW-MILK DOSE PATHWAY FOR EVALUATING
THE DOSE CONTRIBUTION FROM IODINE-131

Hanford Environmental Dose
Reconstruction Project
Dose Code Recovery Activities

T. A. Ikenberry
B. A. Napier

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Battelle
Pacific Northwest Laboratories
Richland, Washington 99352

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1.0 INTRODUCTION

A series of scoping calculations have been undertaken to evaluate the absolute and relative contribution of different exposure pathways to doses that may have been received by individuals living in the vicinity of the Hanford site. These scoping calculations include some pathways that were included in the Phase I air-pathway dose evaluations (HEDR staff 1991, page *xx*), as well as other potential exposure pathways which are being evaluated for possible inclusion in the future HEDR modeling efforts.

This scoping calculation (Calculation 001) examined the contributions of the various exposure pathways associated with environmental transport and accumulation of iodine-131 in the pasture-cow-milk pathway. Addressed in this calculation were the contributions to thyroid dose of infants and adult from 1) the ingestion by dairy cattle of various feedstuffs (pasturage, silage, alfalfa hay, and grass hay) in four different feeding regimes; 2) ingestion of soil by dairy cattle; 3) ingestion of stored feed on which airborne iodine-131 had been deposited; and 4) inhalation of airborne iodine-131 by dairy cows.

Recommendations determined from scoping calculations are provided to the Technical Steering Panel (TSP) of the Hanford Environmental Dose Reconstruction Project (HEDR) with the intent of providing a definitive technical basis to help the TSP decide whether specific exposure pathways should or should not be included in the HEDR dose estimation process for individuals.

2.0 TECHNICAL METHODS

Thyroid doses were calculated for an average infant and adult in an area that was exposed to high concentrations of airborne radioiodine. Calculating doses to an average individual is consistent with guidance provided by the TSP in establishing dose decision levels,[a] which states: "They [dose decision levels] imply a *best estimate* calculation, that is one in which *average* intake, organ size and transfer factors are used." Therefore, parameters used in the calculations were selected to be approximate average, median, or best-estimate values, rather than conservative, upper bound values, while selecting a high exposure location ensured that no other location in the HEDR study area would have doses exceeding those of this scoping calculation. References for all parameter values are provided in Appendices A and B.

Calculations were based on methods presented in Napier et al. (1988 volume 1, pages 4.66 - 4.76) and Napier (1991, pages A.2 - A.6). Doses were calculated on a monthly basis using steady-state assumptions but changing time-dependent parameter values monthly, resulting in set of "semi-steady state" equations. Calculations were performed using the commercially-available spreadsheet program Quattro Pro 4.0 (Borland International, Inc., Scotts Valley, California). Individuals were assumed to have a rural lifestyle, with milk supplied by a backyard cow. Thyroid doses were calculated for all four of the feeding regimes used in Phase I (HEDR staff 1991, page 2.17). Doses from consumption of commercially-produced milk in the same area (HEDR staff 1991, page C.24) fall within the range of these four regimes.

The location of exposure selected was the region of Franklin County included as part of Census District 4 (Figure 1). This area lies directly east of the Hanford site, and was shown in the Phase I air pathway report (HEDR staff 1991, Appendix C) to be one of the most highly impacted regions. The time period selected was the year 1945, which accounted for about 80% of the radioiodine releases from 1944 through 1947 time period (Heeb 1992, 4.36).

(a) "Scoping Document for Determination of Temporal and Geographic Domains for the HEDR Project", attachment to Technical Steering Panel Research Directive 90-2, "Dose Cut-off Limit", dated February 17, 1990.

