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**Responses to National Academy of Sciences Review
Comments on Dosimetry in the Fred Hutchinson Cancer
Research Center's Hanford Thyroid Disease Study**

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Responses to National Academy of Sciences Review Comments on Dosimetry in the Fred Hutchinson Cancer Research Center's Hanford Thyroid Disease Study

Introduction

Battelle Northwest staff cognizant of the Hanford Environmental Dose Reconstruction (HEDR) Project at Battelle was asked to assist researchers at Fred Hutchinson Cancer Research Center (FHCRC) in responding to radiation-dosimetry-related issues raised during a recent National Academy of Sciences review of the Hanford Thyroid Disease Study Draft Final Report.

Battelle staff performing the HEDR Project, under contract to the Centers for Disease Control and Prevention (CDC), developed computer data sets and codes for use in calculating doses to individuals who lived in the vicinity of the Hanford Site in the 1940's and 1950's. A sequence of codes (STRM, RATCHET, and DESCARTES) was utilized to develop the data set for use in the code that computes individual doses (CIDER) (Ouderkirk and Eslinger 1993; Eslinger et al. 1994). The FHCRC, also under contract to CDC, used the HEDR database and CIDER code to estimate radiation doses for the subjects in the Hanford Thyroid Disease Study. The HTDS draft results were presented in a Draft Final Report, which was reviewed at CDC's request by the National Academy of Sciences *Committee on an Assessment of Centers for Disease Control and Prevention Radiation Studies from DOE Contractor Sites, Subcommittee to Review the Hanford Thyroid Disease Study Results and Final Report*. The NAS committee had several questions and made a number of comments, some of which were directed at the dosimetric methods derived from the HEDR codes. Specific issues raised in NAS' Section 4, Evaluation of Dosimetric Methods, include:

- Impact of errors in validation of ^{131}I on pasture grass on individual dose estimates,
- Sensitivity of deposition estimates to selection of wind field representation,
- Validity of consultant F.O. Hoffman's assertion of underestimation of source term,
- Values for intake of milk cattle feed and forage,
- Milk cow feed-to-milk transfer coefficient,
- Impact of errors in the use of dry-to-wet ratios in the validation efforts,
- Enhancement of the library of fetal dose conversion factors,
- Statistical independence of individual dose conversion factors within and across stochastic representations, and
- Accounting for uncertainty in HTDS individual survey responses.

Overview of Report

In order to respond to the NAS comments, they were organized and grouped into related topics, roughly parallel to the list of issues described above. Each of these topics is essentially

independent of the others, and each may be considered separately. Each section of this report addresses a particular topic or group of topics.

Section 1 of the report addresses comments in the National Academy of Sciences Letter Report regarding earlier discussions on the impact of errors introduced in the report *Validation of HEDR Models* (Napier et al. 1994). This section incorporates the first and sixth issues above, since they are directly related. A great deal of this effort had been completed in prior work related to iodine/sagebrush modeling; the pertinent results are abstracted and related directly to the NAS comments.

Section 2 of the report discusses evaluation of the inverse-square wind field model implemented in the RATCHET code. This section incorporates responses to the second issue above. The selection of the inverse-square approach was extensively documented in early HEDR Project reports and public discussions, specifically J.V. Ramsdell, Jr., 1992, *Summary of the March 25-26, 1991 Atmospheric Model Working Meeting*, PNWD-1975 HEDR and J.V. Ramsdell, Jr., and E.D. Skyllingstad, 1993, *A Review of Wind Field Models for Atmospheric Transport*, PNWD-2148 HEDR. It is apparent that these reports were not available for the NAS review. The results of this prior effort have been abstracted and related directly to the NAS comments.

Section 3 of the report addresses assertions of underestimation of iodine releases in later years (1950s and 1960s). This section incorporates responses to the third issue above. Monthly and quarterly reports of historical Hanford stack monitoring results are available. Monitoring for individual processing plant stacks (i.e., B-Plant, T-Plant, REDOX, and PUREX) is available, the monthly stack monitoring values do differ from the Heeb model (STRM), but the aggregate sums by month are relatively close to the Heeb totals. Additional sources of monitoring data are also compared to the HEDR estimates.

Section 4 documents the final milk cow feeding regimes used in the HEDR DESCARTES data files as directed by the HEDR Technical Steering Panel (TSP). This section addresses the fourth issue. The TSP directed the final selection of the 4 commercial and 4 back-yard-cow feeding regimes currently available in the CIDER database. The feeding regimes were not specifically documented in any reports issued by the HEDR Project. The input requirements from the TSP, the TSP's own report on the subject (Price 1994), and the DESCARTES input data files are available. The feeding regimes used are described in detail.

Section 5 addresses milk-cow feed-to-milk transfer coefficients, the fifth issue above. The relationship of the various available data sets on the parameter F_m , the feed-to-milk transfer coefficient, was discussed in one of the last HEDR Project public meetings in Seattle. That information was not available to the NAS for their review. External reviewers and the public extensively discussed the subject in that meeting. The information behind that presentation has been reconstructed and related directly to the NAS comments.

Section 6 addresses issue number 7 above, the fetal dose conversion factor file for CIDER. When the HEDR files were turned over to CDC for use by FHCRC, the file containing dose conversion factors for the prenatal period contained a simplistic default value (Snyder et al. 1994). FHCRC desired to replace that distribution with a more realistic one. The file was recreated with the appropriate distribution and supplied to FHCRC and CDC.

Section 7 describes minor modifications to the CIDER code. These modifications were made to address the last two NAS issues. One set of modifications allows randomization of the order of selection of stochastic dose conversion factors. The CIDER code as originally designed performed no stochastic variable selection; all realizations of all parameters were input from externally-created files. This was done for simplicity in CIDER and for repeatability of the calculations. Following discussions with the FHCRC scientists, a random selection algorithm was developed to permute the inputs. A second set of modifications provided subject-specific stochastic inputs to the CIDER code to account for potential uncertainties in the individual food consumption interview results. Inputs are now either generic and stochastic, by way of Reference Diet files, individual-specific and deterministic by way of direct data input, or new combinations of the two options. A set of algorithms for assigning uncertainty to the interview data was developed; these are described.

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1. Validation of HEDR models

The National Academy of Sciences review of the HTDS dosimetry included a request that “the HEDR investigators supplement their description of the model with an account of the origin of errors made with regard to the estimation of ^{131}I concentrations in pasture grass on the basis of measurements, the impact on the predicted values when the errors are corrected, and a preliminary assessment of the effect of reparameterization on estimates of absorbed dose to the thyroid.” This call came in response to presentations made to the NAS committee by HEDR staff pointing out errors that had been discovered in certain portions of the model validation work reported in Napier et al (1994). These errors included omission of the wet-to-dry conversion factor for sagebrush in the comparison of calculated (dry) sagebrush concentrations and measured (wet) sagebrush concentrations. A second error was the use of an incorrect value in the conversion of counting rates to concentration for the 1949 data, caused when an early draft of a supporting report was used without updating when the final value was published.

The initial results of validation testing of the environmental radiation dosimetry models developed for the Hanford Environmental Dose Reconstruction Project were published in Napier et al. (1994), *Validation of HEDR Models*. Most recently, some minor errors have been identified in certain of the validation attempts published in Napier et al. The first set of errors discovered in the published HEDR validation involves the omission of the wet-to-dry conversion factor for sagebrush in the modeling. The most likely maximum value for the wet-to-dry factor is 2 grams wet/gram dry, evaluated over the course of one year by measurements by the author. However, sagebrush growth is acclimated for the annual precipitation pattern, in which nearly half of the annual rainfall occurs in the winter months. There is significant leaf drop in July and August, the period when the original model indicates highest biomass. Since the sagebrush is not in the human or animal food chain and is just a dead end in the model, these difficulties did not have any impact on the final dose calculations. However, developing a better sagebrush model, particularly the interception portions, and repeating the validation attempts provides strong support for the remainder of the HEDR modeling and the individual radiation dose calculations that use them.

The second error involves the conversion of counts per minute, as recorded in 1949 for the sagebrush samples, to estimated concentration in vegetation. The published results used a conversion factor to get from counts to concentration of 0.0017. The conversion

factor for 1949 described in Denham, Mart, and Thiede (1993) is reported to be 0.0044. The records pertaining to the preparation of Denham, Mart, and Thiede (1993) were retrieved from the Hanford records center and the history of the document was reviewed. The conversion factor was revised from 0.0017 to 0.0044 during the document's final preparation. The conversion factor is a simple product of a constant, the measurement factor M, and the yield factor Y. The yield used is 63 percent (0.63). The yield factor Y is defined as the reciprocal of the yield. In the early drafts, the conversion factor is equal to the constant times M times the yield. In the later report, the conversion factor is equal to the constant times M times the yield factor Y. It is apparent that the early drafts had a simple mathematical error that was fixed prior to the document's issuance. Application of the correct conversion factor would tend to increase the measured concentrations by a factor of about 2.5.

Consideration of the errors together indicate that the concentrations of iodine-131 in sagebrush predicted by the HEDR models tend to be uniformly low by about a factor of 3. While it is possible that either the source term estimate or the atmospheric dispersion/deposition modeling is low by this amount, it can be shown that either of these possibilities is remote. It is most likely that the sagebrush model itself imposes a bias. The model used was a simple one, and for expediency used the same formulation as the vegetable models in the HEDR codes (Ikenberry et al. 1991). The benefit of this model was that the quotient (interception fraction/ biomass) was essentially a constant over time. However, the total interception fraction predicted by this model is always less than 15%. This model uses a sinusoidal plant growth curve - that is known to be not appropriate for sagebrush. It also uses the Chamberlain filtration model to get to interception fraction - and the standard range for that, too. Either or both of those could be inappropriate for sagebrush.

A complete revision to the sagebrush model in the HEDR DESCARTES code was implemented. The results are described below. The results were submitted for peer review, and accepted for publication in the journal *Environmental Radioactivity*. The following sections are the paper that was submitted; a slightly shorter version (omitting the Green Run portion for brevity) was accepted for publication. The article will be published as:

Napier, B.A., P.W. Eslinger, W.E. Nichols, and L. Anderlini. 2000. "Improvements in Modeling Sagebrush Concentrations of Radioactive Iodine Released from the Hanford Site," *Environmental Radioactivity*.

1.1 Background

In 1987, the U.S. Department of Energy directed the Pacific Northwest Laboratory, operated by Battelle Memorial Institute, to conduct the Hanford Environmental Dose Reconstruction (HEDR) Project. The purpose of the HEDR Project was to estimate the radiation dose that individuals could have received as a result of emissions of radioactive materials from the Hanford Site in the south-central part of Washington State.

The HEDR Project determined that ^{131}I in an airborne pathway was the dominant radionuclide in the dose received by most individuals living near the Hanford Site. A series of models and computer codes were developed by the HEDR Project to reconstruct the movement of iodine from the reactors and processing plants through the atmosphere, in the food chain, and finally resulting in dose to humans (Heeb, Gydesen, Simpson, & Bates, 1996; Ramsdell, Simonen, Burk, & Stage, 1996; Farris, Napier, Ikenberry, & Shieler, 1996). Eventually, the modeling domain for dose estimation was expanded to cover a 200,000 km² (75,000 square mile) region including parts of the states of Washington, Oregon, and Idaho (Shieler, Napier, Farris, & Freshley, 1996). Figure 1-1 contains a map showing the location of the Hanford site.

A measure of uncertainty was desired for the dose estimates, and was obtained by running 100 model replications in a stochastic framework. Each model replication utilized randomized values for a large number of input variables. Most of the parameters were selected using a Latin Hypercube scheme. Details on the randomized variables are provided in Snyder, Farris, Napier, Ikenberry & Gilbert (1994).

A series of validation studies on the HEDR models relative to historical sampling data are reported by Napier, Simpson, Eslinger, Ramsdell, Thiede, & Walters (1994). One validation study for deposition of ^{131}I on sagebrush (*Artemisia tridentata*) indicated that the simulation models systematically underestimated historical sampled data during the cold weather months of 1946. This lack of agreement prompted development of a revised model for deposition of airborne ^{131}I on sagebrush.

Because of the historical nature of the data, the original activity units (curies and picocuries) have been retained for reporting the results in this work.

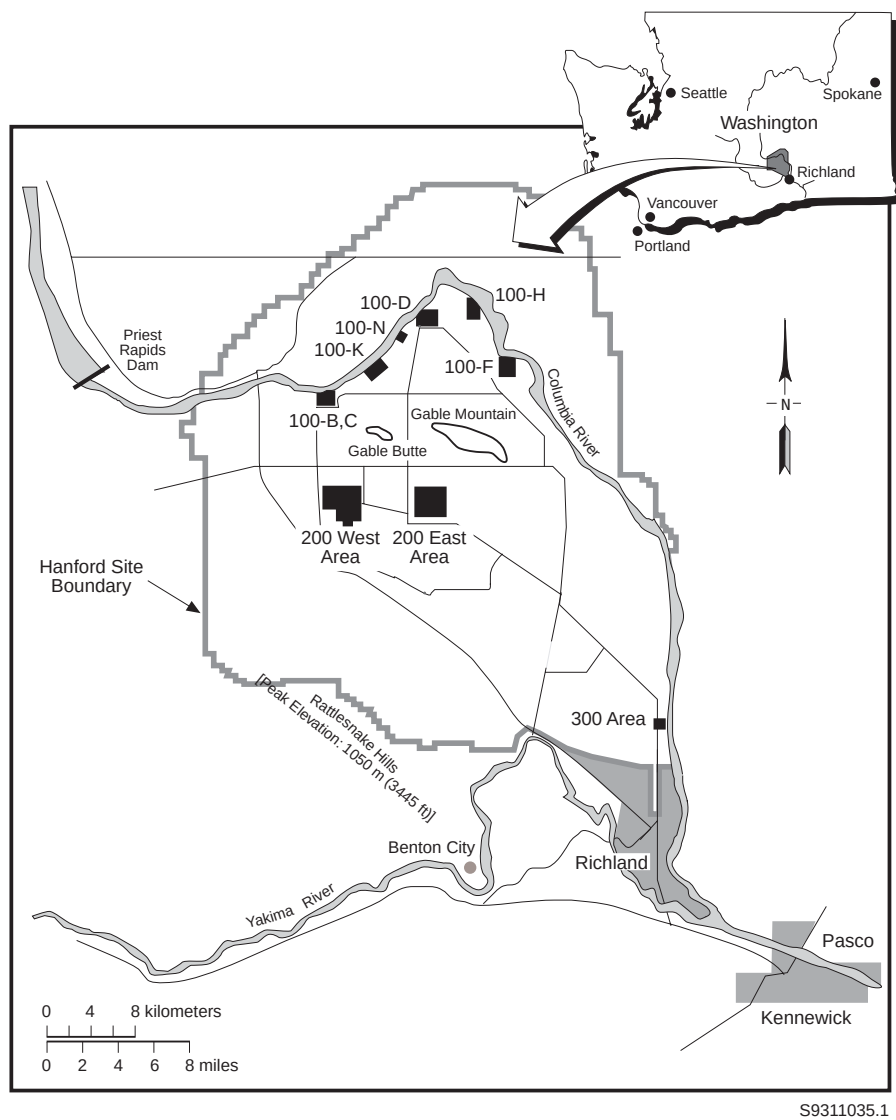


Figure 1-1. Map showing the location of the Hanford Site.

1.2 Derivation of the Concentration Model

The traditional approach to determining deposition and retention of an airborne radioactive material on vegetation uses the following equation:

$$C_{\text{plant}} = C_{\text{air}} V_d \frac{r}{B} \frac{(1 - e^{-(\lambda_r + \lambda_w)t})}{(\lambda_r + \lambda_w)}$$

where

C_{plant}	= the concentration of radionuclide on the plant surface, Bq/g,
C_{air}	= the assumed steady-state concentration of radionuclide in air, Bq/m ³ ,
V_d	= a transfer coefficient termed the “deposition velocity” because of its units, m/s,
r	= the fraction of deposited material intercepted by the vegetation, unitless,
B	= the above-ground biomass of the vegetation, g,
λ_r	= the radiological decay constant, s ⁻¹ , and
λ_w	= the weathering removal constant, s ⁻¹ .
t	= time, s

This equation assumes constant average air concentrations, and for constant air concentration the plant concentration builds up over time to a steady-state, equilibrium value on the vegetation surface. The equation was developed for a conceptual model of microscopic particles drifting downward (the product $C_{\text{air}} V_d$ can be thought of as a downward flux of material, Bq/m² s), being filtered from the air with a fractional interception by plant leaves (the interception fraction r).

A minor modification of this approach considers deposition and/or interception as an equilibrium process between air and plant surface. This conceptual model is more appropriate for gaseous iodine (I₂). The partitioning is driven by concentration and, as discussed below, may be a function of temperature. This approach is described for semi-volatile organic materials by Komp and McLachlen (1997), and adapted for iodine here.

The conceptual model involves rate constants for deposition of iodine onto plant leaves and revolatilization, and includes decay and “weathering.” Weathering addresses loss of radioactive material from the plant by means other than volatilization (such as leaf drop, rainoff, growth dilution, etc., as typically described in the radioecological literature). The differential equation describing this process is

$$\frac{dQ_{\text{plant}}}{dt} = K_{a/p} C_{\text{air}} - (\lambda_r + \lambda_w + K_{p/a}) Q_{\text{plant}}$$

where

- Q_{plant} = quantity of radionuclide on the plant, (Bq),
- $K_{a/p}$ = transfer coefficient from the air to the plant, (m/s),
- $K_{p/a}$ = transfer coefficient from the plant surface back to the air, (m/s).

In this derivation, the transfer from the air to the leaves is the product $K_{a/p} C_{\text{air}}$ and the revolatilization is the product $K_{p/a} Q_{\text{plant}}$. C_{air} is assumed constant for the time period in question, therefore, the equation can be written in terms of air concentration rather than a time varying air quantity. The solution to this equation is

$$Q_{\text{plant}} = K_{a/p} C_{\text{air}} \frac{(1 - e^{-(K_{p/a} + \lambda_r + \lambda_w)t})}{(K_{p/a} + \lambda_r + \lambda_w)}$$

Recognizing that $Q_{\text{plant}} = B C_{\text{plant}}$, this equation can be rewritten as

$$C_{\text{plant}} = K_{a/p} C_{\text{air}} \frac{(1 - e^{-(K_{p/a} + \lambda_r + \lambda_w)t})}{B(K_{p/a} + \lambda_r + \lambda_w)}$$

Note the similarities between this solution and that of the traditional method. The revolatilization rate constant $K_{p/a}$ is thought to be small since there is little evidence of radioiodine rapidly devolving from samples, and if it is much smaller than radioactive decay it can be neglected. The terms $K_{a/p}$ and $V_d r$ are then roughly functionally equivalent; the gas deposition rate constant is essentially the deposition velocity and interception fraction combined. Because the absolute value of $K_{a/p}$ must be estimated from available data, it is specific to the vegetation type used in the estimation. The advantage to the traditional formulation is that the interception term, r , allows the general formula to be applied to many types of vegetation.

1.3 Calibration Data for the Concentration Model

The absolute value of $K_{p/a}$ for sagebrush may be estimated from data presented in Soldat (1965). Soldat presents the results of monitoring air and sagebrush near the Hanford Site following an acute release of ^{131}I in 1963. Soldat's measurements are presented in Table

Table 1-1. Derivation of $K_{a/p}$ using Sagebrush and Air Concentration Data Collected by Soldat in 1963.

Concentration		Days exposed	Derived $K_{a/p}$ (m/d)	Comment
Sagebrush (pCi/g)	Air (pCi/m ³)			
6.5	0.85	9	14.73	sage stems
0.7	0.7	9	1.93	
0.09	0.35	2	1.47	
0.38	0.28	2	7.75	
0.1	0.32	2	1.78	
14	2.3	2	34.76	
91	52.6	1	18.50	most applicable
125	72.7	1	18.39	most applicable
			1.4 to 34.8	Range of data
			18.5	Best estimate

1-1. The release occurred following a series of continuous smaller releases, thus the largest depositions and air concentrations probably have the least interference with pre-existing concentrations. A subset of Soldat's data was used in calibrating $K_{p/a}$ because air concentrations and sagebrush concentrations taken at the same time were needed.

In order to estimate the values of $K_{a/p}$, the biomass of the sagebrush must be estimated. The data of Soldat (1965) were collected in early September; it is assumed that sagebrush were in a summer dormant period with a minimal dry biomass of about 10 g/m². The half-life for ¹³¹I is 8.05 days. Estimates of $K_{a/p}$ derived from the C_{plant} equation are given in Table 1-1. The numerical values are derived assuming that $K_{p/a}$ is negligible and the weathering half-time is 14 days (Snyder, Farris, Napier, Ikenberry, & Gilbert, 1994). The best estimate of $K_{a/p}$ (based on the largest measured values and the time closest to the deposition event) is about 18.5 m/d and the range is from 1.4 to 35 m/d. The estimate for bare sage stems is not significantly different than for leafy sage. This implies that the biomass estimate for the sage should not have a major influence on the concentration estimate.

For a nominal dry biomass of 50 g/m² and an interception fraction of about 0.15 used by HEDR (Snyder et al. 1994), the value of $K_{a/p}$ of 18.5 m/d is equivalent to a deposition velocity of about 0.0014 m/s. This is about equal to the large-area average

deposition velocity of 0.002 m/s produced using the HEDR atmospheric dispersion and deposition computer code RATCHET (Ramsdell et al., 1996; Ramsdell, et al., 1994). This agreement implies that the mass balance required for proper operation of RATCHET is being maintained.