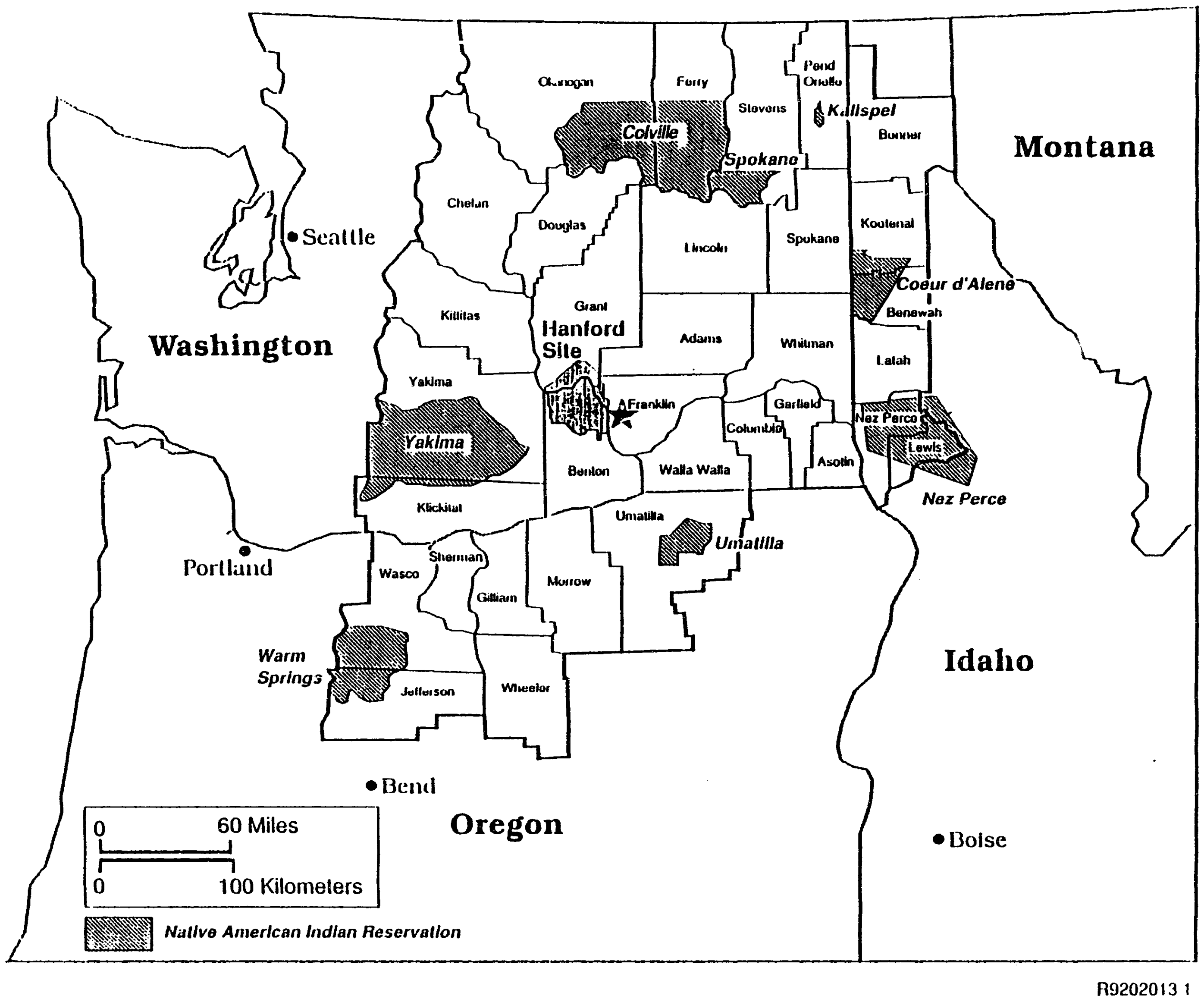

FIGURE 1. Approximate Location (★) Within the HEDR Study Area Selected for Scoping Calculations

Surface deposition and integrated air concentration data used in the scoping calculations were not those used in Phase I but rather were recalculated (J. V. Ramsdell Jr., data transmittal, October, 1992) from the latest Hanford iodine-131 source term information (Heeb 1992, page 4.36) using the RATCHET atmospheric dispersion code (Ramsdell and Burk 1992). Because of time constraints, monthly surface deposition and integrated air concentrations from a single run of the RATCHET code (calculated daily for each node throughout 1945) were used in these scoping calculations.

The Ramsdell data were presented by atmospheric dispersion grid map location, as discussed by Shipler and Napier (1992, page 2), and shown in Ikenberry et al. (1992, page 1.4). The node selected lies within the area encompassed by Franklin County Census District 4, and appeared to be the highest surface deposition value in the general area.

The surface deposition and integrated air-concentration values for the 12 months of 1945 for node location (18,25) (x,y) used in the scoping calculations are shown in Table 1. Also shown are the comparable values for Franklin County census district 4 used in the Phase I air pathway calculations, showing the effect of the increased iodine-131 source term.

2.1 DESCRIPTION OF FEEDING REGIME COMPONENTS

The term "feeding regime" refers to the diet that livestock are placed on by their owners over the course of a year. Four dairy cow feeding regimes were identified for the HEDR 10-county study area during the 1944-1947 time period (Beck et al. 1992, page 48). For the purpose of these scoping calculations, consumption of grain by dairy cows was not considered. Grain had previously been shown to be a minor contributor to dose when consumed directly by humans (Marsh et al. 1992, pages B.1 - B.8). This observation was assumed to apply to the grain-cow-milk-human pathway.

Feeding regimes 1 and 2 are irrigated-land feeding regimes. Cows on feeding regime 1 consume alfalfa hay, pasturage, and silage, while cows on feeding regime 2 consume alfalfa hay and pasturage. Feeding regimes 3 and 4 are dryland feeding regimes, with cows on feeding regime 3 consuming alfalfa hay, and cows on feeding regime 4 consuming grass hay.

TABLE 1. Monthly Surface Deposition and Time-integrated Air Concentration Used in the Scoping Calculations and for the Phase I Air Pathway Calculations

1945	Scoping Calculation for Node 18, 25		Phase I Calculation Franklin County 4	
	Surface Deposition Ci/m^2	Time-integrated Air Concentration $Ci \cdot s/m^3$	Surface Deposition Ci/m^2	Time-integrated Air Concentration $Ci \cdot s/m^3$
January	4.4×10^{-8}	1.8×10^{-5}	9.22×10^{-9}	2.16×10^{-6}
February	8.1×10^{-8}	1.4×10^{-5}	1.71×10^{-8}	3.81×10^{-6}
March	1.8×10^{-7}	2.9×10^{-5}	2.98×10^{-8}	6.93×10^{-6}
April	6.3×10^{-7}	1.5×10^{-4}	3.45×10^{-7}	1.10×10^{-4}
May	5.0×10^{-6}	6.9×10^{-4}	1.05×10^{-6}	3.40×10^{-4}
June	1.3×10^{-6}	2.5×10^{-4}	5.91×10^{-7}	1.55×10^{-4}
July	2.1×10^{-6}	5.6×10^{-4}	4.21×10^{-7}	1.14×10^{-4}
August	1.7×10^{-6}	5.5×10^{-4}	6.94×10^{-7}	2.02×10^{-4}
September	5.3×10^{-6}	2.7×10^{-3}	7.74×10^{-7}	2.55×10^{-4}
October	3.1×10^{-6}	1.7×10^{-3}	9.73×10^{-7}	2.91×10^{-4}
November	7.3×10^{-7}	1.9×10^{-4}	3.44×10^{-7}	7.87×10^{-5}
December	2.3×10^{-6}	9.9×10^{-4}	1.69×10^{-7}	5.34×10^{-5}

2.1.1 Pasture

Fresh pasture is eaten only in feeding regimes 1 and 2 and then only during the months of May, June, July, August, and September (Beck et al. 1992, page 54). Iodine-131 is assumed to be continually deposited on the pasture. The dose to an infant's thyroid from milk supplied by a cow continually consuming fresh pasture during a particular month was calculated as

$$\text{Dose Pasture}_{\text{month } i} = D_{\text{end } i} * \left[\frac{1-e^{-Y*\alpha*f_s}}{Y * f_s}\right] * \left[\frac{\lambda_r}{\lambda_r + \lambda_w}\right] * IR_{cow} \quad (1)$$

$$* TF_{milk} * IR_{infant} * DF_{infant} * 30 \text{ d/month}$$

where $D_{\text{end } i}$ = the surface deposition of iodine-131 on the ground at the end of month i (Ci/m^2); varies by month; value used: see Table 1

Y = maximum dry biomass of a plant (kg/m^2 dry); varies by plant type; value used: 0.3 for pasture

α = empirical interception parameter (m^2/kg); value used: 2.9 for pasture, silage, and alfalfa

f_s = available fraction of maximum wet biomass (unitless); varies by month and plant type; value used: see Appendix B

λ_r = radiological decay constant ($days^{-1}$); value used: 0.086 for iodine-131

λ_w = weathering removal rate constant ($days^{-1}$); value used: 0.0495

IR_{cow} = ingestion rate by cows of various feed types (kg/d); varies monthly by feed type; value used: see Appendix B

TF_{milk} = transfer coefficient for cow's milk (d/l) [Ci/l per Ci/d]; value used: 0.0092

IR_{infant} = milk ingestion rate for an infant (l/d); value used: 1.0

DF_{infant} = ingestion dose conversion factor for an infant (rad [thyroid]/Ci); value used: 1.5×10^7

The second term in equation (1) (a ratio of rate constants λ_r and λ_w) includes the weathering removal of radionuclides from vegetation and accounts for the radiological decay already implicit in the decay-corrected surface deposition values. Use of this term assumes that equilibrium has been reached when it fact it has not, resulting in a underestimation of dose of about 7%.