The values of $K_{a/p}$ in Table 1-1 are all derived for conditions in September 1963. The average monthly temperature in September 1963 was 21.7 degrees (71.1 degrees Fahrenheit) (Hoitink & Burk, 1998). Monthly average temperatures at Hanford typically range from -1 to 24 degrees C (30 to 75 degrees F), with monthly averages in exceptional years dropping as low as -12 or as high as 27 degrees C (10 to 80 degrees F). It is theoretically anticipated that the gas driven rate constant should vary with temperature. Komp & McLachlan (1997) present an integrated van't Hoff equation that provides a means based on thermodynamics for expressing the temperature dependence:

$$K_{a/p}(T) = K_{a/p}(T_{ref}) \exp \left[\left(\frac{1}{T} - \frac{1}{T_{ref}} \right) \frac{\Delta H}{R} \right]$$

where

- T = the absolute temperature of interest, degree Kelvin,
- T_{ref} = a reference absolute temperature, i.e., that for which data are available, degree Kelvin
- ΔH = the enthalpy of phase change between the plant and the air, J/mole, and
- R = the ideal gas constant, J/degree mole.

It is suggested by McLachlan, Welsch-Pausch, & Tolls (1995) that the enthalpy of vaporization can be used for ΔH , which is the equivalent to assuming that the temperature dependence of $K_{a/p}$ is the same as the temperature dependence of the vapor pressure of the material. This makes physical sense and corresponds with the assumptions used in the derivation of the deposition equation of gas-plant equilibrium. The work of Komp & McLachlan (1997) and McLachlan et al. (1995) explicitly addresses semivolatile organic liquids such as PCBs, but it also appears applicable to semivolatile gases such as iodine. For iodine, the numerical value of ΔH for the solid/gas transition is 14.88 kcal/g mole (62,300 J/mole) (Chemical Rubber Co. 1974). The numerical value for R is 8.314 J/degree mole (Rosenbaum 1970).

Table 1-2. Temperature Dependence of $K_{a/p}$ for Sagebrush for $\Delta H_f = 62,300$.

Temperature		$K_{a/p}$ (m/d)
F	K	
10	261	504.0
20	266	276.7
30	272	155.7
40	277	89.7
50	283	52.8
60	289	31.7
70	294	19.4
71	295	18.5
80	300	12.1

Using the best-estimate value of $K_{a/p}$ of 18.5 m/d at 295 K (71 degrees F), estimates can be made for other temperatures. These are provided in Table 1-2. A strong dependence on temperature is seen. At winter temperatures (around 0° C), the rate constant is about 8 times higher than at summer temperatures (around 20° C). This will have a large influence on calculated depositions in winter months.

Soldat (1963) also measured the concentration of ^{131}I on grass. When $K_{a/p}$ is calibrated to the grass data, a value of about 900 m/d is obtained. This leads to implausible results because the predicted concentration on vegetation would be higher than the total deposition over large areas would allow. For grass, alfalfa, or grain fields there is no bare soil, and the gas-to-plant transfer would be limited to the amount of ^{131}I available. This contradicts the initial assumption of constant air concentration, and so the original differential equation in this paper is not applicable for dense vegetation like grass or other cover crops.

1.4 Sagebrush Growth Model

The sagebrush life cycle has two growth peaks. The first peak is associated with leaf growth and occurs early in spring (February or March) when winter precipitation is available (the region is located in a winter-maximum precipitation regime). Most of these leaves drop at the first hot weather (about June). Sampling data on sagebrush leaf drop on a monthly basis are given by Rickard & Vaughan (1988) for two Washington locations. A second peak is associated with the reproductive stage in the fall (late September or early October); this phase lasts only a few weeks (personal communication, W. Rickard, July 1999). Total leaf

dry biomass ranges from a low of about 10 g/m² in the winter to 10-50 g/m² in the spring and fall peaks (Snyder et al. 1994).

Example randomized sagebrush biomass profiles in 1949 are provided in Figure 1-2. These biomass profiles are generated using a simple straight-line leaf growth and leaf drop model. Onset of the spring and fall growth periods are tied to the dates of the last spring frost and first fall frost obtained from historical records at 26 weather stations within the HEDR modeling domain. Data reported by Uresk, Gilbert, & Rickard (1977) indicate that the fall flowering period has a biomass about 60% the amount of the corresponding spring water-leaf dominated biomass.

1.5 Concentration Data from 1946

Beginning in late 1945, a substantial number of vegetation samples were collected regularly at standardized locations in the cities of Richland, Kennewick, Pasco, and Benton

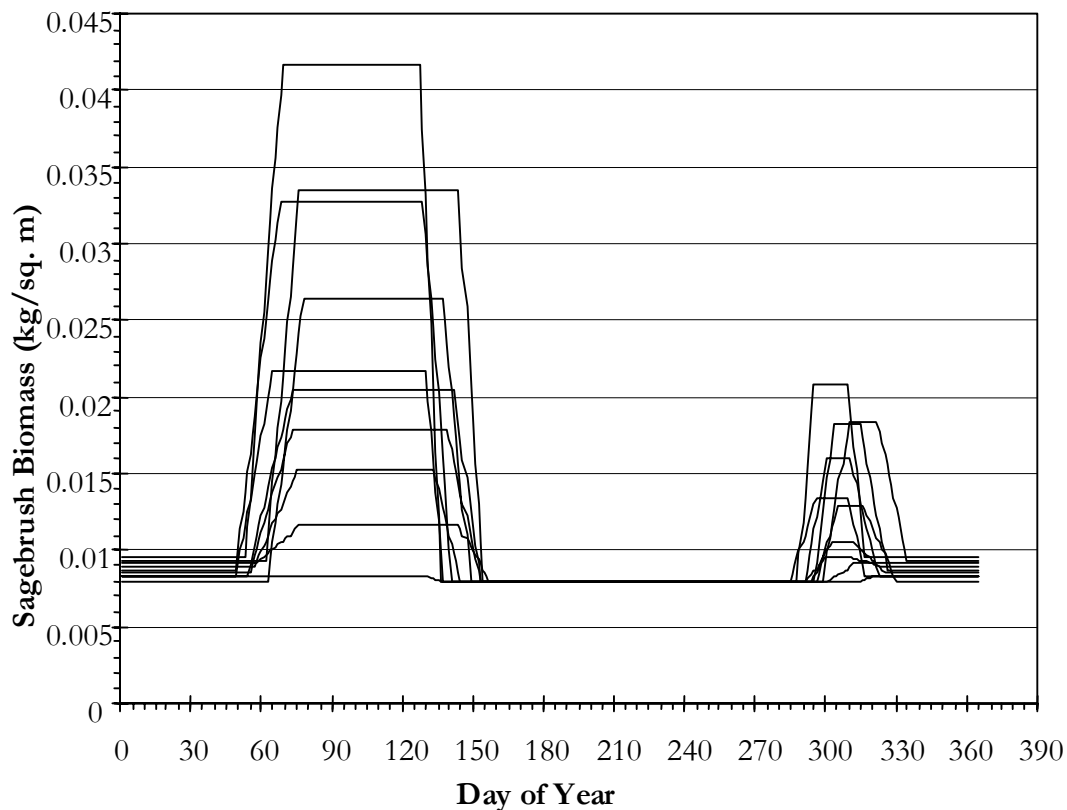


Figure 1-2. Example Replications of Sagebrush Biomass Profiles for North Richland Using 1949 Temperature Data.

City, Washington. Several locations within each city were routinely monitored. The most extensive data set for these locations was collected in 1946, the year of second-highest ^{131}I emissions (Heeb 1994; Heeb et al. 1996).

All transport, accumulation, and dose-related calculations have been performed on a spatial grid system. The grid consists of a rectangular set of nodes numbered sequentially, beginning in the southwest corner. The measurement sequences for Richland fall within two HEDR atmospheric dispersion nodes (469 for north Richland and 442 for south Richland); all of the measurements for Pasco and Kennewick fall within a single node (443); and the measurements for Benton City are on the edges of two nodes (467 to the north and 440 to the south). The northernmost of these Benton City nodes was selected for analysis as more representative.

Hanford historical monitoring data of ^{131}I in vegetation are available for the period beginning in mid-1945 through the present. The data for 1945-1947 are published by Denham, Dirkes, Hanf, Poston, Thiede, & Woodruff (1993). The data for 1948-1951 are published by Hanf, Duncan, & Thiede (1993). To account for biases that were historically not determined, HEDR staff developed conversion and correction factors. These are published by Mart, Denham, & Thiede (1993) for the 1945-1947 data and Denham, Mart & Thiede (1993) for the 1948-1951 data. Although the samples used to measure ^{131}I historically were most often labeled “vegetation,” Denham, Dirkes, Hanf, Poston, Thiede, & Woodruff (1993) note that the samples were usually sagebrush.

These vegetation data are essentially all that are available from mid-1945 through 1950, the time period of high interest for atmospheric releases. The data are uneven in geographic coverage (most monitored locations are either on or close to the Hanford Site) and over time (the monitoring, with a few notable exceptions, was not routinely performed at repeated locations). There are over 3,500 samples reported for the year 1946. Of these, Richland has a complete history consisting of a total of about 550 values; Pasco and Kennewick, combined, have a total of about 645; and Benton City has about 200 values. Another 175 or so were taken at various points along a road west of Richland.

Because many of the data points appear to be reported in more than one source, there are significantly fewer values actually available than the 3,500 reported. Denham et al. (1993) provide original information in the form of laboratory counting records where

possible. However, in some instances, secondary references such as internal Hanford monthly or quarterly reports had to be used.

A third source of indeterminable authorship and quality is also available. Early in the HEDR Project, a hand-written compilation of data from the mid-1940s was found. This compilation is referred to as the "vegetation correlation data sheets," and evidently was prepared in the late 1940s or early 1950s. The data reported in it obviously duplicate much of what was found in the original counting laboratory records (dates and locations), and it also incorporates many of the later correction factors used to convert from counting data to concentration data (Mart et al. 1993). Because project staff have not been able to track the source of these data, they have not been accorded high reliability. However, this source does contain some data on ^{131}I concentrations in vegetation during the latter half of 1946 that is not available from other sources.

In 1946, contamination was measured with a Geiger-Muller detector directly on the vegetation samples (Mart, Denham, & Thiede, 1993). Gilbert, Mart, Streng, & Miley (1992, p. 4.3) and Gilbert et al. (1996) indicate that the uncertainty in the conversion of these count data to concentration could be a factor of up to four for this period. Only the deterministic "best estimate" of Mart, Denham, & Thiede (1993, p. 7.2) has been used in these analyses. Incorporation of this uncertainty in the analyses would indicate a greater overlap than is apparent in the following figures.

1.6 Model Results for 1946

The new sagebrush growth and concentration models were incorporated in the DESCARTES computer code (Shipler et al. 1996; Miley, Eslinger, Nichols, Lessor, & Ouderkirk, 1994). Model results for the year 1946, based on 100 replications, are presented in Figure 1-3 for South Richland, Figure 1-4 for Pasco-Kennewick, and Figure 1-5 for Benton City. The figures show three curves as well as three types of sampled data. The three curves are the minimum, median, and maximum concentrations at each day of the year calculated from a suite of 100 replications. The modeled runs actually start on November 1, 1945, in order to account for the environmental accumulation from releases prior to January 1, 1946.

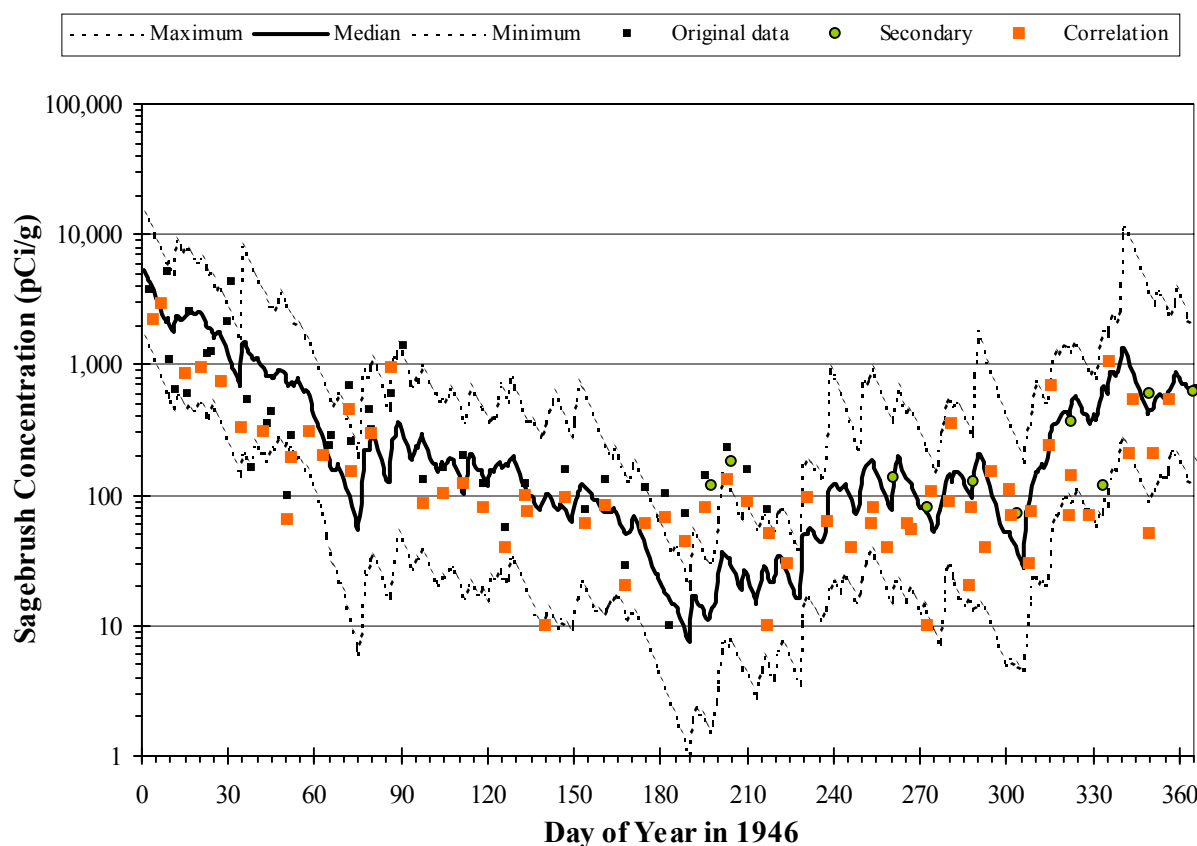


Figure 1-3. Comparison of sagebrush concentration projections with historical data in 1946 for North Richland (model node 442).

The revised model yields sagebrush concentrations that track the general shape of the sampled data throughout the year. The previous sagebrush model underpredicted sagebrush concentrations in winter by an order of magnitude or more (Napier et al., 1994). The comparison at Benton City is remarkably good, especially considering that Rattlesnake Mountain [elevation 1,050 m (3,445 ft)] lies between the major source of emissions [elevation about 223 m (730 ft)] and Benton City [elevation 150 m (490 ft)]. The atmospheric transport model in the RATCHET code (Ramsdell et al. 1996; Ramsdell, Simonen & Burk, 1994) used a wind field extrapolated from surface wind data. This validation result supports the use of surface wind data for the dose modeling studies. A scatter plot of historical sampled values against median modeled values for South Richland is provided in Figure 1-6. The scatter plot shows variability, but no significant bias towards underprediction or overprediction for any of the three major sources of historical data.

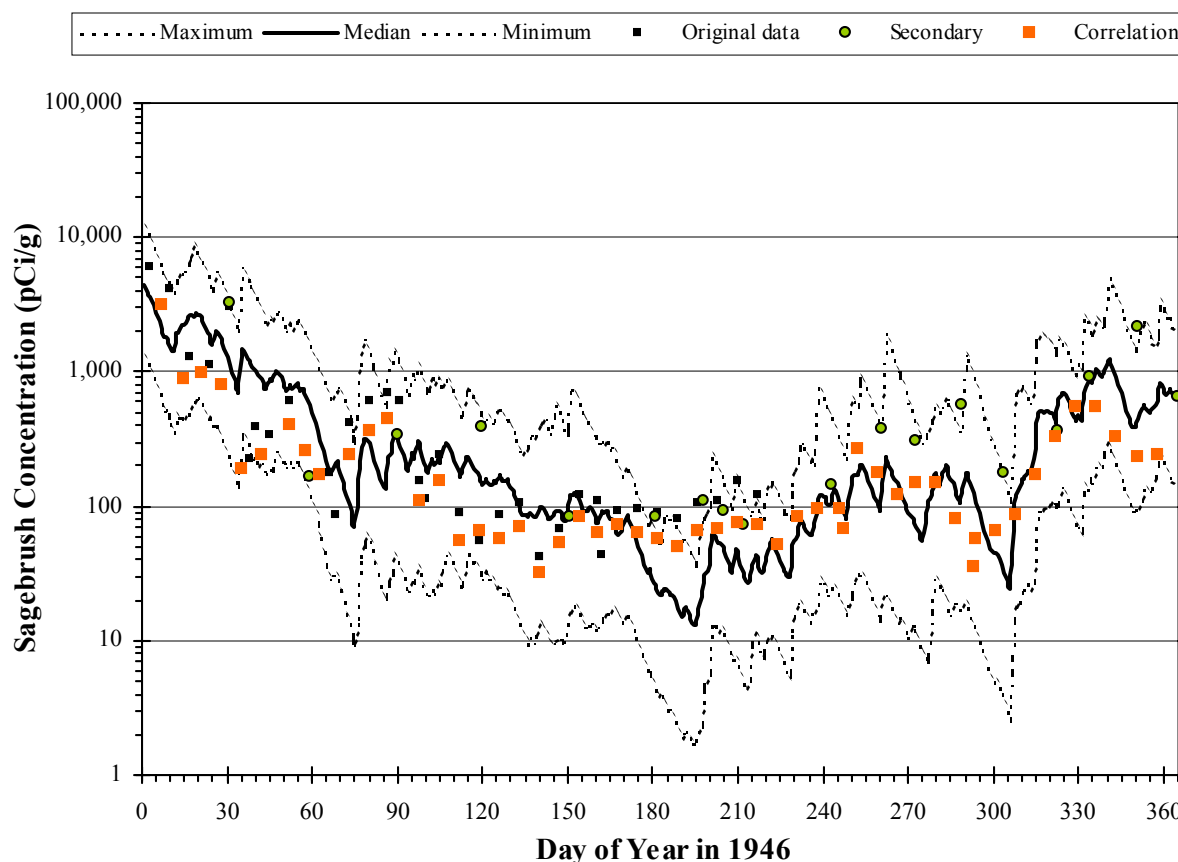


Figure 1-4. Comparison of sagebrush concentration projections with historical data in 1946 for Pasco/Kennewick (model node 443).

1.7 1949 Green Run Data

The Green Run experiment that began on December 2, 1949, was part of the development of monitoring methods for intelligence efforts directed towards the emerging Soviet nuclear program. A description of the experiment was prepared by Jenne & Healy (1950). In brief, a planned release of about 330 TBq (9,000 Ci) of ^{131}I to the atmosphere was made over a short period beginning late December 2, 1949. Extensive environmental monitoring efforts were made throughout the inland Northwest in the weeks following the release.

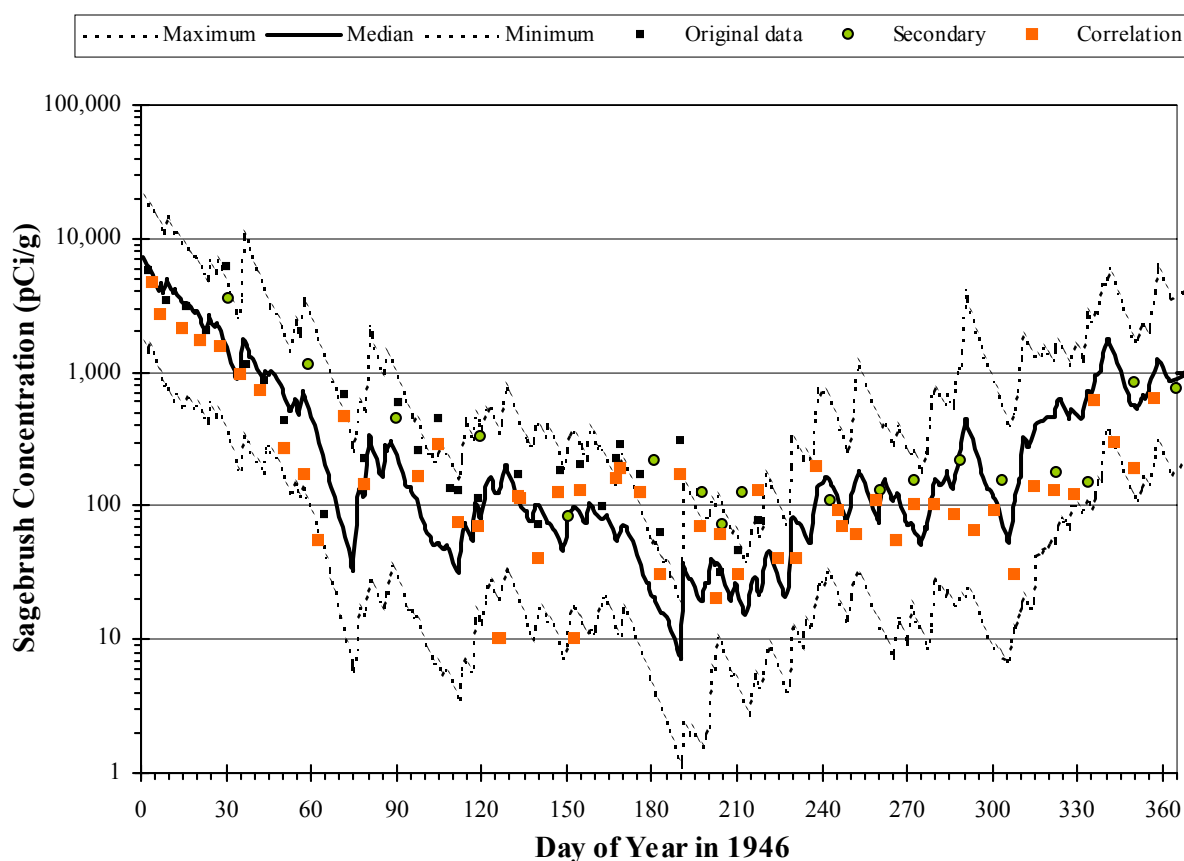


Figure 1-5. Comparison of sagebrush concentration projections with historical data in 1946 for Benton City (model node 467).

Sampling efforts intensified during and after the Green Run release. About 618 samples taken during the month of December 1949 are available throughout the HEDR atmospheric dispersion domain. Singlevich (1950) and Parker (1950) both report that 1,365 vegetation samples were taken. Many of these, however, were on the Hanford Site.

During the initial days after the release, most monitoring efforts concentrated on the Hanford Site. The first off-site forays were made on December 5. Two cars were sent north, one to Ritzville, Moses Lake, and Coulee City, Washington; the other to Walla Walla, Colfax, and Spokane, Washington. On December 6, these two groups continued east to Ellensburg and north of Spokane, Washington, respectively. Additional measurements were taken on December 7 between Yakima, Pasco, and Ritzville, Washington. Additional sampling was conducted on later days, but later dates were not modeled for this paper.

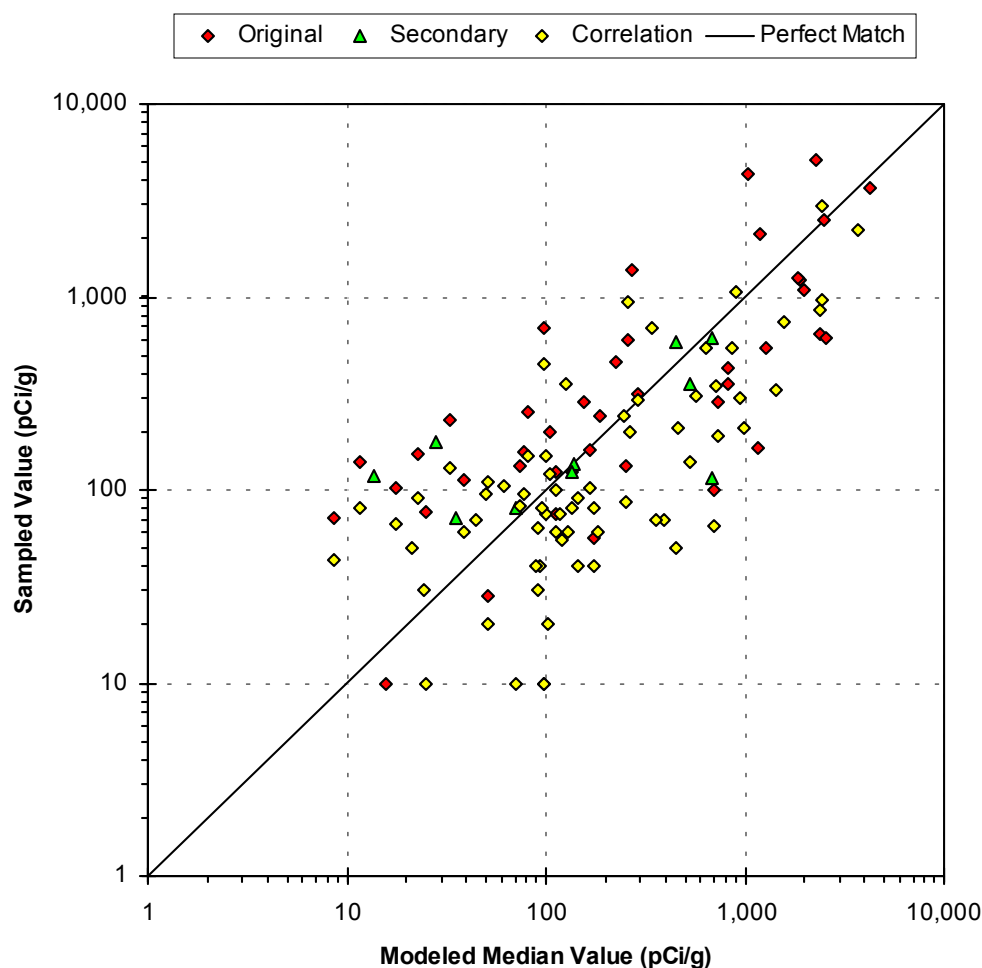


Figure 1-6. Scatter Plot of Historical Sampled Values Against Median Modeled Values for South Richland (model node 442).

By 1949, techniques for radionuclide detection in environmental samples had improved over those available in 1946. Concentration measurements of iodine-131 in vegetation were made with a multi-step chemical extraction process, in which the iodine-131 was removed from the sample and the resulting solution counted. This provided much better counting geometry and reduced the uncertainty about absorption of beta emissions within the sample. The conversion from detected counts per minute to concentration was made as described in Denham et al. (1993, p. 8.1). A complete description of the available information is provided in Hanf et al. (1993). Unfortunately, the laboratory used for counting the environmental samples was itself contaminated with ^{131}I during the course of the Green Run event, resulting in a detection limit of around 0.4 Bq/g (10 pCi/g) (Jenne & Healy 1950, p. 17).

1.8 Green Run Model Results

The 1949 green run data provide a look at the spatial validity of the model, whereas the 1946 data provided a look at the temporal validity at a few locations. Results for December 5 and 6, 1949, are provided in Figures 1-7 and 1-8, respectively. The contours on the plots are the median DESCARTES-modeled concentrations (from a suite of 100 replications) of ^{131}I in sagebrush. Each sampled data point is given a score in the range 1 to 6. The scores are defined as given in Table 1-3.

The historical meteorological information indicates that the wind velocity was rather slow and towards the southeast during the early period during and after the release. The plume would have drifted from the central Hanford site towards the city of Walla Walla, Washington, and stagnated in that area. The night of December 4-5, a cold front moved through the region from south to north, pushing the plume rapidly to the north.

Visual inspection of the results for December 5 and 6 (Figures 1-7 and 1-8) indicates that the primary plume had already passed by the time the monitoring crews arrived. The general footprint shape is influenced by the preceding three days' weather, moving first to the east and then the north. The plume footprint is decreasing in area over time through the decay of the ^{131}I . The scores on the figures indicate that the model is overpredicting the deposition on the southern and eastern sides of the footprint but doing well on the west. The deposition gradient is quite steep on the southeastern side of the footprint, and more gradual to the north and west in the direction the plume traveled.

If the model had a relatively small error in position as a function of time, a very minor misprediction from December 2 through 5 could be amplified. This possibility was investigated as a sensitivity analysis by shifting the pattern to see whether this would compensate for the general pattern of misprediction. If the calculated plume footprint is moved one or two calculational nodes to the northwest, the scores associated with each data point are greatly improved; nearly all fall into the range between 2 and 5. Apparently, the model predicts that, during the approximately 52 hours following the start of the release, the plume drifted about 15 km (10 mi) more to the southeast than actually occurred between December 2 and 4 (prior to the passage of the cold front). This misprediction of less than 0.3 km/hr (0.2 mph) is readily explained because of the integer nature of the historically available wind speeds.

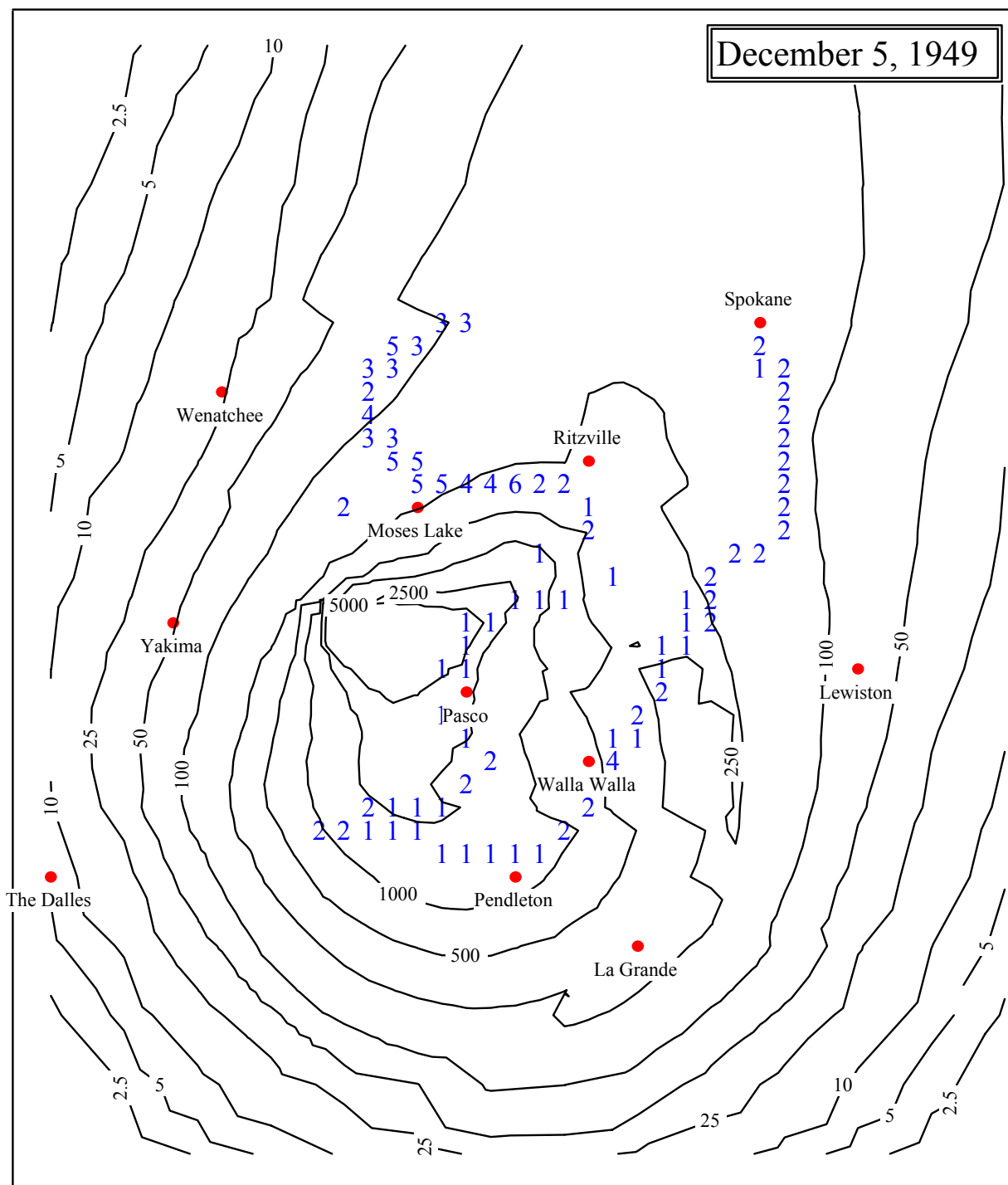


Figure 1-7. Map Illustrating Estimated Median Deposition of ^{131}I on Sagebrush for December 5, 1949, and Scores of Measured Data Relative to Estimated Concentrations.

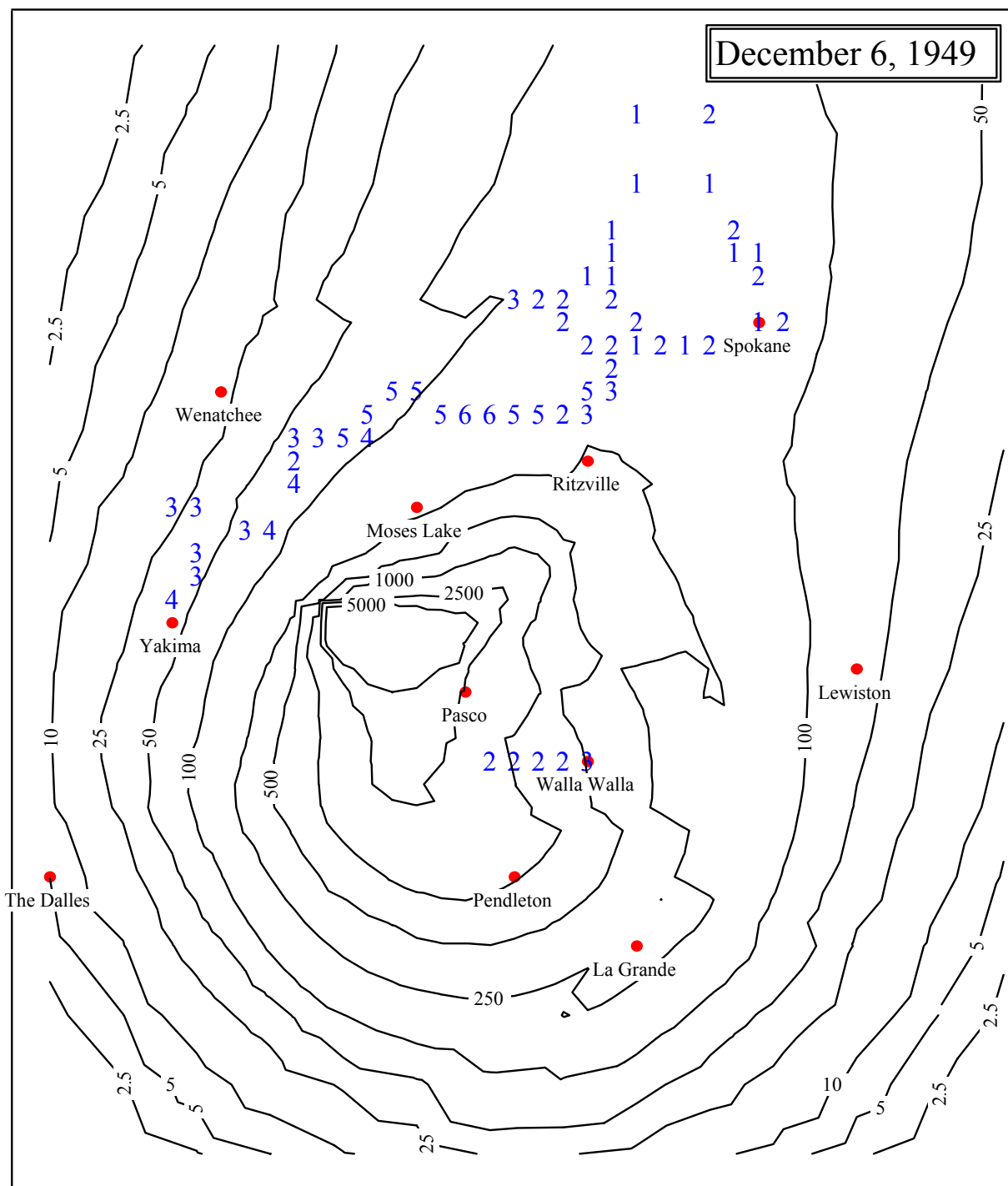


Figure 1-8. Map Illustrating Estimated Median Deposition of ^{131}I on Sagebrush for December 6, 1949, and Scores of Measured Data Relative to Estimated Concentrations.

Table 1-3. Explanation of the Sample Scores for Figures 1-7 and 1-8

Score	Explanation
1	The sampled value was below the smallest modeled value
2	The sampled value was between the minimum and 25 th percentile of modeled values
3	The sampled value was between the 25 th percentile and the median of modeled values
4	The sampled value was between the median and 75 th percentile of modeled values
5	The sampled value was between the 75 th percentile and maximum of modeled values
6	The sampled value was above the largest modeled value

1.9 Model Validation Summary and Conclusions

A temperature-driven model for ^{131}I on sagebrush has been implemented in the HEDR environmental accumulation model. This model includes a realistic biomass growth model for sagebrush and a thermodynamic model of air-plant deposition.

This model is specific to sagebrush in the regions of eastern Washington State. The results for summer months are similar to those obtained using the traditional deposition/interception model, but the temperature-dependent model for ^{131}I accumulation on sagebrush presented here provides a good fit to the historical data for releases from the Hanford site over the entire annual temperature cycle. It is a significant improvement over the air-interception fraction models used in earlier studies. The temperature dependence is required to match historical data from cold weather months.

These results validate the ^{131}I source term, atmospheric transport, and environmental accumulation models used by the HEDR project for these time periods. The time-series results for Richland, Kennewick-Pasco, and Benton City indicate that the models have an excellent ability to track the measured concentrations over time at specific locations. The Benton City result is particularly striking, because this location is shielded from the source by a 1,050-m (3,445-ft) mountain. For the 1949 single release, the models predicted the appropriate shape and magnitude of the resulting deposition footprint, but slightly mispredicted the location (by about 15 km within a 200,000 km² calculational domain). The model predictions were very close to the actual occurrence for this single event. On a long-

term average over a large number of releases (the design intent of the models), the effects of exact locations of individual plumes should tend to average out.

1.10 References for Section 1

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2. Estimation of wind fields for the RATCHET code

The National Academy of Sciences review of the HTDS dosimetry noted that the RATCHET model has a significant source of uncertainty built in: the interpolation of the wind fields from historically monitored wind speeds and directions at regional weather stations. The NAS suggests that “there should at least be a study of the sensitivity of the dispersion estimates with respect to local errors in the wind field. According to Ramsdell et al. (1994), inverse-square-distance weighting was used for interpolation. That method does not produce any information about the uncertainties associated with the interpolated values. The paper does not justify the choice of a method; in particular, it is known to be very sensitive to the location pattern of the data points. Inverse-square-distance weighting is known to be “isotropic”; that is, it incorporates the distance from the data points to the interpolation point but not the directions. In the case of wind fields, one would expect the direction from an interpolation point to a data point to be important. The algorithm is also insensitive to the directions between the pairs of data points; it incorporates only their relative distances from the interpolation point.”

It is apparent that the NAS reviewers did not have access to a directly relevant report. The HEDR project report by J.V. Ramsdell and E.D. Skyllingstad entitled *A Review of Wind Field Models for Atmospheric Transport*, PNWD-2148 HEDR (1993), addresses most of these concerns directly. A copy of this report has been provided to the HTDS staff. A summary of the report and its pertinent points follows. Other reports that also address this issue include Ramsdell (1992) *Summary of the March 25-26, 1991 Atmospheric Model Working Meeting*, and Nappo (1992) *Review of the Regional Atmospheric Transport Code for Hanford Emission Tracking (RATCHET)*.

The report *A Review of Wind Field Models for Atmospheric Transport*, PNWD-2148 HEDR (1993), was produced by the technical task that estimated the transport and deposition of radionuclides released to the atmosphere. The report describes methods used to transform observed wind data into wind fields. The wind fields are prepared in the Regional Atmospheric Transport Code for Hanford Emission Tracking (RATCHET) and used to determine where the radionuclides went after being released to the atmosphere. Wind fields play an essential role of the process of estimating the air concentrations and surface contamination at specific locations in the vicinity of Hanford.

This report describes the procedure used in the transformation of observed wind directions and speeds to wind fields for use in atmospheric transport calculations in RATCHET. The report discusses alternative procedures described in the literature and evaluates the alternatives based on the

wind data available for use in the HEDR Project. Wind data from 1944 to 1950 for the region around the Hanford Site are described in a separate report by Stage et al.

Techniques for preparing wind fields are evaluated on the basis of their data needs. Not all techniques for wind field estimation are appropriate for the HEDR Project because of the limited data available for the study.

This report focuses on RATCHET. Specifically, it describes procedures for estimating wind fields from observed (measured) wind data. Wind fields are used to calculate the transport of radionuclides released to the air from Hanford operations. Figure 2-1 shows the process that occurs within RATCHET. Observed wind data are used to generate wind fields. These fields are then used to move the puffs containing radionuclides within the model domain. Ultimately, the radionuclide concentrations in puffs are used to calculate time-integrated air concentrations and surface contamination at specific locations. Thus, wind fields are key elements in the process of estimating air concentrations and surface contamination at specific locations.

2.1 Model Domain And Wind Data

The intended use of the RATCHET code is to calculate daily time-integrated air concentrations and surface contamination in eastern Washington, northeastern Oregon, and northern Idaho for the period from December 1944 through 1949. The atmospheric model domain (shown in Figure 2-2) covers about 75,000 sq. mi. It is a rectangle centered at 46° 40' N, 118° 45' W. The Hanford Site, shown by the hatched area, is slightly west of the center of the domain. Distances within the domain can be determined using the tick marks on the domain border, which are spaced at 12-mi intervals.