The equation for calculating thyroid dose to adults is the same as above in equation (1), but the following substitutions are made for the ingestion rate of infants and the infant dose conversion factor:

IR_{adult} = milk ingestion rate for an adult (l/d); value used: 0.5

DF_{adult} = ingestion dose conversion factor for an adult (rad [thyroid]/Ci); value used: 1.8×10^6.

As noted previously, references for all parameter values are provided in Appendices A and B.

2.1.2 Silage

Silage is eaten by cows only in feeding regime 1. In this model, silage is harvested on September 15. There is a two-week holdup time (Beck et al. 1992, page 62), and consumption of silage by cows begins October 1, continuing through the end of the year. The dose to an infant's thyroid from milk supplied by a cow consuming harvested and stored silage during a particular month after harvest was calculated as

$$\text{Dose Silage}_{\text{month } i+n} = D_{\text{end } h} * \left[\frac{1-e^{-Y*\alpha*f_s}}{Y*f_s}\right] * \left[\frac{\lambda_r}{\lambda_r+\lambda_w}\right] * \left(e^{-\lambda_r(15+30*n)}\right)$$

$$* IR_{cow} * TF_{milk} * IR_{infant} * \left[\frac{1-e^{-\lambda_r 30d}}{\lambda_r}\right] * DF_{infant} \quad (2)$$

where n = an integer; the number of complete months elapsed since harvest; values used: 0 for October, 1 for November, 2 for December

$D_{\text{end } h}$ = the surface deposition of iodine-131 on the ground at the end of the month (h) when harvest took place (Ci/m^2); varies by month; value used: see Table 1

Y value used: 0.3 for silage.

The term $e^{-\lambda r(15+30n)}$ accounts for the decay of radionuclides from the day of silage harvest to the start of the month of consumption by the cow. The term $(1 - e^{-\lambda r30})/\lambda_r$ is a consumption integral, which converts decreasing daily intake of radionuclides to total intake during the month.

2.1.3 Alfalfa Hay and Grass Hay

Alfalfa hay is eaten by cows in feeding regimes 1, 2, and 3. There are three cuttings of alfalfa, assumed to be in May, July, and August. These dates are consistent with the range of those determined by Beck et al. (1992, page C.10). A 15-day holdup time between harvest and the beginning of hay consumption is assumed to allow for hay cutting, curing, baling, and transportation. This holdup time is not explicitly called out by Beck et al. (1992) for hay as it is for silage; however, an implicit holdup time of 30 days was discovered to exist in the Phase I HEDR code, and a holdup time of 15 days seems to be a reasonable assumption of the time needed for hay preparation (D. S. Barth, verbal communication, November 13, 1992).

Grass hay is eaten by cows in feeding regime 4. Grass hay is harvested once, in June, consistent with the date determined by Beck et al. (1992, page C.14). As with alfalfa, there is assumed to be a 15-day holdup time between harvest and the beginning of hay consumption.

In this analysis, cows consume contaminated hay from July through December. Hay consumed prior to the first cutting in June was harvested during 1944 and was assumed to be uncontaminated, except for small contributions from deposition on stored feed during early 1945, because atmospheric releases of radionuclides did not begin until late December 1944 (Heeb 1992, page 4.36). By 1946 contamination in the hay would have decayed to negligible levels, with the only contamination present being that which was continually deposited on the stored feed. The equation for calculating the monthly infant thyroid dose from milk supplied by a cow consuming alfalfa from a particular cutting of grass hay in a particular month after hay harvest is

$$\text{Dose Hay}_{\text{month } i+n} = D_{\text{end } h} * \left[\frac{1-e^{-Y*\alpha*f_s}}{Y * f_s}\right] * \left[\frac{\lambda_r}{\lambda_r + \lambda_w}\right] * \left(e^{-\lambda_r(15+30*n)}\right) * f_{hay}$$

$$* IR_{cow} * TF_{milk} * IR_{infant} * \left[\frac{1-e^{-\lambda_r 30d}}{\lambda_r}\right] * DF_{infant} \quad (3)$$

where n = the number of complete months elapsed since harvest values used: 1 for first month, 2 for second month, and so on

Y value used: 0.2 for alfalfa, 0.3 for grass

f_{hay} = the fraction of a particular hay cutting consumed (unitless): values used: 1.0 for June & July, 0.5 for August, and 0.33 for September, October, November, December.

This equation is summed over all hay cuttings. References for parameter values are provided in Appendix A.

2.2 SOIL INGESTION BY COWS

Soil is assumed to be ingested continually by cows in all feeding regimes. The rate of soil ingestion (kg/day) varies with the feeding regime and season. Dairy cows on feeding regimes 1 and 2 (irrigated pasture regimes) eat less soil in the spring, summer, and fall than those on feeding regimes 3 and 4 (dryland regimes), because of the move in spring to irrigated pastures for grazing. Dryland regime dairy cows are assumed to be in pens or on unirrigated land during the entire year.

The dose to an infant's thyroid from consumption of milk supplied by a cow continuously consuming soil was calculated as

$$\text{Dose Soil}_{\text{month } i} = D_{\text{end } i} * FS_{\text{cow}} * \left[\frac{1}{\rho_{\text{csl}}}\right] * TF_{\text{milk}} * IR_{\text{infant}} \quad (4)$$

$$* DF_{\text{infant}} * 30 \text{ d/month}$$

where FS_{cow} = the cow's soil consumption rate (kg/d); varies monthly; value used: see Appendix B

ρ_{csl} = density of soil layer consumed by cows (kg/m^2); value used: 13 (assumed 1-cm depth of soil consumed).

The areal density of soil consumed by domestic livestock is assumed to be approximately 13 kg/m^2, representing a soil depth of 1 cm. The upper-soil layer and root-zone layer described by Ikenberry et al. (1992, page 2.12) are appropriate for resuspension and re-deposition, as well as for plant uptake, but do not adequately describe the way domestic livestock would be expected to ingest soil. References for parameter values are provided in Appendices A and B.

2.3 DEPOSITION ON STORED FEED

Radioactive material may be deposited on stored feed that has already been harvested and is being stored outside. This pathway affects hay consumed by cows on all four feeding regimes.

The outer surface of the feed may become contaminated, which, when subsequently fed to cows, may result in contamination of the milk. In this case, the stored feed that became contaminated was assumed to be bales of hay, each having one surface exposed to fallout, as might be represented by feeding bales off of the top of a stack. The exposed upper surface area of the bale was taken to be 0.62 m^2 (48 in. x 20 in.), and the mass of the bale to be

30 kg (66 lbs). Values for these parameters were empirically determined. The exposed individual bales of hay were assumed to be continuously exposed and fed to dairy cows.

The dose to an infant's thyroid from consumption of milk as a result of a dairy cow's consumption of bales of hay continuously exposed to deposited radioactive material was calculated as

$$\text{Dose Feed Dep}_{\text{month } i} = D_{\text{end } i} * SA_{\text{bale}} / \text{Mass}_{\text{bale}} * IR_{\text{cow}} * TF_{\text{milk}} * IR_{\text{infant}} * DF_{\text{infant}} * 30 \text{ d/month} \quad (5)$$

where SA_{bale} = the exposed surface area of stored feed (m^2) value used: 0.62 (individual hay bale)

$Mass_{bale}$ = mass of stored feed (kg) valued used: 30 (individual hay bale).

References for parameter values are provided in Appendix A.

2.4 INHALATION OF AIRBORNE CONTAMINATION BY DAIRY COWS

A dairy cow also breathes the radioactive material present in the air. The inhaled radioactive material may be transferred from the lungs to the milk and contribute to the dose received from drinking the milk. The dose to an infant's thyroid from consumption of milk as a result of a dairy cow continually inhaling air contaminated with radioactive material was calculated as

$$\text{Dose Inhal}_{\text{month } i} = X_i * IHR_{\text{cow}} * ADJ_Z * TF_{\text{milk}} * IR_{\text{infant}} * DF_{\text{infant}} \quad (6)$$

where X_i = the time-integrated air concentration in month i ($Ci \cdot s/m^3$); varies monthly; value used: see Table 1.

IHR_{cow} = inhalation rate of cows (m^3/s); value used: 0.0017 (100 l/min)

ADJ_z = adjustment factor to account for differences in transfer to milk between inhalation and ingestion (unitless); value used: 0.48

References for parameter values are provided in Appendix A.