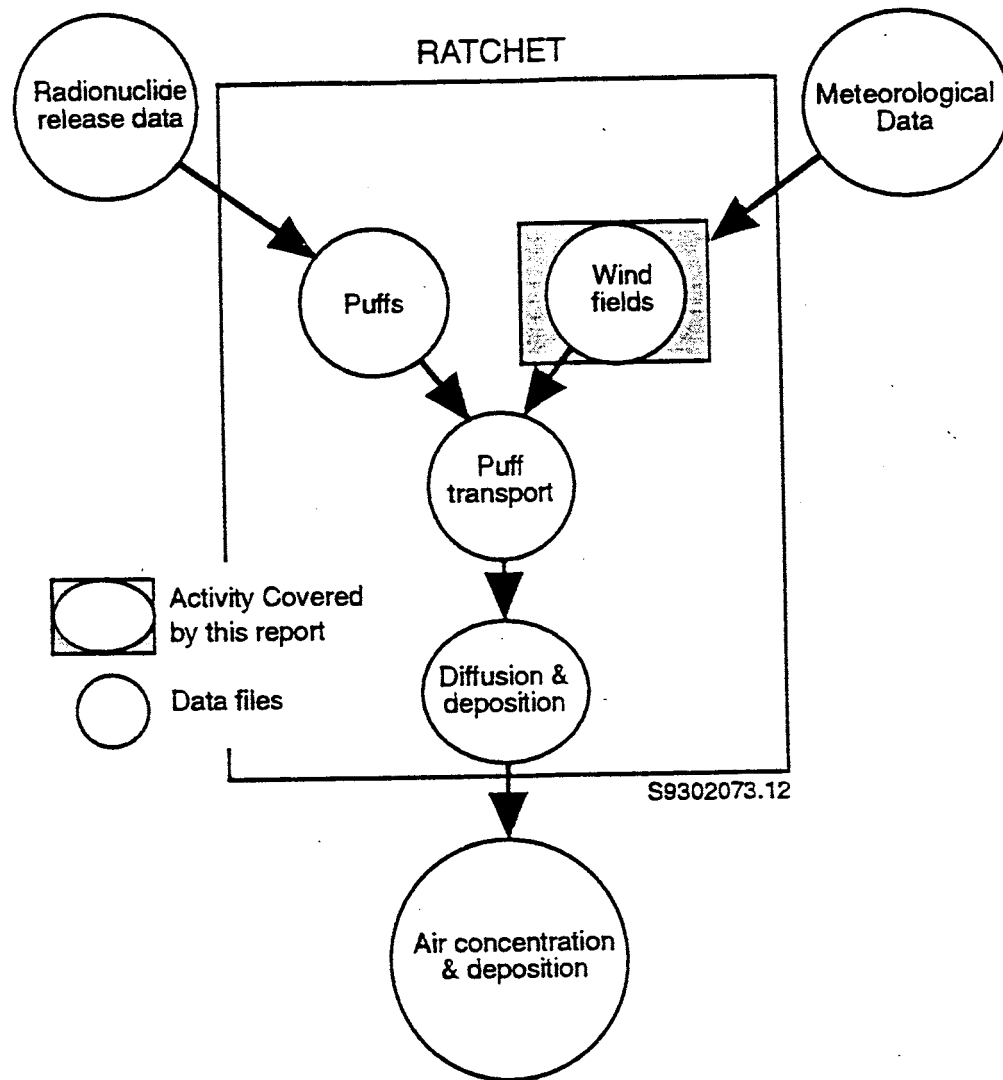


Figure 2-1. RATCHET Procedure to Prepare Wind Fields/Move Puffs

There are meteorological data for 25 locations in and adjacent to the atmospheric model domain. Figure 2-2 shows these locations. However, data are not available for all of the locations for the full period under consideration. Typically, at any time, available meteorological data are limited to 10 to 15 locations. The meteorological records available for the HEDR study period are described by Stage et al. (1993). The records contain data from surface meteorological observations the domain. Distances within the domain can be determined using the tick marks on the domain border, which are spaced at 12-mi intervals.

Atmospheric dispersion models frequently use upper-air wind and temperature data obtained with balloon-borne instruments. Unfortunately, no upper-air data are available for the mid-1940s

for the HEDR atmospheric model domain. The first measurements of this type were not made until the late 1940s, well after the period of the maximum releases to the atmosphere. As a result, the atmospheric transport and dispersion estimates for the HEDR Project must be based on surface meteorological data.

From 1944 through 1949, meteorological observations were made and recorded at hourly intervals on the half hour. Wind speed observations were made by an observer watching a dial for a 1-min period and recording an estimate of the average speed, in knots. Wind direction observations were made by watching lights on a compass dial and recording the direction in compass points (22.5° wide sectors). Hanford wind records are an exception to the general rule. Hourly-average wind directions and speeds were estimated from data recorded on strip charts. Wind speeds were recorded in miles per hour, and wind directions were recorded to the nearest 10°.

Figure 2-2 provides an indication of the general topography in the area. The figure shows the relatively flat mid-Columbia River Basin and the mountainous regions that surround the basin. It can be seen that many of the meteorological stations are in places where topography could have had an influence on the observed winds. Stage et al., (1993) discuss the potential topographic effects at each location.

2.2 Wind Field Estimation

The RATCHET computer code implements a puff diffusion model. A series of circular puffs is used to represent the plume that contains the material released to the atmosphere. Each puff is characterized by the position of its center, horizontal and vertical diffusion coefficients, and the amount of material in the puff. The wind at the center of each puff is used to calculate the puff's movement. These winds are allowed to change as a function of time and space. Therefore, the code must include a procedure for estimating the wind at the positions of puffs from available wind data.

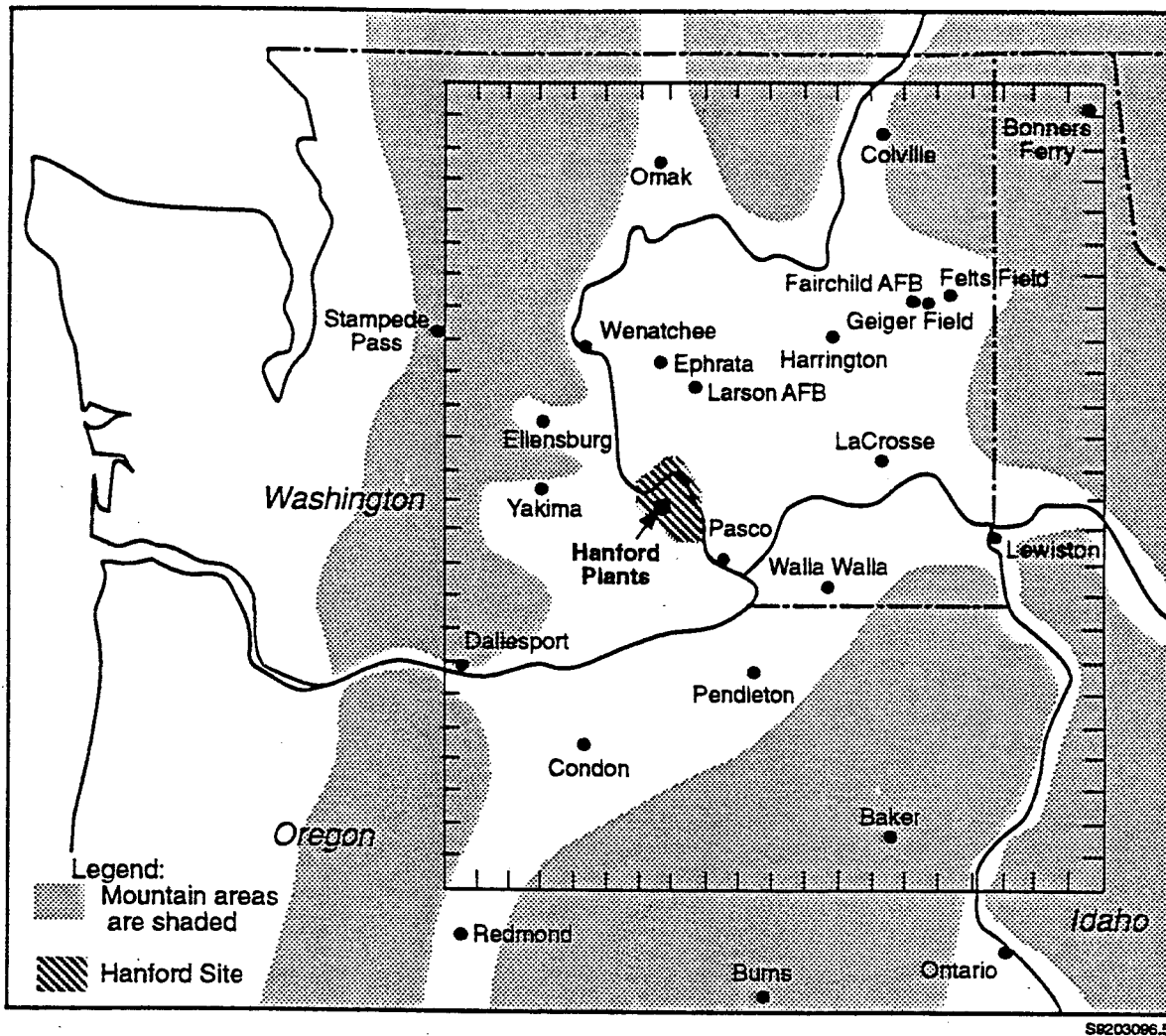


Figure 2-2. Meteorological Stations within the HEDR Atmospheric Domain

Wind data are used to define wind fields, and the winds at puff positions are calculated from the wind fields. The wind field in RATCHET represents winds at 10 m above the ground. Surface wind measurements were not made at this height in the 1940s. Therefore, the observed wind data are adjusted to a height of 10 m prior to preparation of the wind field. Similarly, puffs are released at heights above 10 m, and the winds at the release height are estimated from winds at 10 m. A wind profile model is used in both cases.

In RATCHET, the wind field is defined at equally spaced nodes within the atmospheric model domain. This type of wind field representation is called a gridded wind field. If upper-air wind data were available, gridded wind fields could include specification of the wind at several levels

in the vertical at each node. After the gridded wind field is calculated, the winds at puff positions are determined by interpolation as needed.

This report is primarily concerned with the preparation of gridded wind fields. Preparation of gridded wind fields has three steps. The first step involves adjustment of the measured winds to a standard reference height. The second step uses a combination of interpolation and extrapolation to make an initial estimate of the field. Throughout the remainder of this report, the term interpolation will implicitly include extrapolation, if appropriate. The third step involves adjustment of the initial gridded wind field to make the field conform to some predefined criteria. One common set of criteria limits the implicit vertical component of the wind vector and adjusts the horizontal components to conserve the mass of the air. Many atmospheric diffusion models skip this third step.

Interpolation of wind data to the nodes of the grid is usually done using one of several weighted averaging techniques. In these techniques, weights are assigned to the individual wind observations as a function of distance between the grid node and the observation point. The choice of weighting techniques is generally a subjective decision made by the modeler. Many factors, including the number of measurement locations and the topography surrounding the stations, may be considered in selecting a weighting technique.

After an initial estimate of the wind field has been made, the wind field may be adjusted to conform to criteria established by the modeler. Frequently, adjustment techniques are used to produce what are commonly referred to as mass-consistent wind fields. These techniques compute a vertical motion field from the original two-dimensional, horizontal wind field, constrain the vertical motions, and adjust the horizontal winds to conserve air mass. The adjustment techniques used to produce mass-consistent wind fields require information about the atmospheric structure (such as the upper-level winds, stability, and mixed-layer height) and use more sophisticated mathematics than basic interpolation methods.

The most advanced adjustment techniques involve the use of numerical models to predict changes in the winds. With these methods, gridded wind fields and temperatures are used to initialize a numerical model. Then, the model is used to simulate winds until the next observation period. In this way, the winds can be made to satisfy the full set of equations of motion. However, the computational requirements of these models limit their operational use and exceed the resources of the HEDR Project

2.3 Model Uncertainty

The HEDR codes, including RATCHET, are designed to account for uncertainty in input data. This is accomplished using Monte Carlo techniques. The full set of HEDR codes is executed a number of times using different input and parameter values. Selection of the input and parameter values for each run is subject to the constraint that all values must be consistent with available data. The results of each run represent one estimate of what might have actually occurred. Uncertainty is represented by the differences in results among the runs.

This section of the report describes the uncertainties in the input data available for use with the RATCHET code. The uncertainties exist in meteorological data and in the atmospheric release source term. A qualitative understanding of the uncertainties associated with the imprecision of the meteorological data and the timing of atmospheric releases provides a basis for evaluation of the importance of other sources of uncertainty. The last part of the section presents preliminary results from 100 realizations of the RATCHET code for 1945 to provide an indication of the ranges of time-integrated air concentrations that result from incorporation of uncertainty in the model.

2.4 Wind Data Uncertainty

The RATCHET code treats one form of uncertainty in wind data explicitly. That form of uncertainty is imprecision in the recorded values. The wind data for each station consist of a wind direction sector and a wind speed, which is recorded as an integer. As the hourly data for each station are read by the code, a specific wind direction within the reported wind direction sector is randomly selected as an estimate of the actual average direction for the hour. Similarly, a wind speed is selected that is within the range of precision of the recorded value. For the Hanford Meteorological Station a wind direction is selected from a 10° sector, and a wind speed is selected within ± 0.5 mph of the recorded speed. For other stations the width of wind sectors is 22.5°, and the precision of the wind speeds is ± 0.5 kn. The random wind direction and speed components differ from station to station, hour to hour, and run to run.

There are two additional sources of uncertainty in wind data that are not accounted for in RATCHET that might be considered. The first of these is uncertainty associated with winds at low wind speeds, and the other is the uncertainty associated with using a 1-min observation to represent an hourly average.

For wind speeds near the threshold of the instruments, there is a large uncertainty in both the direction and speed. Schere and Coates (1992) assume that uncertainty in both wind speed and

direction are related to the reported wind speed. The uncertainty in speed varies from 2 m/s in calm conditions to 1 m/s at high speeds. For near calm conditions, the wind direction is randomly varied through 360°. As the wind speed increases, the random variability in wind directions decreases to a few degrees ($<6^\circ$ when the wind speed is 10 m/s).

The RATCHET code does not account for the uncertainty associated with using 1-minute observations to represent hourly-average winds. This uncertainty should be somewhat less than the changes in wind direction from one hour to the next. The wind direction differences for 1-hour time lag provide a qualitative indication of the magnitude of uncertainties that might be associated with use of 1-minute observations. The standard deviation of the differences in wind direction at the 200-foot level of the HMS tower for consecutive hours (lag = 1 hr) is about 40° . However, the HMS data are estimates of hourly-averages taken from strip charts. Therefore, larger uncertainty might be expected at the remaining stations. The standard deviations of differences in wind directions for consecutive hours at Walla Walla and Fairchild Air Force Base were computed from station data in the HEDR meteorological database. The standard deviations are 47° and 38° , respectively. Thus, we conclude that the use of the 1-minute observations should be of the order of 30° to 50° .

2.5 Hourly Release Rate Uncertainty

There is another source of uncertainty in the input to RATCHET that is equivalent to uncertainty in winds. That source of uncertainty is the uncertainty in the hourly release rates. Heeb (1992) discusses the preparation of hourly release rates. These release rates include uncertainty in the time that each release started, the duration of each release, and in the amount released. The uncertainty in the start of releases varies from a few hours to a day or two. In general, it is of the order of one shift (8 hours).

Wind direction data from the 200 ft level of the Hanford Meteorology Tower, and from Walla Walla and Fairchild Air Force Base have been examined to assess the relationship between uncertainty in release time and uncertainty in wind direction. Figure 2-3 shows the frequency distributions for the difference in wind directions at the 200-foot level of the HMS tower for observations separated by one, two, six, and twelve hours. In each case the distribution is approximately symmetrical with a maximum at zero. However, the width of the distribution increases as the time between observations (lag) increases. The standard deviation of the differences

for lags from 0 to 24 hours are shown in Figure 2-4. The standard deviation reaches a maximum for lags of about 12 hours. This maximum, along with the decrease in standard deviation for longer lags, is caused by diurnal wind patterns. Wind directions for 1945 through 1947 from Walla Walla and Fairchild Air Force Base near Spokane were also examined.

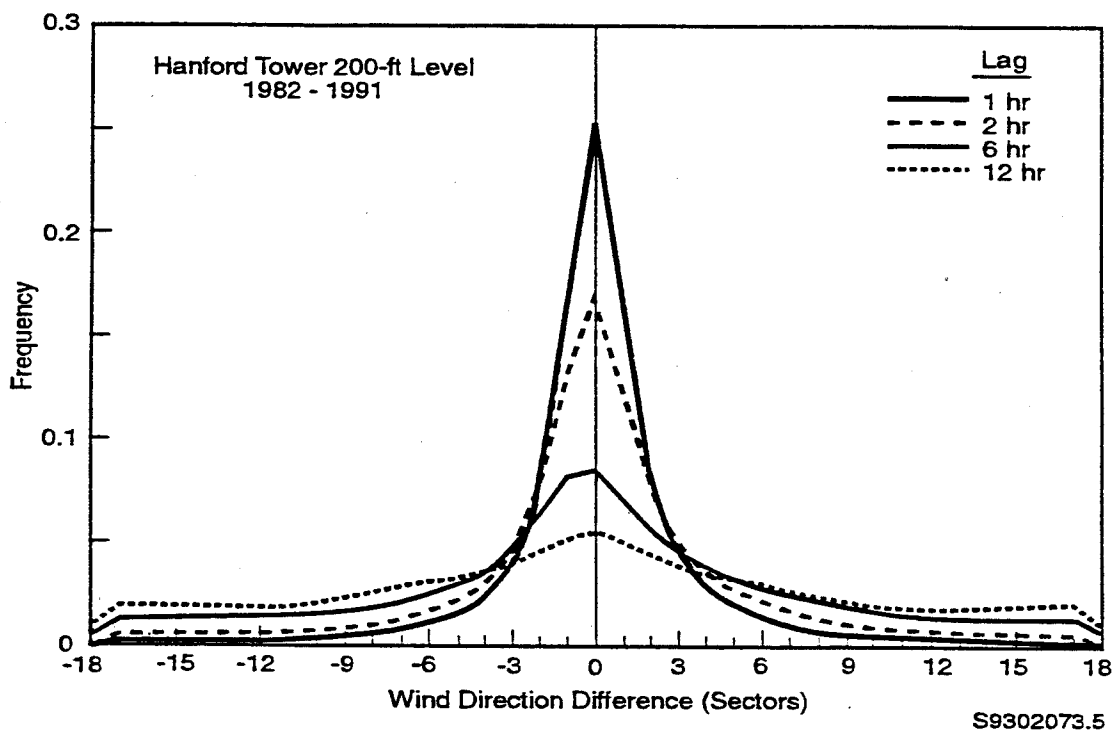


Figure 2-3. Frequency of Wind Direction Shifts at the HMS Tower

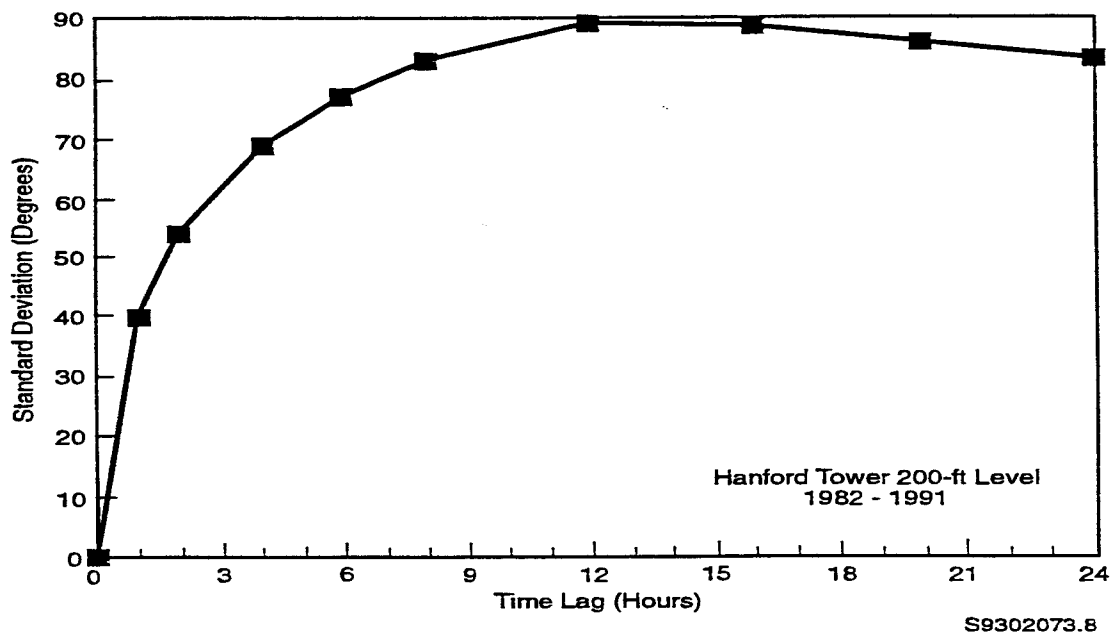
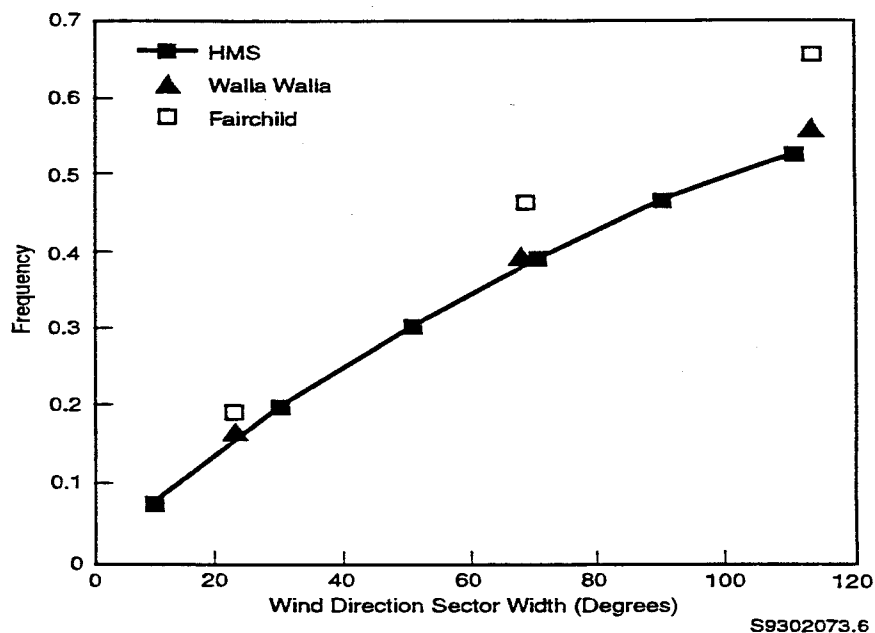


Figure 2-4. Standard Deviation of Wind Direction Differences as a Function of Time Lag

The frequencies that wind directions from observations made 8 hrs apart fall within a common sector have been determined from data from HMS, Walla Walla, and Fairchild AFB. Figure 2-5 shows how this frequency increases as the sector width increases. The sector width must be increased to about 90 degrees before there is a 50 percent likelihood the directions will be in the same sector. Again assuming that uncertainty in release times can be associated with lag times between observations, Figure 2-5 indicates the wind direction uncertainty associated with an 8-hour uncertainty in release times is 80 to 100 degrees.

A rough comparison can be made between the uncertainty in the use of 1-minute observations to represent hourly average winds and the uncertainty associated with release times. Figure 2-6 show the change frequencies of consecutive hourly wind direction observations falling in a common sector with change in sector width. Approximately 50 percent of the time, the wind directions in consecutive observations will be within a sector 30 degrees wide. If this width represents the uncertainty associated with 1-minute observations and the 90 degree sector width from Figure 5-5 represents the uncertainty associated with release times, the uncertainty in release times is much more significant than the uncertainty in the 1-minute observations.

**Figure 2-5.** Cumulative Frequency of Wind Direction Differences for Observations Separated by Eight Hours (HMS, Walla Walla, and Fairchild AFB)

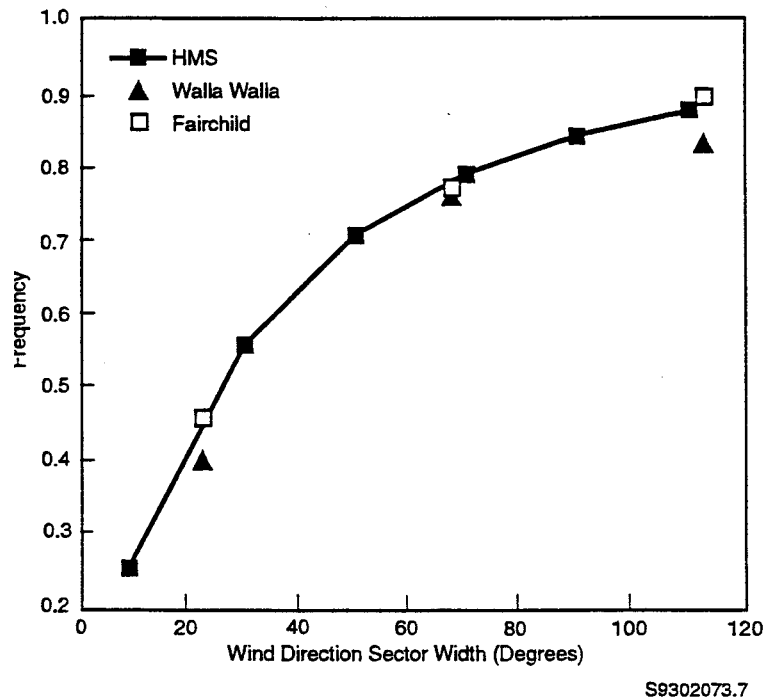


Figure 2-6. Frequency of Consecutive Wind Direction Observations in a Common Sector (HMS, Walla Walla, and Fairchild AFB)

2.6 Preliminary Estimates Of Model Output Variability

The uncertainties in wind direction associated with uncertainties in release times are large. These uncertainties are directly related to the initial transport direction. If the HEDR project were concerned with hourly dose estimates, the uncertainties in wind direction would lead to larger, and perhaps unacceptable, uncertainties in the dose estimates. However, the HEDR project is concerned with annual dose estimates. Therefore, it is appropriate to ask how the estimates of annual time-integrated air concentrations and surface contamination vary in uncertainties in response to uncertainty in model input.

The RATCHET code has generated 100 realizations of time-integrated air concentrations and surface contamination for use in model evaluation studies. Figure 2-7 shows the locations of 43 nodes within atmospheric model domain that have been given names. Figure 2-8 provides an indication of the geographical pattern of time-integrated air concentrations based on median values at the 43 named nodes. The pattern, although well defined, is somewhat broader than would be expected for an individual realization.

The pattern in Figure 2-8 is consistent with patterns found in previous studies of dispersion from Hanford (Hilst 1951; Nickola 1951, 1952, 1953). As a result, there is some assurance that there are no major errors in the processing of wind data in RATCHET. However, the figure does not indicate the range of variation of time-integrated air concentrations at each node within the 100 realizations. Table 2-1 lists the tenth, fiftieth, and ninetieth percentile time-integrated air concentrations for each of the nodes. At 28 of the 43 named nodes, the 90th percentile time-integrated air concentration was less than a factor of two larger than the 10th percentile value. And, at only one node (Meadows, Idaho) did the 90th percentile value exceed the 10th percentile value by more than a factor of 5. This node, in the extreme southeast corner of the model domain, also has the lowest median time-integrated concentration of the 43 named nodes.

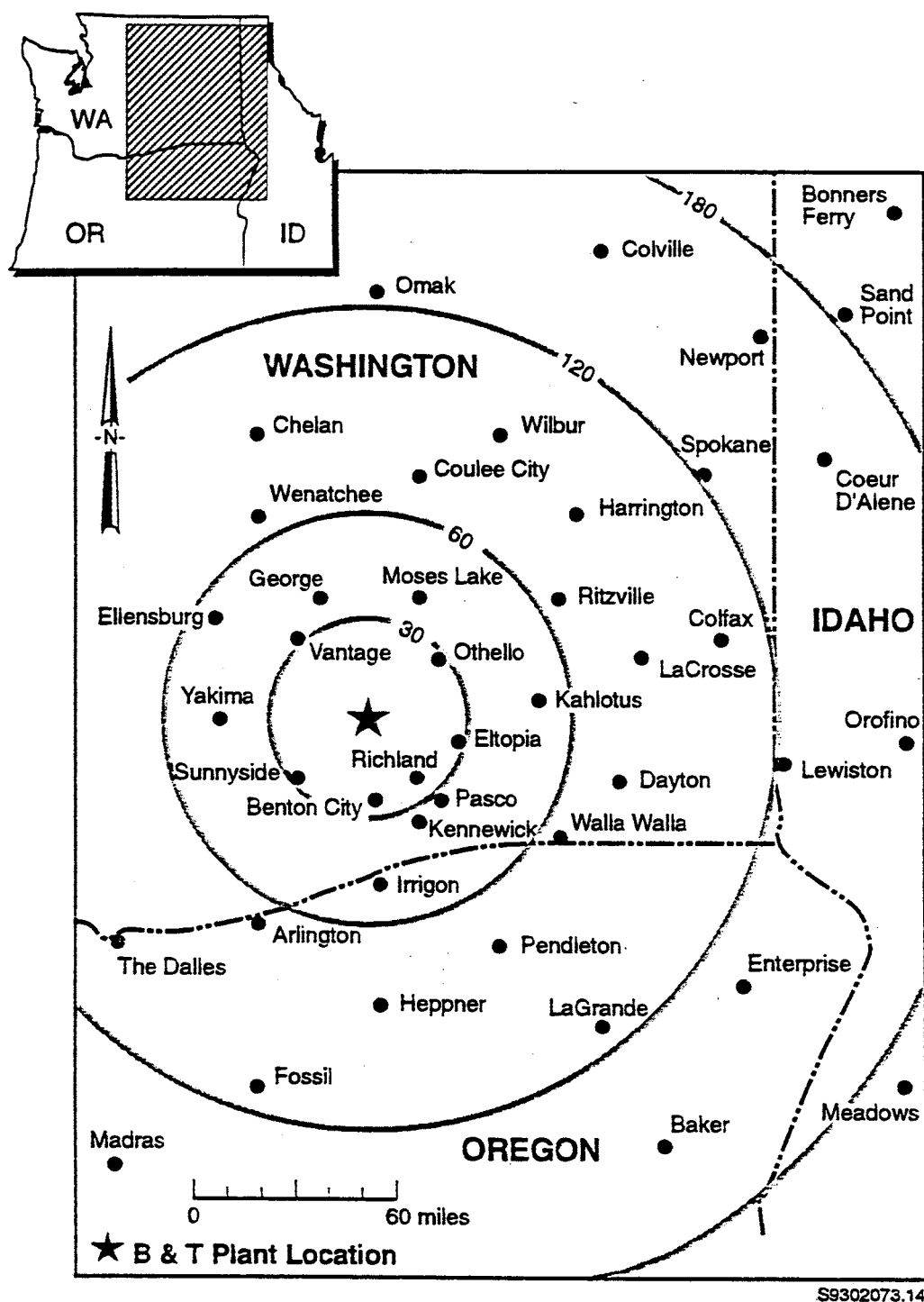


Figure 2-7. Named Node Locations within the HEDR Atmospheric Domain

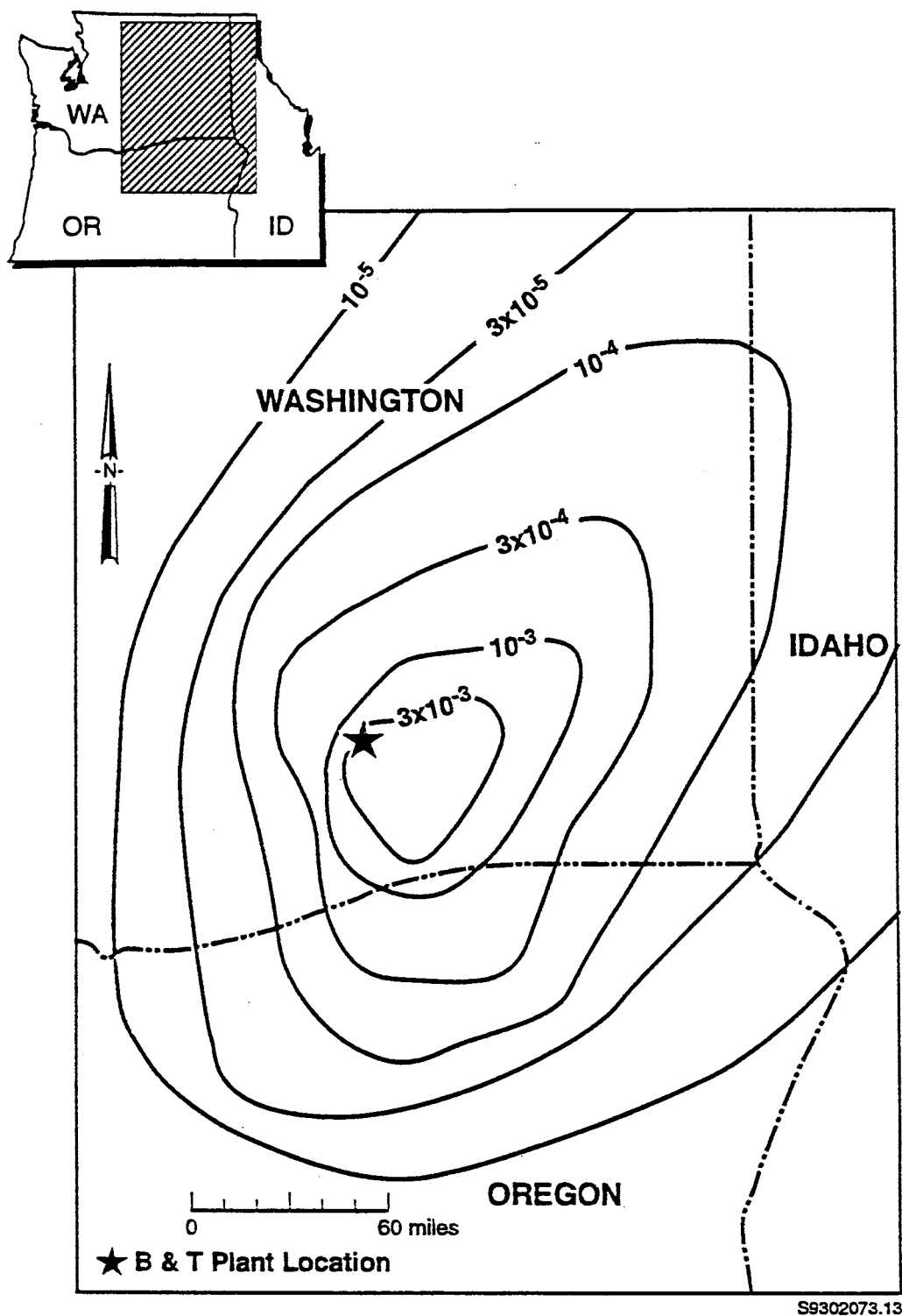


Figure 2-8. Geographical Pattern of Median Iodine-131 Time-Integrated Air Concentrations [(Ci-sec)/m³] (1945)

It is clear from the values in Table 2-1 that rather large uncertainties in the hourly release rates and station winds do not result in large variations of annual time-integrated air concentrations between model realizations. The integration over time performed by the model filters out most of the variability in model input. This finding is consistent with the improvement in dispersion model performance as the time period being modeled increases that has been reported by model evaluation studies, e.g. Weber, et al. (1984); Carhart, et al., (1989); Klug, et al., (1992). It is reasonable to interpret this result as indicating that climatological patterns are more important for estimating dispersion of continuing long-term releases than individual hourly patterns.

2.7 Wind Field Models

There are several ways of representing the spatial variation of wind in atmospheric dispersion models. Wind fields may be specified using polynomial functions that permit direct calculation of winds at puff positions. However, most models, including RATCHET, use gridded wind fields to calculate the transport of material.

Observed wind data are rarely, if ever, available for the nodes on a grid covering the domain of atmospheric transport model. Therefore, the model must generate gridded wind fields from the available data. The usual method of generating gridded wind fields is to calculate an initial estimate of the field using interpolation of the observed winds followed by adjustment of the field, if desired.

This section of the report describes some of the common techniques use for interpolating winds and adjusting wind fields. Techniques involving transform functions (Lamb and Hati 1987), polynomial basis functions (Allwine and Whiteman 1985), and data assimilation (Yamada and Bunker 1988; Andren 1990) are not addressed because their computational requirements exceed HEDR Project resources. Pielke (1989) provides additional rationale for not considering data assimilation techniques by stating that determining an accurate initial state may be impossible.

Table 2-1. Time-integrated Air Concentrations for 1945(Ci-sec/m³) based on 100 Realizations of the RATCHET Code.

Node Name	Percentile		
	10th	50th	90th
Arlington, OR	3.16e-5	4.71e-5	6.30E-5
Baker, OR	4.08e-6	7.90e-6	1.24e-5
Benton City, WA	1.85e-3	2.61e-3	4.37e-3
Bonnors Ferry, ID	3.37e-5	4.28e-5	5.60e-5
Chelan, WA	1.03e-5	1.60e-5	2.67e-5
Colfax, WA	1.64e-4	2.18e-4	2.68e-4
Colville, WA	6.60e-5	8.20e-5	1.12e-4
Coeur d'Alene, ID	5.38e-5	6.71e-5	8.46e-5
Coulee City, WA	8.68e-5	1.17e-4	1.64e-4
The Dalles, OR	5.46e-6	1.03e-5	1.73e-5
Dayton, WA	1.85e-4	2.34e-4	3.10e-4
Ellensburg, WA	4.09e-5	5.80e-5	9.42e-5
Eltopia, WA	5.66e-3	7.08e-3	8.64e-3
Enterprise, OR	6.22e-6	1.02e-5	1.60e-5
Fossil, OR	3.59e-5	5.16e-5	7.80e-5
George, WA	9.69e-5	1.42e-4	1.93e-4
Harrington, WA	2.46e-4	3.00e-4	4.00e-4
Heppner, OR	1.79e-4	2.34e-4	3.14e-4
Irrigon, OR	7.28e-4	9.09e-4	1.20e-3
Kahlotus, WA	1.58e-3	1.89e-3	2.42e-3
Kennewick, WA	2.96e-3	3.58e-3	4.53e-3
LaCrosse, WA	4.06e-4	5.14e-4	6.49e-4
LaGrande, OR	1.68e-5	2.33e-5	3.44e-5
Lewiston, ID	5.96e-5	8.91e-5	1.32e-4
Madras, OR	4.48e-6	6.86e-6	1.02e-5
Meadows, ID	7.48e-7	1.57e-6	3.86e-6
Moses Lake, WA	2.74e-4	3.58e-4	5.33e-4
Newport, WA	9.50e-5	1.15e-4	1.42e-4
Omak, WA	9.94e-6	1.69e-5	2.90e-5
Orofino, ID	1.48e-5	2.15e-5	3.08e-5
Othello, WA	9.72e-4	1.24e-3	1.54e-3
Pasco, WA	3.70e-3	4.40e-3	5.38e-3
Pendleton, OR	3.96e-4	5.40e-4	6.38e-4
Richland, WA	6.42e-3	7.92e-3	9.66e-3
Ritzville, WA	6.12e-4	7.40e-4	9.48e-4
Sandpoint, ID	4.77e-5	5.97e-5	7.62e-5
Spokane, WA	1.70e-4	2.04e-4	2.53e-4
Sunnyside, WA	1.85e-4	2.52e-4	3.47e-4
Vantage, WA	2.27e-4	3.07e-4	4.07e-4
Walla Walla, WA	2.88e-4	4.02e-4	5.56e-4
Wenatchee, WA	1.06e-5	1.76e-5	2.77e-5
Wilbur, WA	8.44e-5	1.17e-4	1.62e-4
Yakima, WA	2.36e-5	4.05e-5	6.46e-5

2.7.1 Interpolation Methods The interpolation process involves adjusting the observed winds to standard heights, converting the winds from direction and speed to east-west and north-south

components, and interpolating to grid nodes. When wind data are available for several levels, the process is repeated at each level.

Wind directions are expressed in degrees and range from 0° (north) to 359° (1° west of north). As long as two wind directions are not too different, and not near north, the directions may be averaged with reasonable results. However, if the one direction is just west of north, say 355°, and the other is just east of north, say 005°, the result is near south (180°). As a result, horizontal interpolation of the winds is generally done using cartesian (east-west and north-south) components of the wind vector rather than wind direction and speed. The transformation from direction and speed to cartesian components is made using trigonometric functions

$$u = -s \sin \theta$$

and

$$v = -s \cos \theta$$

where u is the east-west component of the vector (+ for transport to the east), v is the north-south component (+ for transport to the north), s is the wind speed, and θ is the wind direction.

Given the u and v wind components at reporting stations, the common method of obtaining an initial wind field estimate is interpolation using a weighted average,

$$C_{ij} = \sum_{k=1}^n C_k W_k(r) / \sum_{k=1}^n W_k(r) \quad (1)$$

where C_{ij} is the wind component (either u or v) at grid node i,j , C_k is the observed wind component at the station k , n is the total number of stations, $W_k(r)$ is the weighting function, i and j are the grid increments, and r is the distance from the grid interpolation point to the station. This scheme is easy to implement and is widely used in applications where fast wind-field estimation is a priority.

Several methods have been proposed for determining the weights used in horizontal interpolation. Goodin et al. (1979) discuss both interpolation and weighting methods. Among the methods discussed are $1/r^n$ weighting, and functions that use more complicated functions, such as exponentials and fitted polynomials. In general, weights are inversely related to the distance between node and the observation point.

The set of weighting factors in most common usage is simply

$$W_k(r) = \frac{1}{r^n} \quad (2)$$

where n is 1, 2, or 3. This weighting scheme may be modified by establishing an arbitrarily assigned radius of influence, R and setting the weight to zero when the distance exceeds R (Wendell 1979; Goodin et al. 1980).

The usual value of n is 2. However, the choice of n should depend on the characteristics of the observing station. For example, when data are very sparse, such as upper-level data over a mesoscale region, a $1/r$ weighting can be used to obtain smooth variations in the wind field. On the other hand, use of $1/r^2$ or $1/r^3$ weighting increases the weight given to a wind observation near its measurement point and decreases the weight as other wind measurement points are approached. With a dense station network, using an exponential or $1/r^3$ may be more appropriate, to limit the radius of influence of each station and preserve sharp features such as fronts.

Figure 2-9 shows the variation of weights given to winds between two measurement points for $1/r$, $1/r^2$, and $1/r^3$ weighting. It shows that increasing n increases the weight given to measured winds near their measurement point. It also shows that increasing n decreases the region in which transitions take place. Note that all of these schemes give equal weights to winds from two stations at a point equidistant from the stations. Figure 2-10 shows an example of effect of two different weighting factors on transport fields derived from the same observed winds. The fields in the example are based winds observed at 15 PST from December 19, 1944. The field shown in Figure 2-10(a) was derived using $1/r$ weighting in Equation (1). Figure 2-10(b) shows the field derived using $1/r^2$ weighting.