A parameter that deserves further explanation is the adjustment factor ADJ_z, which considers the differences in the fractional transfer to body fluids from inhalation and ingestion, respectively. The adjustment factor is the ratio of inhalation and ingestion fractional transfers. Zack (1985) provides this information for 28 elements.

3.0 RESULTS/DISCUSSION

The results of calculations for each of the milk pathway components for the year 1945 in Census District 4 of Franklin County are presented in Tables 2 and 3 for infants and adults, respectively. As expected, irrigated feeding regimes 1 and 2 produced the highest thyroid doses in adults and infants. Infant thyroid doses were 530 and 490 rad, respectively, while adult thyroid doses were 32 and 30 rad, respectively. Doses from dryland feeding regimes 3 and 4 were approximately 14% and 7%, respectively, of doses from irrigated feeding regimes. Infant doses were 71 and 39 rad, respectively, for regimes 3 and 4, while adult doses were 4.3 and 2.3 rad, respectively.

TABLE 2. Dose to Infant Thyroids and Percent Contribution for Each of the Components of the Milk Dose Pathway in Franklin County 4[a]

PATHWAYS	FEEDING REGIMES							
	1		2		3		4	
Pasture	470	88%	470	95%	----------		----------	
Silage	41	7.7%	----------		----------		----------	
Alfalfa hay	6	1.1%	6.2	1.3%	39	55%	----------	
Grass hay	----------		----------		----------		6.6	17%
Soil ingestion	8.6	1.6%	8.6	1.8%	14	20%	14	37%
Deposition on stored feed	8.6	1.6%	11	2.2%	17	24%	17	44%
Inhalation	0.9	0.2%	0.9	0.2%	0.9	1.2%	0.9	2.3%
Total thyroid dose (rad)	530		490		71		39	

(a) Dose from dairy cow ingestion of grain is not included.

TABLE 3. Dose to Adult Thyroids and Percent Contribution for Each of the Components of the Milk Dose Pathway in Franklin County 4[a]

PATHWAYS	FEEDING REGIMES							
	1		2		3		4	
Pasture	28	88%	28	95%	-----------		-----------	
Silage	2.5	7.7%	-----------		-----------		-----------	
Alfalfa hay	0.4	1.1%	0.4	1.3%	2.3	55%	-----------	
Grass hay	-----------		-----------		-----------		0.4	17%
Soil ingestion	0.5	1.6%	0.5	1.8%	0.9	20%	0.9	37%
Deposition on stored feed	0.5	1.6%	0.7	2.2%	1	24%	1	44%
Inhalation	0.05	0.2%	0.05	0.2%	0.05	1.2%	0.05	2.3%
Total thyroid dose (rad)	32		30		4.3		2.3	

(a) Dose from dairy cow ingestion of grain is not included.

The dose in feeding regimes 1 and 2 was dominated by ingestion of fresh pasture, which contributed approximately 90% (88%, 95%) in both regimes. Doses from consumption of silage contributed about 8% of the total dose in feeding regime 1, while alfalfa hay consumption contributed approximately 1% to both feeding regimes 1 and 2. Doses from soil ingestion, deposition on stored feed, and cow inhalation were negligible contributors, approximately 2% or less.

The dose contribution in regimes 3 and 4 was not nearly so neatly defined. Consumption of alfalfa hay was the largest contribution to feeding regime 3 (55%), although there was significant contribution from soil ingestion (20%) and stored feed deposition (24%). Inhalation by cows was a insignificant contributor (1%).

Deposition on stored feed was the largest contributor for feeding regime 4, contributing over 44% of the total dose. Next was soil ingestion at 37%, while consumption of grass hay contributed 17% of the total dose. Inhalation by cows was a small 2% contributor.

As a check on the magnitude of the scoping calculation results, the results were compared to the range of results produced in Phase I of the HEDR Project for Franklin County Census District 4 (HEDR staff 1991, page C.24). Phase I calculations did not include the pathways of soil ingestion, deposition on stored feed, and inhalation by dairy cows. As shown in Table 4, the results for feeding regimes 1 and 2 were consistent with the Phase I results, falling just above the median of the calculations as shown in Table 2 but well within the 95th percentile value. Considering the increase by a factor of 1.7 in iodine-131 source terms over those used in Phase I (Heeb 1992, page 4.36), these results are comparable to the 50th percentile values. This is not unexpected, since doses are dominated by pathways included in the Phase I results.