Qualitatively, the wind fields appear nearly equivalent. In both cases, there is a region of nearly calm wind in the vicinity of the Hanford Site; there are relatively strong southeasterly winds near Pendleton; there are relatively strong easterly winds in the vicinity of

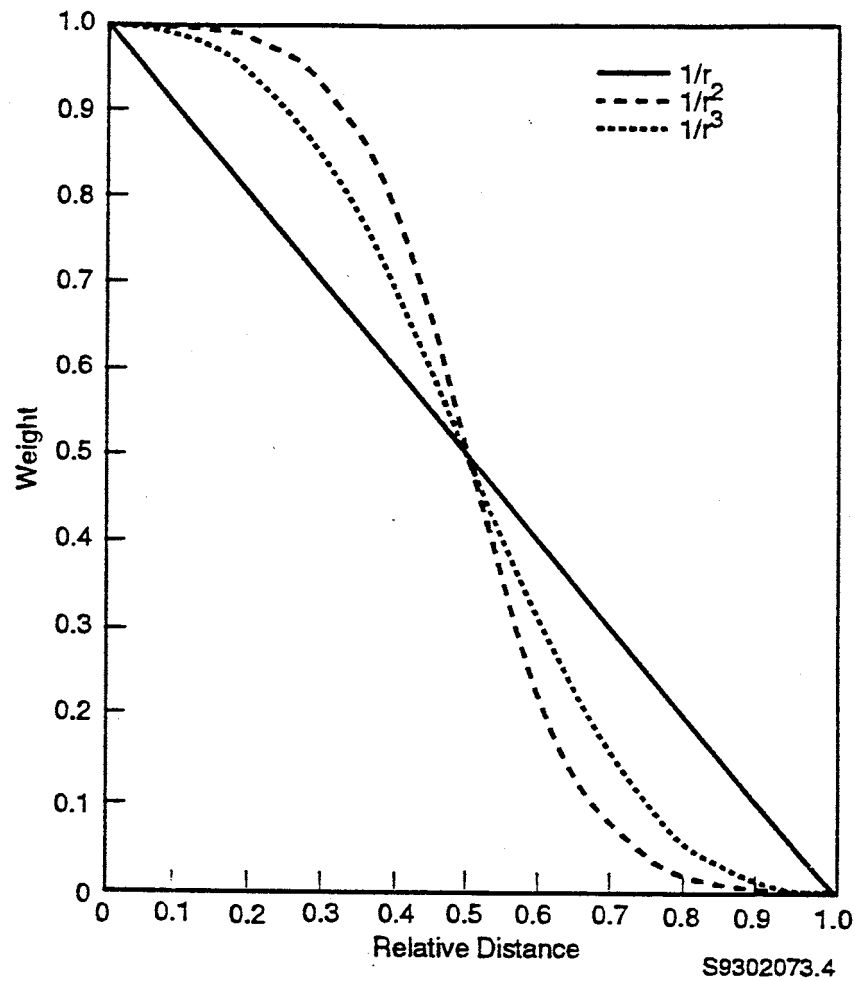


Figure 2-9. Interpolation Variations for Three Weighting Schemes

Spokane, and there are northerly winds along the western edge of the model domain. The primary difference between the wind fields is in the size of the low wind speed area near Hanford. The larger area in Figure 2-10(b) is caused by the additional weight that $1/r^2$ assigns to the HMS wind data in the vicinity of the station. Secondary differences, e.g., the smoothness of the spatial variations in the wind field, are also noticeable at the HMS.

Optimal interpolation is a more sophisticated interpolation scheme than the simple distance weighting schemes. It uses statistical correlations among stations in determining interpolation weights. As a result, optimal interpolation may identify and decrease the influence of unrepresentative observations. However, the statistical aspects of optimal interpolation require substantial analysis of climatological records. As a consequence, the operational mesoscale use of optimal interpolation has been quite limited. Although the interpolation scheme has been tested in

mesoscale regions by Cats (1980) and Johnson (1982), no use with a transport model has been reported.

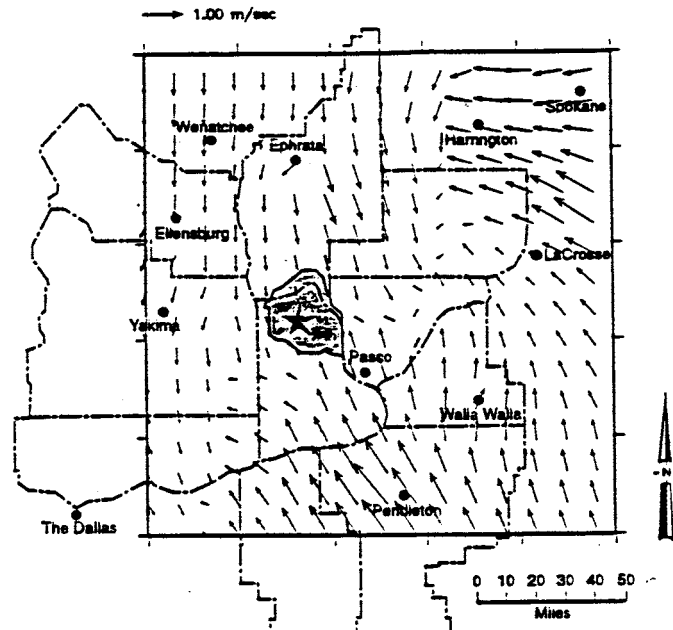
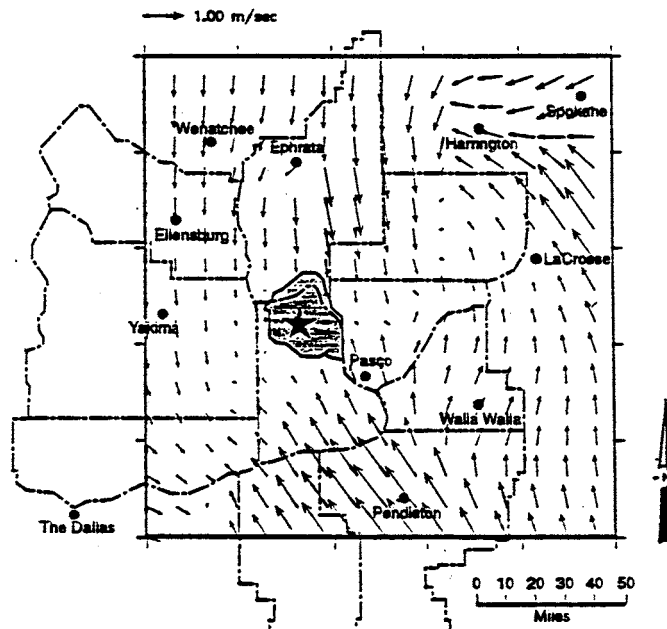
2.7.2 Adjustment Techniques Wind fields generated using an interpolation technique are often used directly in transport and diffusion models (e.g. Ramsdell et al. 1983; Wang and Waldron 1990; Scire et al. 1984). However, there are cases where wind fields are adjusted to conserve the air mass within the model domain or fit the equations of motion. Three techniques are commonly used to perform these adjustments: mass consistent methods, transform methods, and data assimilation methods. Transform and data assimilation techniques are too computationally intensive to be used in the RATCHET code and are not discussed further.

One of the first questions raise about wind fields is: are they mass consistent? That is do they conserve mass? Note that the question specifically refers to the mass of the air in the model domain. Assuming that air is an incompressible fluid, a mass-consistent wind field is a wind field in which the continuity equation is satisfied at every point. With this assumption, the continuity equation is

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \quad (3)$$

where u , v and w are the wind components, x and y are the horizontal coordinates, and z is the vertical component. Diffusion models that compute concentrations using a two-dimensional flux equation require mass-consistent wind fields to conserve mass of the material being dispersed. This is not an issue in the HEDR Project because RATCHET implements a puff model in which the diffusion and depletion of material are treated independently of the transport.

However, adjustment of an initial wind field using a constraint based on the continuity equation has other potential benefits. For example, it can reduce the effects of small-scale features such as local terrain or short-lived weather disturbances (i.e. cumulus convection) on an interpolated regional wind field. These are the reasons for considering use of a mass-consistent wind field in RATCHET.

(a) $1/r$ Interpolation(b) $1/r^2$ Interpolation

an

Figure 2-10. Comparison of Wind Fields Using Two Weighting Schemes

The most popular method for achieving mass consistency is the variational calculus approach originally applied to transport modeling by Sherman (1978). In this technique, an initial gridded wind field is changed by a minimal amount in an overall least squares sense, while assuring continuity of mass or some other dynamical constraint, such as conservation of vorticity. Ross et al. (1988), minimizes the equation

$$E(u, v, w) = \iiint \{ \alpha_1^2 (u - u_0)^2 + \alpha_1^2 (v - v_0)^2 + \alpha_2^2 (w - w_0)^2 \} dV \quad (4)$$

subject to the mass constraint given in Equation (3). In equation (4), V is a unit volume, u_0 , v_0 , and w_0 are the initial interpolated horizontal and vertical wind components, and α_1 and α_2 are coefficients that determine the degree of adjustment to the initial wind field.

Equation (4) represents an estimate of the area-averaged kinetic energy difference between the initial wind field and the nondivergent adjusted wind field. Minimization of this equation ensures that changes to the wind field are made with a minimal impact on the overall wind energy. In regions of complex terrain, the solution of Equations (3) and (4) can be affected by terrain features. Sherman (1978) solved the minimization by assuming that the surface terrain followed a series of steps between grid points. However, this leads to large velocity errors at the surface as shown by Lewellen, et al. (1982). More recent implementations have used terrain following coordinates to produce a smooth representation of terrain effects (Ross et al. 1988; Traci et al. 1978).

The main difficulty in using mass-consistent adjustment techniques is the number of free parameters that must be empirically or subjectively determined. Minimization of Equation (4) with a constraint based on Equation (3) requires a knowledge of the upper-level winds and the mixed-layer height or level of zero vertical motion. Data on upper-level winds are not available for the HEDR atmospheric model domain for the period of interest. As a result, they must be estimated from surface data. The height of the top surface must be estimated, and vertical velocities at the top surface must be specified. In general, vertical velocities at the top surface are not known, and are usually assumed to be equal to zero. In addition, it is necessary to estimate coefficients α_1 and α_2 in Equation 4.

The estimates of α_2 and α_1 influence the final wind field by controlling the relative changes in the wind components. If α_1 and α_2 are small, the imposed constraint has a relatively large impact on the final wind field. Conversely, if α_1 and α_2 are large, the initial winds are not strongly modified.

Finally, the ratio α_1/α_2 determines the relative amount of adjustment of the vertical wind component with respect to the horizontal winds.

The NOABL scheme for generating mass consistent wind fields (Traci, et al., 1978) was implemented in RATCHET to examine the effects on wind fields and code execution times. The implementation uses three atmospheric layers. It assumed zero initial vertical velocity and a mixed layer height of 1000 m. The upper-level winds were estimated by the average of the gridded wind components over the model domain.

Figure 2-11 illustrates the effects of α_1 and α_2 on wind fields. All three parts of the figure are based on wind data for 2100 PST, December 22, 1944. Figure 2-11(a) shows the initial wind field estimate based on $1/r^2$ interpolation of the data. Figures 2-11(b) and -11(c) show wind fields following modification by the NOABL adjustment scheme (Traci, et al. 1978). The only difference in the adjustment scheme used to generate Figures 2-11(b) and 2-11(c) is in the ratio of the parameters α_1 and α_2 .

An α_1/α_2 ratio of 0.001, which qualitatively corresponds to unstable atmospheric conditions, was used to generate Figure 2-11(b). The wind directions in this figure show little change from the original $1/r^2$ field. In contrast, in Figure 2-11(c), the α_1/α_2 ratio is 1, which is more typical of neutral atmospheric conditions. The result is a noticeable change in wind directions in the southeast portion of the domain. Figures 2-11(b) and 2-11(c) both show smoother wind speed transitions than seen in Figure 2-11(a). The difference is particularly noticeable in the convergence zone near Pasco.

A variety of simple techniques have been devised to reduce the subjective treatment of the parameters α_1 and α_2 . For example, Ross et al. (1988) used a simple Froude number approximation to estimate α_1/α_2 . This approximation has the effect of including the atmospheric stability in their adjustment. Another approach was tried by Barnard, et al., (1987) who modeled flow in a small region ($\sim 4 \text{ km}^2$) of complex terrain. They used observed wind data to assist in selection of α_1/α_2 .

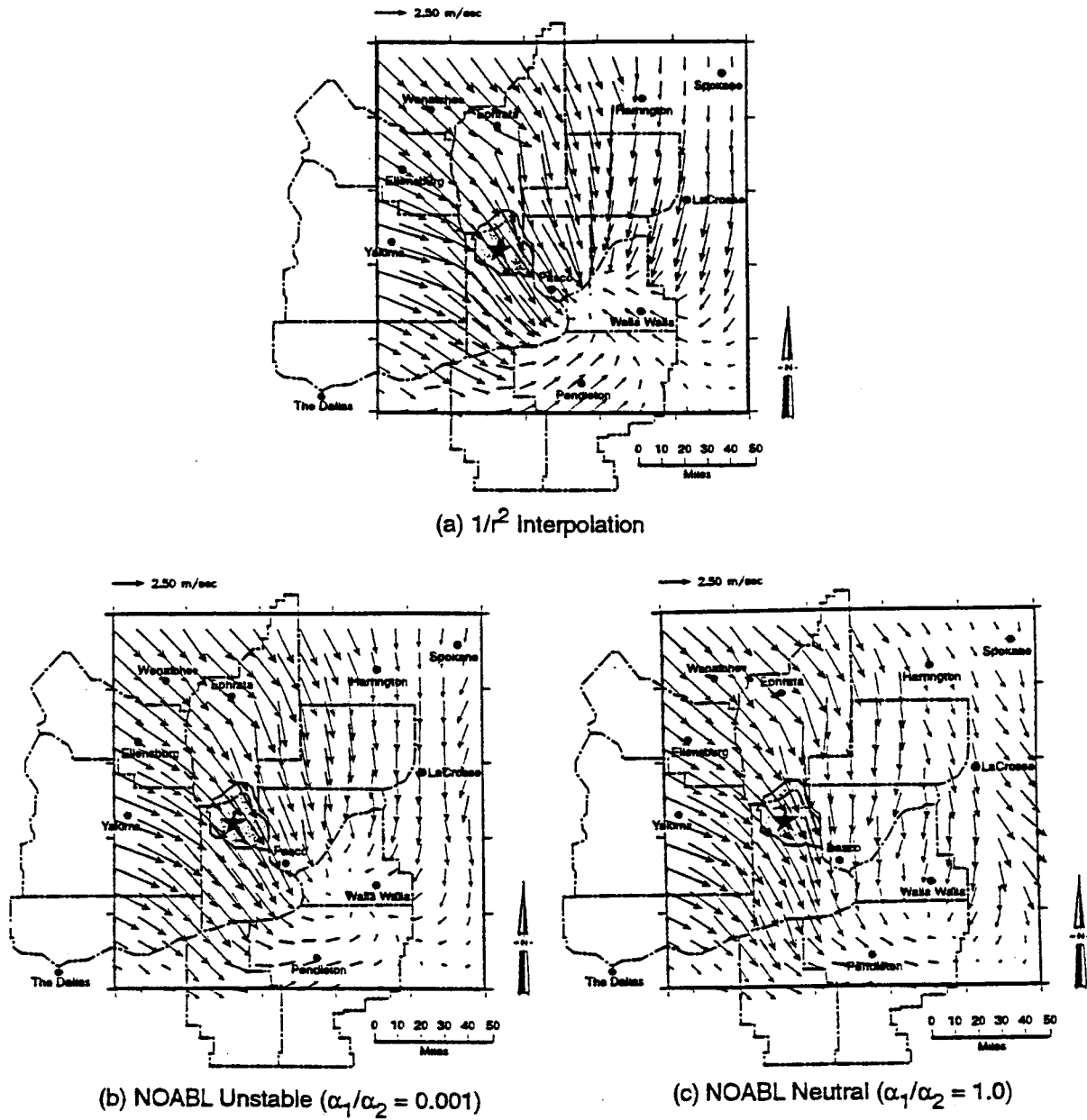


Figure 2-11. NOABL Adjustments to Estimated Wind Fields

Similarly, a variety of methods have been used to estimate the height of the top surface. King and Bunker (1984) and Goodin, et al. (1980) assigned values based on radiosonde observations of the boundary layer structure. Guo and Palutikof (1990) set the top surface using a climatological-based look-up table for night and day. Ultimately, the selection of the top surface depends on the number of observations available for a particular application. When observations are sparse, climatological values can be used with reasonable success (Guo and Palutikof 1990).

One of the significant problems associated with mass consistent techniques is the general lack of model verification for mesoscale applications. Dispersion model comparisons presented in Lewellen, et al. (1985) and Lewellen and Sykes (1985) do not show that models using mass-consistent wind fields are better than models using interpolated fields without adjustment. Limited testing is reported in King and Bunker (1984) where the transport and diffusion model described in Davis, et al. (1984) is applied at three different locations. Although reasonable model performance is demonstrated, the relative merit of adjusted wind fields over the original interpolated wind fields is not discussed. Walmsley, et al. (1990) compare the results of four complex terrain wind field models to each other and to a reference observation point. Again, the model results show good agreement with the observing stations, however, the number of observation points (3) was too small to test for interpolation accuracy. Other model evaluations, such as Mathur and Peters (1990) present resultant fields of vertical motion, which by definition should be reduced by the mass consistency requirement.

2.7.3 Horizontal Interpolation Of Winds

Various methods have been developed for interpolating winds from randomly spaced observation points to evenly-spaced nodes on a grid. Several of these methods have been described. RATCHET uses weighted interpolation with $1/r^2$ weighting. This is one of the common methods, if not the most common method of weighting. No other single interpolation method has replaced the $1/r^2$ weighted averaging method in common usage.

Differences among hourly wind fields that result from differences in interpolation methods are generally small. Figure 2-10 showed an example of changes resulting from weighting. The HEDR system of codes accounts for uncertainties in release times that are of the order of 8 hours. The changes in wind fields associated with passing weather systems and diurnal thermal effects over this period are larger than the differences in wind fields associated with interpolation methods. Therefore, it is our recommendation that $1/r^2$ weighted averaging continue to be used for horizontal interpolation of winds in RATCHET.

2.7.4 Wind Field Adjustments

The review of wind field adjustment techniques indicates that the techniques usually require more information than is readily available for the HEDR atmospheric model domain for the period of interest. Undocumented experiences with a wind field model based on the code of Allwine and Whiteman (1985) indicate that the use of transform methods for calculation of wind fields requires more time than can reasonably be allotted for wind field calculations in RATCHET. Data assimilation techniques for adjusting wind field have been dismissed from consideration for the same reason. For example, a typical 24 hour model run requires roughly 53 minutes of Cray XMP computer time (Geai, et al. 1988). Design specifications for the RATCHET code (Ramsdell and Burk 1992, p. 4.1) established requirement that RATCHET execution take no more than 1 s per hour of real time simulation.

Two mass consistent wind field adjustment algorithms (Traci et al. 1978; Mathur and Peters 1990) have been implemented in modified versions of RATCHET for evaluation. These algorithms use different methods of adjustment of the wind field. Under most conditions the differences among the initial wind fields generated by $1/r^2$ weighted averaging and the adjusted fields are small. See Figure 2-11(c) for an example of the relatively large changes. However, there are significant differences in the time required for program execution. When the wind field adjustment algorithm proposed by Mathur and Peters is used, RATCHET execution takes more than twice as long as execution with only $1/r^2$ interpolation. The algorithm proposed by Traci et al. increases RATCHET execution time by almost a factor of 3.

Calculations with the RATCHET code indicate that the execution speed design criteria can be met even using a mass consistent wind field adjustment algorithm. The question then becomes whether there is sufficient value added by mass consistent algorithm to justify the additional computational time.

Dispersion model evaluations involving short releases (Lewellen et al., 1982; Lewellen and Sykes 1985; Lewellen et al., 1986; Weber et al., 1987; Klug et al., 1992) have failed to find that models using wind fields adjusted for mass-consistency produce better concentration predictions than models that use interpolated wind fields without adjustment. Weber et al. (1984) suggest that correct treatment of wind fields is less important in estimating long-term concentrations than it is in estimating short-term concentrations. The same suggestion is offered by Carhart et al. (1989).

Mass consistent wind fields have not been demonstrated to have value in estimating short-term concentrations. The relatively small range of time-integrated air concentrations calculated for 1945 shown in Table 2-1 given the uncertainties in model input would indicate that mass consistent wind fields would be of less value in estimating long-term concentrations than they are in estimating short-term concentrations. Unless future model evaluation studies offer positive evidence that the additional computational time required to adjust wind fields for mass consistency improves model performance in predicting concentrations it is not warranted in RATCHET. Therefore, we recommend that RATCHET continue to rely on interpolated wind fields for transport calculations.

2.8 References for Section 2

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3. HEDR Source Term Estimates

The National Research Council committee review (NRC 2000) of the HTDS draft final report repeated the concern of Hoffman et al. (1999) that portions of the ^{131}I source term could have been underestimated. According to the NRC report, the main points raised by the Hoffman et al. report are

- The HEDR project estimates of the amounts of ^{131}I processed and released in 1959 and 1960 are substantially less than the amounts reported by Warren (1961), which are the source of HEDR release estimates.
- The HEDR project documents use Warren (1961) as a source but do not evaluate the credibility of his values; for example, he projected an unrealistically high scrubber efficiency.
- The HEDR project misapplied measured release-factor data from 1959-1960 to the period 1951-1957, when less emission-control equipment was in place.
- The HEDR project incorrectly accounted for operation of the silver reactors in the B and T plants by inexperienced personnel during the first 18 months after installation in 1951.
- The HEDR project substantially underestimated the source-term uncertainties for the B, T, and REDOX plants.
- The HEDR project inadvertently used the medians instead of the arithmetic means of the monthly source terms for the air-concentration and ground-deposition calculations.
- The HEDR project did not propagate the source-term uncertainties to air concentrations, ground deposition, and doses.

These can be summarized as four main questions:

- Have errors in the published source term affected the HEDR or HTDS dose estimates?
- Is the HEDR source term consistent with the data from Warren (1961) for the period 1959 - 1960?
- Does the HEDR source term underestimate the releases in the 1950s and 1960s?
- Are uncertainties in the source term appropriately propagated throughout the following parts of the calculation?

3.1 Use of median versus mean monthly source terms

Hoffman et al. (1999) discovered an error in the monthly source terms published in C.M. Heeb 1994. *Radionuclide Releases to the Atmosphere from Hanford Operations, 1944 – 1972*, PNWD-2222 HEDR. Heeb indicated that the tabulated values of the data were means, and the calculations subsequently performed assumed them to be means. Table B.1 as published in PNWD-2222 HEDR contained the error, starting in August of 1951, of using a median rather than a mean release factor for ^{131}I . This caused an underestimation in the reported source term for the remaining months of a factor ranging from around 1.25 to 3.0, depending on which emitting facility was in operation at the time. The corrected table is presented as Table 3-1. This table has been available on the Internet since November 1999 at the address <http://www.pnl.gov/eshs/cap/hra/pub/hedr.html>. The subsequent data files used in the dose calculations have also been corrected. As a result, the HEDR DESCARTES computer program was rerun and an updated environmental concentration database (used as input to the CIDER computer code) was issued to Centers for Disease Control and Prevention and to the Washington State Department of Health. Because the corrections apply only for times after August 1951, these corrections have essentially no impact on published HEDR reports (for which representative doses were reported for 1944 through 1951 - releases for all of 1951 are increased by about 25%). The estimated overall release of ^{131}I from the Hanford Site increases by about 3% when this error is integrated from 1944 through 1972.

3.2 Considerations of the I-131 Releases Reported by J.H. Warren (1961)

It has been suggested that the data in the report by Warren (1961) used by Heeb (1994) to estimate radionuclide release fractions from the REDOX and PUREX facilities do not agree with the releases ultimately prepared by Heeb (1994). It has been further suggested that there may be an error in Heeb's estimates, since the final release estimates do not "replicate the data used to generate them." (Paraphrased by this author).

The presentation of tons of fuel processed through the REDOX and PUREX facilities in Heeb (1994, Table A.3) appears to be accurate. This information is corroborated in Roberts et al. (1992), Jenkins and Foster (1978), Gydesen (1992a), and Gydesen (1992b). It has most recently been heavily reviewed in the development of the Hanford Defined Wastes model and Hanford Best Basis Inventory (Kupfer et al. 1999). Kupfer et al. (1999) have made adjustments to Heeb's database to account for minor variations in the processing after 1966 (primarily to account for

Table 3-1. Estimated Monthly Releases to the Atmosphere from Separations Plant
Operations 1944-1972 (Ci/month)

Year	Month	T Plant Processed	T Plant Released	B Plant Processed	B Plant Released	REDOX Processed	REDOX Released	PUREX Processed	PUREX Released	All Released
1944	Dec	2360	2140							2140
1945	Jan	1350	1220							1220
1945	Feb	2350	2130							2130
1945	Mar	2300	2080							2080
1945	Apr	19900	18000	11800	10700					28700
1945	May	38600	34900	43700	39500					74500
1945	Jun	24600	22200	26800	24200					46500
1945	Jul	25900	23400	26100	23600					47000
1945	Aug	42400	38400	37200	33700					72100
1945	Sep	42700	38700	55300	50000					88700
1945	Oct	49500	44800	52200	47300					92100
1945	Nov	18200	16500	23500	21300					37800
1945	Dec	21100	19100	47800	43300					62300
1946	Jan	2340	2120	10600	9630					11800
1946	Feb	2960	2680	5210	4720					7400
1946	Mar	2310	2090	6480	5860					7950
1946	Apr	5730	5180	7180	6500					11700
1946	May	4760	4310	9910	8970					13300
1946	Jun	172	156	4930	4460					4620
1946	Jul	966	874	5170	4680					5560
1946	Aug	93	84	9460	8560					8650
1946	Sep	523	473	7950	7200					7670
1946	Oct	485	439	4840	4380					4820
1946	Nov	2280	2060	3830	3460					5520
1946	Dec	2170	1960	6010	5440					7400
1947	Jan	1850	1670	4960	4490					6160
1947	Feb	2490	2260	1740	1580					3830
1947	Mar	2190	1980	4020	3640					5620
1947	Apr	2220	2010	3150	2850					4850
1947	May	1970	1780	2430	2200					3990
1947	Jun	862	780	965	873					1650
1947	Jul	1150	1040	1390	1260					2300
1947	Aug	512	464	873	790					1250
1947	Sep	530	480	805	729					1210
1947	Oct	339	307	202	183					490
1947	Nov	174	157	133	120					278
1947	Dec	194	176	113	102					278
1948	Jan	45	41	196	178					219
1948	Feb	114	103	196	177					280
1948	Mar	105	95	81	74					168
1948	Apr	180	162	65	59					221
1948	May	95	27	14	4					31
1948	Jun	67	19	85	24					43
1948	Jul	192	55	284	81					135

Year	Month	T Plant Processed	T Plant Released	B Plant Processed	B Plant Released	REDOX Processed	REDOX Released	PUREX Processed	PUREX Released	All Released
1948	Aug	286	81	223	63					145
1948	Sep	197	56	223	63					119
1948	Oct	279	79	320	91					170
1948	Nov	323	81	289	72					153
1948	Dec	327	82	299	75					156
1949	Jan	435	109	350	88					196
1949	Feb	363	91	48	12					103
1949	Mar	719	180	245	61					241
1949	Apr	255	64	264	66					130
1949	May	284	71	277	69					140
1949	Jun	148	37	168	42					79
1949	Jul	207	52	171	43					94
1949	Aug	273	68	72	18					86
1949	Sep	277	69	282	71					140
1949	Oct	257	64	311	78					142
1949	Nov	239	60	165	41					101
1949	Dec	28700	7180	255	64					7240
1950	Jan	183	46	184	46					92
1950	Feb	160	40	168	42					82
1950	Mar	240	60	240	60					120
1950	Apr	240	60	182	46					105
1950	May	259	65	240	60					125
1950	Jun	146	37	259	65					101
1950	Jul	552	138	411	103					241
1950	Aug	3350	839	2800	701					1540
1950	Sep	2480	620	2700	676					1300
1950	Oct	1480	369	1940	485					854
1950	Nov	961	240	1190	15					255
1950	Dec	2190	548	1620	20					568
1951	Jan	6520	65	1160	12					77
1951	Feb	4060	41	4630	46					87
1951	Mar	5470	109	11900	237					346
1951	Apr	25000	1250	22900	1140					2390
1951	May	40400	5330	33400	4410					9740
1951	Jun	39200	4890	13900	1730					6620
1951	Jul	20700	2490	13200	1580					4070
1951	Aug	41300	1400	32500	1100					2500
1951	Sep	27200	922	24900	844					1770
1951	Oct	31000	1050	41300	1400					2450
1951	Nov	30300	1030	47600	1610					2640
1951	Dec	27700	939	21600	732					1670
1952	Jan	51300	1740	34200	1160	1770	60			2960
1952	Feb	19500	661	30000	1020	11000	373			2050
1952	Mar	43600	1480	9410	319	21000	712			2510
1952	Apr	22600	766	1570	53	43400	1470			2290
1952	May	10100	342	533	18	34900	1180			1540
1952	Jun	198	7	895	30	16900	573			610
1952	Jul	4010	136			4750	161			297

Year	Month	T Plant Processed	T Plant Released	B Plant Processed	B Plant Released	REDOX Processed	REDOX Released	PUREX Processed	PUREX Released	All Released
1952	Aug	6350	215			11000	373			588
1952	Sep	131	4			9800	332			337
1952	Oct	142	5			3130	106			111
1952	Nov	1040	35			5830	198			233
1952	Dec	8240	279			1300	44			323
1953	Jan	102	3			6340	215			218
1953	Feb	655	22			994	34			56
1953	Mar	744	25			3320	113			138
1953	Apr	6320	214			6840	232			446
1953	May	3790	128			6730	228			357
1953	Jun	7290	247			6950	236			483
1953	Jul	11600	393			19400	658			1050
1953	Aug	3370	114			9210	312			426
1953	Sep	2700	92			6210	211			302
1953	Oct	2720	92			17800	603			696
1953	Nov	5200	176			541	18			195
1953	Dec	865	29			9990	339			368
1954	Jan	11000	373			4640	157			530
1954	Feb	1310	44			2280	77			122
1954	Mar	651	22			4540	154			176
1954	Apr	554	19			3310	112			131
1954	May	3520	119			5570	189			308
1954	Jun	1640	56			3730	126			182
1954	Jul	1610	55			656	22			77
1954	Aug	2120	72			821	28			100
1954	Sep	3430	116			2060	70			186
1954	Oct	7730	262			132	4			267
1954	Nov	1630	55			60	2			57
1954	Dec	2270	77			863	29			106
1955	Jan	1610	55			416	14			69
1955	Feb	2280	77			5320	180			258
1955	Mar	182	6			17000	576			582
1955	Apr	2750	93			51	2			95
1955	May	2360	80			0	0			80
1955	Jun	843	29			2310	78			107
1955	Jul	751	26			2040	69			95
1955	Aug	0	0			1580	54			54
1955	Sep	1570	53			4640	157			211
1955	Oct	1300	44			4230	143			187
1955	Nov	193	7			27	1			7
1955	Dec	22	1			2210	75			76
1956	Jan	1	0			470	16	15	0	16
1956	Feb					1310	44	4	0	44
1956	Mar					295	10	10	0	10
1956	Apr					78	3	2260	6	8
1956	May					1840	62	230	1	63
1956	Jun					1290	44	5530	14	58
1956	Jul					141	5	44	0	5

Year	Month	T Plant	T Plant	B Plant	B Plant	REDOX	REDOX	PUREX	PUREX	All
		Processed	Released	Processed	Released	Processed	Released	Processed	Released	Released
1956	Aug					99	3	219	1	4
1956	Sep					68	2	1250	3	5
1956	Oct					36	1	803	2	3
1956	Nov					203	7	2550	6	13
1956	Dec					1310	44	1560	4	48
1957	Jan					254	9	1220	3	12
1957	Feb					457	16	748	2	17
1957	Mar					182	6	714	2	8
1957	Apr					681	23	1490	4	27
1957	May					547	19	1210	3	22
1957	Jun					286	10	1360	3	13
1957	Jul					818	28	2400	6	34
1957	Aug					1130	38	2670	7	45
1957	Sep					1480	50	2120	5	56
1957	Oct					1740	59	5880	15	74
1957	Nov					2850	97	7420	19	115
1957	Dec					5610	190	9660	24	214
1958	Jan					1450	49	13500	34	83
1958	Feb					9240	313	33500	84	397
1958	Mar					5420	184	25400	64	247
1958	Apr					4300	146	19900	50	196
1958	May					8570	291	19900	50	340
1958	Jun					3210	109	1150	3	112
1958	Jul					2770	94	7190	18	112
1958	Aug					1900	64	3260	8	73
1958	Sep					1740	59	10800	27	86
1958	Oct					0	0	7600	19	19
1958	Nov					0	0	15000	38	38
1958	Dec					0	0	12400	31	31
1959	Jan					0	0	9830	25	25
1959	Feb					0	0	5040	13	13
1959	Mar					0	0	7620	19	19
1959	Apr					0	0	5400	14	14
1959	May					0	0	7690	19	19
1959	Jun					8	0	13500	34	34
1959	Jul					2	0	3870	10	10
1959	Aug					4	0	12800	32	32
1959	Sep					0	0	19200	48	48
1959	Oct					2	0	10200	26	26
1959	Nov					71	2	6840	17	20
1959	Dec					0	0	10900	27	27
1960	Jan					8	0	37800	95	95
1960	Feb					64	2	9990	25	27
1960	Mar					19	1	1400	4	4
1960	Apr					50	2	4090	10	12
1960	May					4	0	5070	13	13
1960	Jun					14	0	1240	3	4
1960	Jul					4	0	6620	17	17

Year	Month	T Plant	T Plant	B Plant	B Plant	REDOX	REDOX	PUREX	PUREX	All
		Processed	Released	Processed	Released	Processed	Released	Processed	Released	Released
1960	Aug					102	3	25500	64	67
1960	Sep					0	0	2090	5	5
1960	Oct					0	0	8	0	0
1960	Nov					0	0	5620	14	14
1960	Dec					0	0	14900	37	37
1961	Jan					0	0	4620	12	12
1961	Feb					0	0	5270	13	13
1961	Mar					14	0	4980	13	13
1961	Apr					1	0	1560	4	4
1961	May					0	0	3340	8	8
1961	Jun					0	0	4990	13	13
1961	Jul					15	0	2440	6	7
1961	Aug					54	2	5530	14	16
1961	Sep					59	2	3390	8	11
1961	Oct					104	4	3960	10	13
1961	Nov					390	13	2010	5	18
1961	Dec					5	0	80	0	0
1962	Jan					488	17	371	1	18
1962	Feb					300	10	130	0	11
1962	Mar					46	2	42	0	2
1962	Apr					0	0	22	0	0
1962	May					2	0	106	0	0
1962	Jun					5	0	167	0	1
1962	Jul					1	0	723	2	2
1962	Aug					2	0	380	1	1
1962	Sep					0	8	4	0	8
1962	Oct					0	0	222	1	1
1962	Nov					0	0	266	1	1
1962	Dec					0	0	2470	6	6
1963	Jan					0	0	0	0	0
1963	Feb					0	0	104	0	0
1963	Mar					0	0	500	1	1
1963	Apr					32	1	225	1	2
1963	May					4	0	456	1	1
1963	Jun					53	2	359	1	3
1963	Jul					0	0			0
1963	Aug					0	0	108	0	0
1963	Sep					0	0	209	72	72
1963	Oct					4	0	95	0	0
1963	Nov					0	0	70	0	0
1963	Dec					0	0	210	1	1
1964	Jan					0	0	159	0	0
1964	Feb					0	0	42	0	0
1964	Mar							322	1	1
1964	Apr					0	0	316	1	1
1964	May					0	0	624	2	2
1964	Jun					20	1	306	1	1
1964	Jul					0	0	206	1	1

Year	Month	T Plant	T Plant	B Plant	B Plant	REDOX	REDOX	PUREX	PUREX	All
		Processed	Released	Processed	Released	Processed	Released	Processed	Released	Released
1964	Aug					0	0	1110	3	3
1964	Sep					0	0	0	0	0
1964	Oct					0	0	1330	3	3
1964	Nov					0	0	969	2	2
1964	Dec					1	0	57	0	0
1965	Jan					1	0	52	0	0
1965	Feb					2	0	41	0	0
1965	Mar					8	0	86	0	1
1965	Apr					25	1	21	0	1
1965	May					109	4	250	1	4
1965	Jun					3	0	27	0	0
1965	Jul					28	1	27	0	1
1965	Aug					20	1	60	0	1
1965	Sep					4	0	29	0	0
1965	Oct					0	0	497	1	1
1965	Nov					1	0	40	0	0
1965	Dec					0	0	658	2	2
1966	Jan					2	0	1470	4	4
1966	Feb					0	0	7	0	0
1966	Mar					3	0	167	0	1
1966	Apr					0	0	793	2	2
1966	May					3	0			0
1966	Jun					239	8			8
1966	Jul					54	2			2
1966	Aug					7	0	0	0	0
1966	Sep					1	0	1	0	0
1966	Oct					0	0	167	0	0
1966	Nov					0	0	0	0	0
1966	Dec							0	0	0
1967	Jan							137	0	0
1967	Feb							69	0	0
1967	Mar							248	1	1
1967	Apr							0	0	0
1967	May							166	0	0
1967	Jun							0	0	0
1967	Jul							0	0	0
1967	Aug							10	0	0
1967	Sep							3	0	0
1967	Oct							0	0	0
1967	Nov							3	0	0
1967	Dec							0	0	0
1968	Jan							0	0	0
1968	Feb							0	0	0
1968	Mar							1	0	0
1968	Apr							4	0	0
1968	May							1	0	0
1968	Jun							1	0	0
1968	Jul							0	0	0

Year	Month	T Plant	T Plant	B Plant	B Plant	REDOX	REDOX	PUREX	PUREX	All
		Processed	Released	Processed	Released	Processed	Released	Processed	Released	Released
1968	Aug							2	0	0
1968	Sep							0	0	0
1968	Oct							2	0	0
1968	Nov							0	0	0
1968	Dec							0	0	0
1969	Jan							0	0	0
1969	Feb							0	0	0
1969	Mar							0	0	0
1969	Apr							0	0	0
1969	May							0	0	0
1969	Jun							0	0	0
1969	Jul							0	0	0
1969	Aug							0	0	0
1969	Sep							0	0	0
1969	Oct							0	0	0
1969	Nov							0	0	0
1969	Dec							0	0	0
1970	Jan							1	0	0
1970	Feb							0	0	0
1970	Mar							0	0	0
1970	Apr							0	0	0
1970	May							0	0	0
1970	Jun									
1970	Jul									
1970	Aug									
1970	Sep									
1970	Oct									
1970	Nov									
1970	Dec									
1971	Jan									
1971	Feb									
1971	Mar							0	0	0
1971	Apr							0	0	0
1971	May							0	0	0
1971	Jun							0	0	0
1971	Jul							0	0	0
1971	Aug							0	0	0
1971	Sep							0	0	0
1971	Oct									
1971	Nov									
1971	Dec									
1972	Jan									
1972	Feb							0	0	0
1972	Mar							0	0	0
1972	Apr									
1972	May									
1972	Jun									
1972	Jul									

Year	Month	T Plant Processed	T Plant Released	B Plant Processed	B Plant Released	REDOX Processed	REDOX Released	PUREX Processed	PUREX Released	All Released
1972	Aug									
1972	Sep									
1972	Oct									
1972	Nov									
1972	Dec									
Total		939882	339548	789167	407650	391835	13288	508075	1343	762015

aluminum- versus zirconium-clad fuels and to introduce other non-Hanford-origin fuel sources), but none to the time period in question.

Calculation of releases requires the conversion of tons processed through each facility, the average holdup (cooling time) of the fuel, and the power level of the reactor(s) that produced it, into the quantity of iodine-131 in the fuel at the time of dissolving. Heeb (1994) provides all of these required pieces of information on a monthly average basis. Warren (1961) does not provide the quantities of fuel processed that resulted in the reported releases.

Probably the most important point, corroborated by Heeb (1994), Gydesen (1992a,b), Roberts et al. (1992), Jenkins and Foster (1978), and others, is that no daily information exists for this time period. (See specifically Gydesen (1992b, page 3.8, paragraph 3) – the daily records are reported to have been destroyed.) *The Warren report appears to be an exception to this statement*, except that the information is partial and therefore cannot be corroborated with other sources.

Warren's information was used by Heeb only to estimate the fractional release of radioiodine from the facilities. Not enough data are provided on source and quantity of fuel to allow it to be used in the modeling; therefore it was not a direct input to the release estimates made using the release fraction. However, the releases reported in Warren are parallel to those presented in other sources, particularly the monthly reports issued by the staff of the Hanford Radiation Protection Operation. It is apparent from the raw data of Warren and the compiled data of these reports that both used the same sources. The values derived from Warren's figures and those in the monthly reports for 1959 and 1960 are essentially identical (see Table 3-2). If the releases and release fractions estimated based on Warren's work are assumed to be valid, then their basis also supports the idea that, at least during this time period, the monitoring results are also valid.

The daily information on burnup in processed fuel in Warren (1961) is compatible with the monthly averages given in Heeb (1994), if it is assumed that the individual daily listings (and not the longer clusters) correspond to 1 to 3 dissolver batches per day of about 1 ton each.

Radioactive decay is not a linear process; it is exponential. Therefore, the average holdup is not the best descriptor for evaluating radioactive decay. One ton of fuel cooled for 100 days, mixed with 99 tons of fuel cooled for 201 days, provides 100 tons cooled an average of 200 days. However, the release of radioiodine from the 1 ton of 100-day material will be about 60 times

greater than the combined release of the other 99 tons. This general problem appears to be the basis of the discrepancy when the Warren values for 1959-1960 are compared to Heeb's; Warren had access to detailed daily information (which no longer exists) about the fuel, and only reported the releases from the short-cooled material. The age of this short-cooled fuel was sufficiently less than the average to make the estimates of total release from all of the fuel appear to be in error.

Heeb (1994) used a mass-balance model to account for all the fuel from all the reactors through all the processing plants. To a large extent, the model assumes that the first fuel to be irradiated is the first fuel to be processed, since the daily records are not available. Due to the lack of necessary information, recreating the fine structure within a month, such as fuel processing "out of order", could not be done by HEDR. (Some detail has been added for the period after 1966 by Kupfer et al. 1999). Because the focus of HEDR was the early period (1944-1951) at the direction of the HEDR Technical Steering Panel, extended to 1957 to support the Fred Hutchinson Cancer Research Center's Hanford Thyroid Disease Study, and releases are documented to have been much lower in the 1958-1972 period, refinements for the later years were not considered to be warranted.