Results for feeding regimes 3 and 4 fell very close to the 95th percentile values of the Phase I results. If the differences from the Phase I source term are considered, as well as the large contributions from pathways not included in the Phase I calculations (soil ingestion, stored-feed deposition), results are somewhat above the median values of Phase I dose estimates. The remaining differences can be attributed to the use of an implicit 30-day post-harvest holdup time in the Phase I code; the holdup time in the scoping calculations was only 15 days, accounting for a difference of about a factor of 4.

TABLE 4. Comparison of Phase I Air Pathway Results to Scoping Calculation Results for Franklin County 4

Feeding Regime	Calc.	Infant Thyroid Doses 5th	50th	95th	Adult Thyroid Doses 5th	50th	95th
1	Phase I	54	370	2300	4	25	160
	Scoping		530			32	
2	Phase I	45	330	2400	4	26	190
	Scoping		490			30	
3	Phase I	1	11	96	0.07	0.6	5.5
	Scoping			71			4.3
4	Phase I	0.03	1.2	46	0.01	0.1	1.6
	Scoping			39			2.3

4.0 RECOMMENDATIONS

Scoping calculations were performed for that portion of Franklin County considered to be the most exposed area in the HEDR study region. Based on these results, the following recommendations are made regarding exposure pathways and calculational methods for the calculating individual doses for the HEDR project:

EXPOSURE PATHWAYS

- The soil ingestion pathway should be included in calculations involving animal ingestion of feedstuffs, principally because of contributions to the dryland feeding regimes 3 and 4. Soil ingestion could be omitted from irrigated-type feeding regimes (e.g., 1 and 2) where it contributes negligibly to the dose.

- Deposition of radioactive material from the air onto stored feed should be included in calculations involving animal ingestion of stored feedstuffs, principally because of contributions to the dryland feeding regimes 3 and 4. Stored feed deposition could be omitted from irrigated-type feeding regimes (e.g., 1 and 2) where it contributes negligibly to the dose.

- The cow inhalation pathway should not be included in any calculations. Contribution to the dose is negligible in all scoping calculations.

CALCULATIONAL METHODS

- A soil density of approximately 13 kg/m^2 (soil depth of 1 cm) should be used for the pathway of soil ingestion by domestic livestock. The upper-soil layer and root-zone layer described by Ikenberry et al. (1992, page 2.12) are appropriate for resuspension and re-deposition, as well as for plant uptake, but do not adequately describe the way domestic livestock would be expected to ingest soil.

- A 15-day hold-up time between hay harvest and animal consumption should be included to allow for cutting, curing, baling, and transportation of hay prior to feeding. This is more appropriate than the 30-day hold-up included in the Phase I HEDR code, and is consistent with Beck et al. (1992, page 62) for silage and grain hold-up times.

5.0 QUALITY ASSURANCE

Quality assurance was undertaken in accordance with PNL-MA-70, Volume 1, Procedures for Quality Assurance Program, under PNL administrative procedure PAP-70-301, "Hand Calculations, General." Complete documentation of the calculation was prepared by the senior author, who independently prepared the calculational spreadsheet and performed the spreadsheet calculations. A thorough review was conducted by the second author, who is chief scientist for the HEDR Project. Independent technical review was also performed by a technical expert not involved with the HEDR Project. Spreadsheet documentation is on file with the senior author and available for review.

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APPENDIX A

DESCRIPTION OF VARIABLES AND VALUES USED

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DESCRIPTION OF VARIABLES AND VALUES USED

Parameter Symbol	Description of Parameter and Value Used in Scoping Calculation	Reference
$D_{end\ i}$ $D_{end\ h}$	Surface deposition of iodine-131 on the ground at the end of month i and harvest month h (Ci/m^2); varies by month; value used: see Table 1.	Ramsdell Jr., J. V., personal communication, October 1992
Y	Maximum dry biomass of a plant, kg/m^2 dry; value used: 0.3 for pasture and silage; 0.2 for alfalfa; combines the Y and f_d parameters presented in Shindle et al.	Shindle et al. 1992, pages 2.4 and 2.5
α	Empirical interception parameter, m^2/kg; value used: 2.9 for pasture, silage, and alfalfa	Shindle et al. 1992, page 2.6
f_s	Fraction of maximum biomass available, unitless; varies monthly for pasture, silage, and alfalfa; value used: see Appendix B	Shindle et al. 1992, page 2.5
TF_{milk}	Transfer coefficient for cow's milk, Ci/l per Ci/d; (d/l) value used: 0.0092	Snyder et al. 1992, page ^{131}I TF_{milk_ind}
IR_{infant}	Milk ingestion rate for an infant, l/d; value used: 1.0	Callaway Jr., J. M. 1992, page 19
IR_{adult}	Milk ingestion rate for an adult, l/d; value used: 0.5	Callaway Jr., J. M. 1992, page 19
DF_{infant}	Dose conversion factor for infant ingestion, rad (thyroid)/Ci; value used: 1.5×10^7	Shindle et al. 1992, page 2.18

Parameter Symbol	Description of Parameter and Value Used in Scoping Calculation	Reference
DF_{adult}	Dose conversion factor for adult ingestion, rad (thyroid)/Ci; value used: 1.8×10^6	Shindle et al. 1992, page 2.18
IR_{cow}	Ingestion rate by cows of various feed types, kg/d; varies monthly by feed type value used: see Appendix B	Beck et al. 1992, page 54
λ_r	Radiological decay constant, $days^{-1}$; value used: 0.086 for iodine-131 (T_r = 8.05 days)	Snyder et al. 1992, page ^{131}I λ_{rad}
λ_w	Weathering removal rate constant, $days^{-1}$; value used: 0.0495 (weathering halftime = 14 days)	Snyder et al. 1992, page λ_{weath}
f_{hay}	Fraction of total hay consumption from a given hay cutting; value used: 1.0 June, July; 0.5 August; 0.33 September to December	Beck et al. 1992, page 61
FS_{cow}	Soil ingestion rate of dairy cows, kg/d; varies by season (month) and feeding regime type; values used: see Appendix B	Snyder et al. 1992, page FS_{cow} Darwin 1992, all
ρ_{csl}	Density of soil layer consumed by cows, kg/m^2; value used: 13 (assumed 1 cm depth)	derived from data in: Snyder et al. 1992 page ρ_{usl} Ikenberry et al. 1992, page 2.15
SA_{bale}	Exposed surface area of stored feed, m^2; value used: 0.62 for an individual hay bale	empirically determined
$Mass_{bale}$	Mass of stored feed, kg; value used: 30 for an individual hay bale (66 lbs)	empirically determined
IHR_{cow}	Cow inhalation rate, m^3/s; value used: 0.0017 (100 l/min) 59-(90)-104 l/min [85-(130)-150 m^3/d]	Black and Barth 1976, page 15, Zack 1985, page 739

Parameter Symbol	Description of Parameter and Value Used in Scoping Calculation	Reference
ADJ_z	Adjustment factor to account for differences in transfer to milk between inhalation and ingestion (unitless); value used: 0.48	Zack 1985, page 741
X_i	the time-integrated air concentration in month i ($Ci \cdot s/m^3$); varies monthly; value used: see Table 1	Ramsdell Jr., J. V., personal communication, October 1992

APPENDIX B

TIME-DEPENDENT VARIABLES AND VARIABLE VALUES USED IN THE SCOPING CALCULATION

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TIME-DEPENDENT VARIABLES AND VARIABLE VALUES USED IN THE SCOPING CALCULATION

Parameter Symbol	f_s	f_s	f_s	FS_{cow}	FS_{cow}	IR_{cow}	IR_{cow}	IR_{cow}	IR_{cow}	f_{hay}
Feed Type	pasture	silage	alfalfa	soil	soil	pasture	silage	hay	hay	hay
Feeding Regime				1 & 2	3 & 4	1 & 2	1 & 2	1 & 2	3 & 4	all
units	none	none	none	kg/d	kg/d	kg/d	kg/d	kg/d	kg/d	none
MONTH										
January				2	2				9	
February				2	2				9	
March				2	2				9	
April				2	2				9	
May	0.9		0.75	1	2	4.25			9	
June	0.9		0.75	0.5	2	8.5		1	9	1
July	0.9		0.75	0.5	2	8.5		1	9	1
August	0.9		0.75	0.5	2	8.5		1	9	0.5
September	0.8	0.5	0.75	1	2	4.25		5.25	9	0.33
October				2	2		4.25	5.25	9	0.33
November				2	2		4.25	5.25	9	0.33
December				2	2		4.25	5.25	9	0.33

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