Only the total emissions from all separations plants are significant to doses beyond the Hanford site boundary. Table 3-2 lists various reported total releases for the time period in question. Releases are presented from HEDR, Warren, and Hanford Site monthly and annual reports (identified by HW- number). The values quoted here for Heeb (1994) are those revised using the mean release factor, rather than the median as originally reported. Figures 3-1 and 3-2 illustrate the release estimates of Heeb compared with the releases reported by the Hanford environmental monitoring group. Figure 3-1 is the data plotted linearly, and Figure 3-2 is the same data plotted logarithmically.

A close reading of Heeb, Table A.3, shows that beginning in November 1958, REDOX began processing primarily long-cooled, enriched-uranium fuels. Only smaller batches of natural uranium fuels were occasionally processed. Some of these smaller batches (but not all) correspond to the times that Warren reports non-negligible iodine releases. If these batches were to have shorter cooling times, it is not likely that they would cause the overall average cooling time to be greatly reduced.

The largest discrepancy between Heeb and Warren occurs in the period of September to October 1960. Warren's detailed dissolver-charging records (reproduced here as Figure 3-3)

Table 3-2. Monthly Releases of ^{131}I to the Atmosphere as Reported by Various Sources

	<u>Updated PNWD-2222 HEDR</u>			<u>Warren</u>			<u>Results from historical reports</u> (As 30x daily or 4x weekly reported)			<u>Anderson</u> (1974)	
	REDOX	PUREX	Totals	REDOX	PUREX	Totals	REDOX	PUREX	Totals	HW Report	Ci/year
	Ci/month	Ci/month	Ci/month	Ci/month	Ci/month	Ci/Month	Ci/month	Ci/month	Ci/month		
Jan-59	0.01	24.60	24.60	0.1	19.0	19.1	0.1	14.0	14.0	HW-59092	-
Feb-59	0.00	12.60	12.60	0.1	15.1	15.2	0.1	20.0	20.0	HW-59454	-
Mar-59	0.00	19.10	19.10	0.1	12.2	12.3	0.1	13.0	13.0	HW-59918	-
Apr-59	0.00	13.50	13.50	8.6	24.6	33.2	4.8	24.4	29.2	HW-60413	-
May-59	0.01	19.20	19.20	9.5	21.5	31.0			35.2	HW-60642	-
Jun-59	0.27	33.80	34.00	2.9	25.7	28.6			24.8	HW-61441	-
Jul-59	0.08	9.68	9.75	6.2	9.8	16.0			14.3	HW-61441	-
Aug-59	0.12	32.00	32.10	1.7	27.4	29.1			21.6	HW-61826	-
Sep-59	0.01	48.00	48.00	6.6	21.3	27.9	7.2	11.6	18.8	HW-62277	-
Oct-59	0.08	25.50	25.60	4.6	13.4	18.0	4.4	18.4	22.8	HW-62699	-
Nov-59	2.41	17.10	19.50	13.6	16.8	30.4	12.4	16.8	29.2	HW-63179	-
Dec-59	0.00	27.30	27.30	12.8	23.5	36.3	11.6	20.8	32.4	HW-63557	-
Annual totals			285.25			297.2			275.3		289
				Annual totals		296.0					
				HW-64371							
Jan-60	0.28	94.50	94.80	1.4	23.5	24.9	1.5	34.0	35.0	HW-63920	-
Feb-60	2.18	25.00	27.20	0.7	20.1	20.8	0.7	18.0	19.0	HW-64253	-
Mar-60	0.64	3.50	4.14	6.1	7.1	13.2	0.6	5.5	6.1	HW-64757	-
Apr-60	1.71	10.20	11.90	5.5	15.0	20.5	5.8	15.0	21.0	HW-65154	-
May-60	0.14	12.70	12.80	1.3	15.5	16.8	2.9	16.0	19.0	HW-65613	-
Jun-60	0.48	3.10	3.58	4.0	6.7	10.7	5.3	10.0	15.0	HW-66009	-
Jul-60	0.14	16.60	16.70	60.4	22.4	82.8	61.0	21.0	82.0	HW-66420	-
Aug-60	3.46	63.80	67.20	9.2	43.2	52.4	8.0	44.0	51.0	HW-66778	-
Sep-60	0.00	5.23	5.23	9.3	43.8	53.1	9.4	44.0	53.0	HW-67060	-
Oct-60	0.00	0.02	0.02	0.3	6.2	6.5	0.3	4.9	5.2	HW-67439	-
Nov-60	0.00	14.10	14.10	0.1	23.3	23.4	0.1	24.0	24.0	HW-67752	-
Dec-60	0.00	37.30	37.30	0.0	39.0	39.0	0.0	38.0	38.0	HW-68127	-
Annual totals			294.97			364.2			368.3		351
				Annual totals							

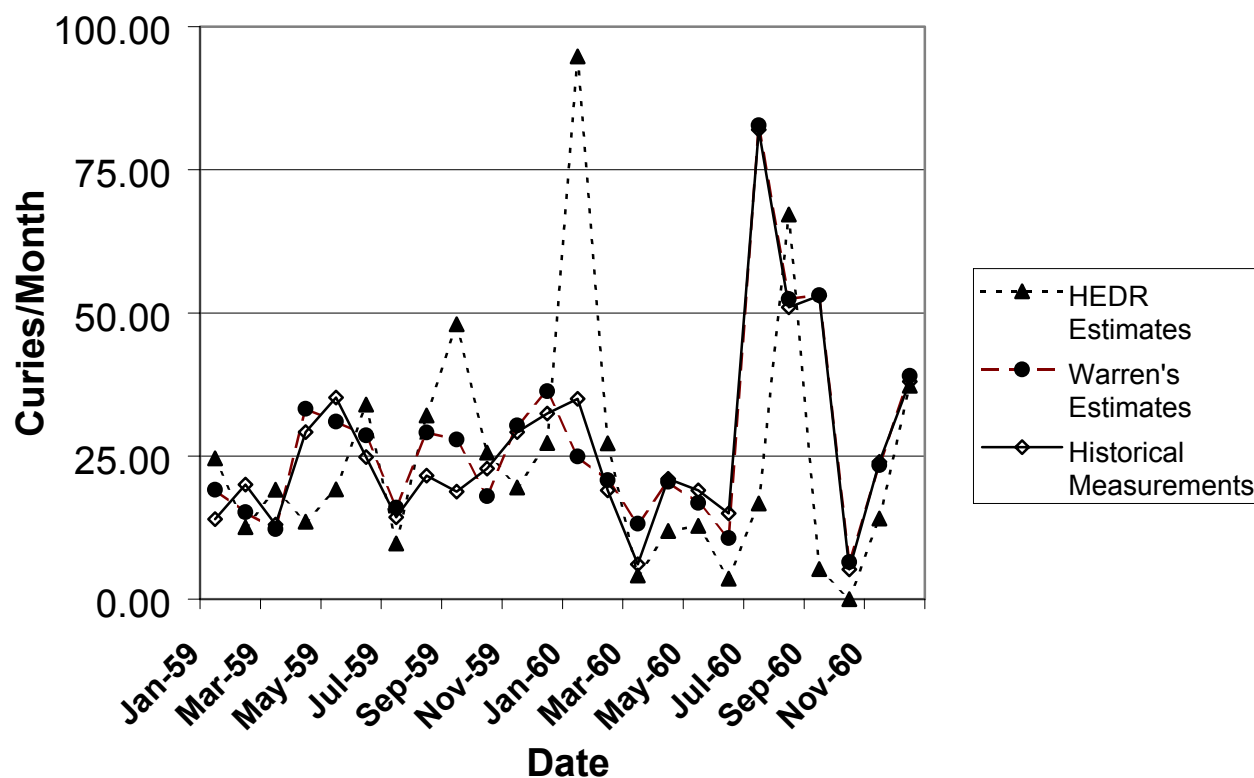


Figure 3-1. Comparison of releases reported by Heeb, Warren, and contemporaneous Hanford authors (linear scale).

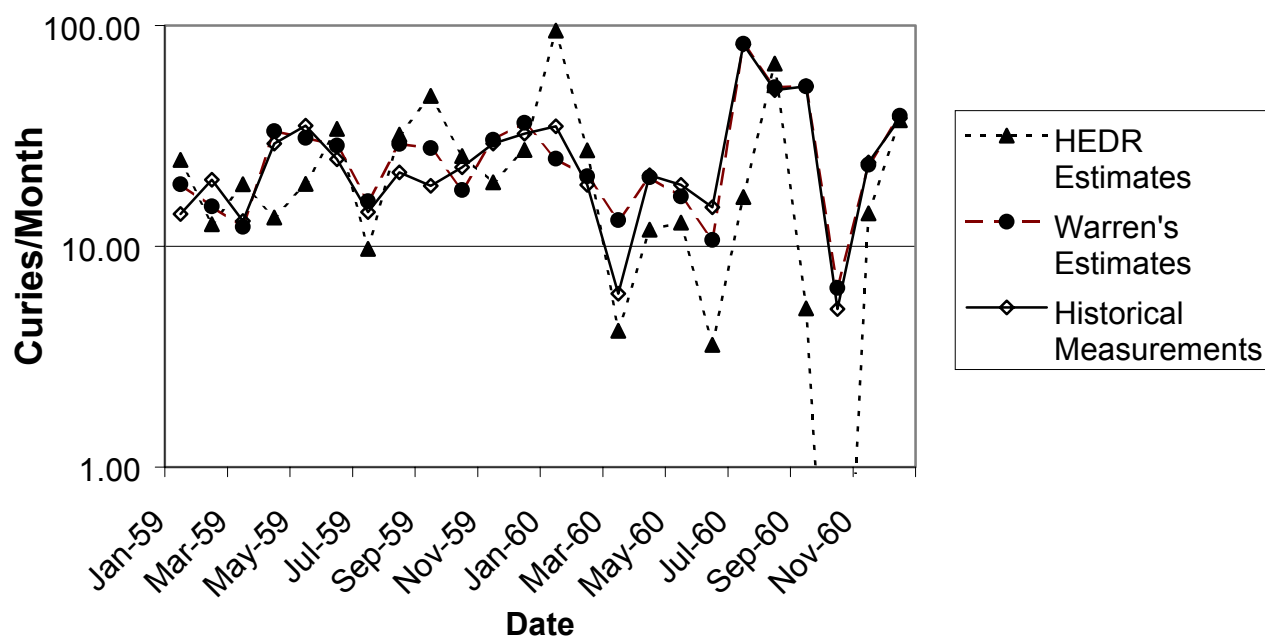


Figure 3-2. Comparison of releases reported by Heeb, Warren, and contemporaneous Hanford authors (logarithmic scale).

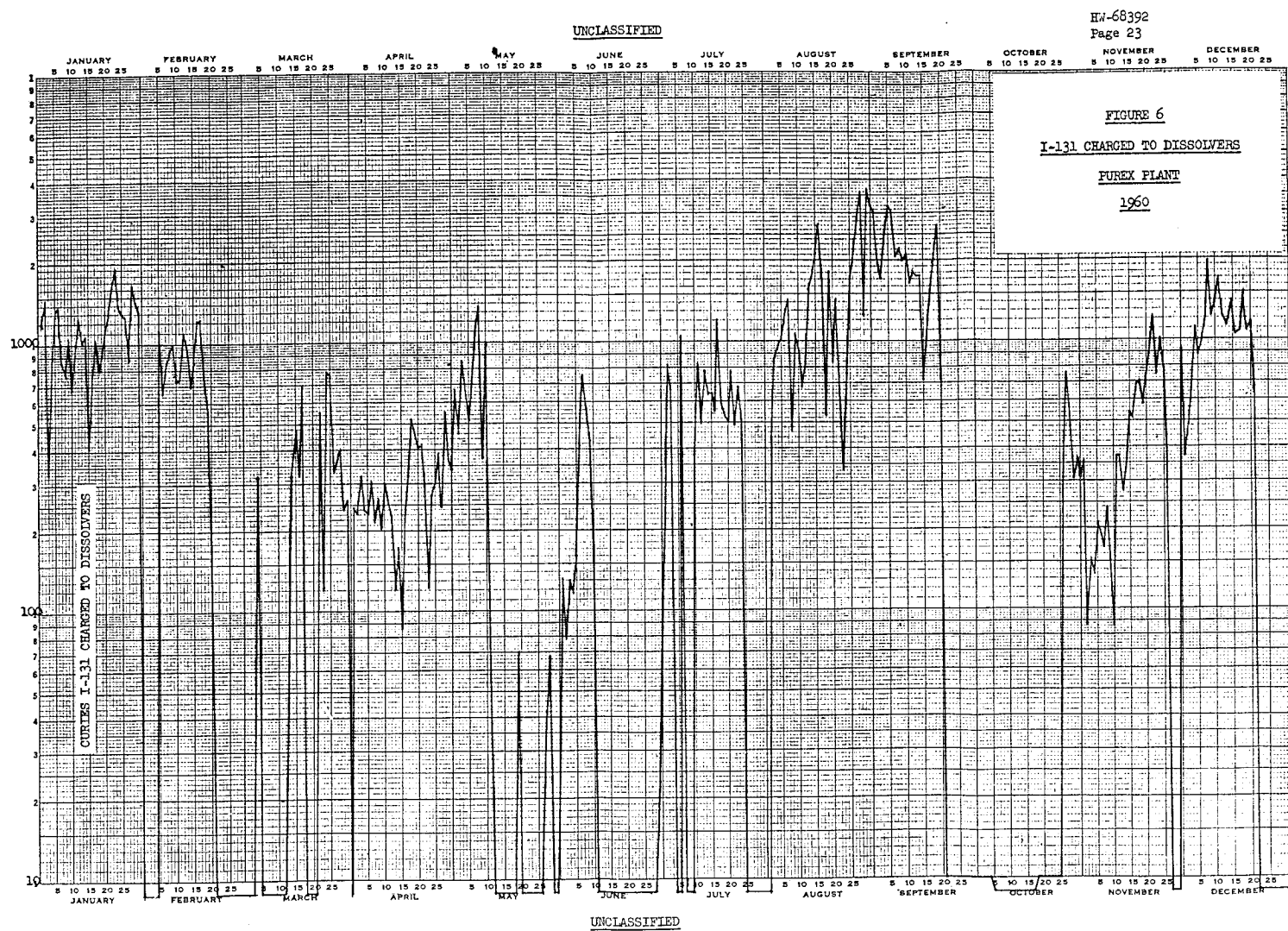


Figure 3-3. Dissolver Charging Record for PUREX 1960 (Warren 1961)

indicate that a period of considerable dissolving activity in August and September was followed by a period of no operations from about September 20 through October 26, 1960. If Heeb's accounting model were off by as little as 5 days during this period, the release ratios for September and October of 1960 could be resolved. The exact dates of releases are difficult to track; the Hanford monthly monitoring reports are not for the exact days of the reported month. The reports generally lag the actual month by about a week (i.e., the May 1959 monthly report [HW-60505] is actually for April 26 to May 24, 1959). Even this level of detail is available for very few months.

Note that Heeb describes an uncertainty factor for I-131 releases of 4.8. Applied to his calculated total values, this effectively bounds the releases reported in other contemporaneous reports.

A final method of checking the reasonableness of both Heeb's and Warren's total release estimates is to compare environmental concentrations predicted using them with the actual measurements made in the environment in 1959 and 1960 (Junkins et al. 1960; Foster and Nelson 1961). Table 3-3 illustrates the results of using an atmospheric dispersion factor estimated with the results of the HEDR atmospheric transport model RATCHET (Ramsdell et al. 1994) in conjunction with the Heeb and Warren reported total iodine releases. After the dissipation of bomb-test fallout in early 1959, it is apparent that the HEDR model would overpredict concentrations of I-131 in North Richland (HEDR node 469) by about a factor of 2 for either Heeb's or Warren's estimates of release. For neither source is the predicted environmental concentration dramatically different from the available historical evidence.

The resources are not available to completely recheck Heeb's model of radioiodine generation, throughput, and release. However, the overall HEDR estimates of I-131 release to the environment are consistent with a number of reports contemporaneous to Warren's. An increase in the variability of the releases based on monthly average cooling times rather than daily information is apparent. While the plant-by-plant releases (REDOX and PUREX) show variability, the total releases, particularly when annualized, are very similar to existing historical documentation. The apparent lack of correspondence between Warren's (1961) reported releases and the estimates of Heeb (1994) should not result in significant changes to the ultimate dose estimates calculated from the Heeb source n. Even with the apparent discrepancies between Warren and Heeb, nothing could be done, at this time, to improve the estimates of Heeb (1994).

Table 3-3. Atmospheric Concentrations of ^{131}I in North Richland Estimated Using Heeb's and Warren's Data Compared with Measurements

YearMonth	RATCHET dispersion (s/m3)	PNWD2222 Totals Ci/month	Warren Total Ci/month	Heeb Predicted (pCi/m3)	Warren Predicted (pCi/m3)	N.Richland Measured (pCi/m3)	Heeb P/O	Warren P/O	Comments
1959Jan	1.27E-08	24.63	19.13	0.117	0.091	0.332	0.352	0.273	1959 Air Data from HW-64371 High fallout Medium fallout Low fallout Fallout free below
1959Feb	1.26E-08	12.63	15.20	0.066	0.079	0.152	0.431	0.519	
1959Mar	1E-08	19.00	12.26	0.071	0.046	0.059	1.203	0.776	
1959Apr	6.56E-09	13.50	33.24	0.034	0.084	0.064	0.534	1.314	
1959May	6.68E-09	19.26	31.01	0.048	0.077	0.031	1.549	2.494	
1959Jun	3.36E-09	34.02	28.64	0.044	0.037	0.015	2.937	2.473	
1959Jul	4.2E-09	9.75	16.00	0.015	0.025	0.074	0.206	0.339	
1959Aug	5.85E-09	32.00	29.11	0.070	0.064	0.042	1.665	1.514	
1959Sep	7.46E-09	48.14	27.90	0.138	0.080	0.028	4.945	2.866	
1959Oct	8.39E-09	25.46	18.02	0.080	0.056	0.055	1.449	1.026	
1959Nov	9.64E-09	19.54	30.35	0.073	0.113	0.078	0.931	1.447	
1959Dec	1.28E-08	27.25	36.32	0.130	0.173	0.059	1.350	1.253	
Annual total 1959		285.17	297.18		Average		1.463	1.358	1960 Air Data from HW-68435
1960Jan	1.27E-08	94.78	24.95	0.449	0.118	0.139	3.231	0.850	
1960Feb	1.26E-08	27.18	20.79	0.141	0.108	0.034	4.150	3.174	
1960Mar	1E-08	4.14	13.17	0.015	0.049	0.021	0.737	2.341	
1960Apr	6.56E-09	11.93	20.53	0.030	0.052	0.093	0.324	0.558	
1960May	6.68E-09	12.76	16.80	0.032	0.042	0.011	2.894	3.809	
1960Jun	3.36E-09	3.57	10.70	0.005	0.014	0.016	0.289	0.866	
1960Jul	4.2E-09	16.64	82.77	0.026	0.130	0.015	1.738	8.642	
1960Aug	5.85E-09	67.34	52.44	0.147	0.115	0.027	5.450	4.244	
1960Sep	7.46E-09	5.21	53.13	0.015	0.153	0.051	0.294	2.996	
1960Oct	8.39E-09	0.02	6.47	0.000	0.020	0.029	0.002	0.699	
1960Nov	9.64E-09	14.00	23.41	0.052	0.087	0.011	4.733	7.914	
1960Dec	1.28E-08	37.25	39.03	0.178	0.186	0.023	7.724	8.093	
Annual total 1960		294.84	364.19		Average		2.630	3.682	

Daily records for the periods of interest simply do not exist. Fine-tuning the Heeb estimates for 1959 and 1960 would not in any way alter or improve the estimates for 1944-1957. Furthermore, Heeb's total releases are within 15% of Warren's for the years 1959 and 1960 and the Warren estimates are well within uncertainty estimates of Heeb.

3.3 Releases throughout the 1950s and 1960s

Similar comparisons to monitored releases can be made for other years beyond 1959 and 1960. Atmospheric emissions were not continuously monitored during the early years of Hanford Site operation. Primitive equipment was installed during canyon building construction, but it was not routinely used (Patterson 1948). In addition, actual monitoring of the emissions of ^{131}I was difficult and the accuracy claimed generally ranged from a factor of 2 to 3 up to an order of magnitude. The techniques and equipment improved with time, so that by the period evaluated by Warren (1961), the accuracy should have been less than a factor of 2. It should have remained this good throughout the remainder of the operations. Routine reporting of the emissions from the T Plant stack in the Hanford Operations monthly reports begins in about March of 1951 (HW-20671). Similar routine reporting from the 200-East Area B Plant stack begins in September 1951, where in comparing T Plant and B Plant releases it is noted that "Similar monitoring facilities were established at the 200 East Area during the month" (HW-22304).

Figure 3-4 illustrates the total releases reported by month in the Hanford Health Instruments Section (later Radiological Sciences Department, Radiation Protection Operation, or Regional Monitoring Activities) sections of the Hanford Laboratories monthly reports. The full set of these reports is available through the DOE Reading Room at the Consolidated Information Center (Washington State University Tri-Cities Library). They are compared with the HEDR estimates. The values quoted here for Heeb (1994) are those revised using the mean release factor, rather than the median as originally reported. Several interesting things can be observed in Figure 3-4. First, although the question was raised about the *low* values in Heeb for REDOX in 1959 and 1960, for the year 1958 the Heeb monthly REDOX values are actually *larger* than those reported by other authors. Note the relatively high values for PUREX reported in the monthly reports for November 1958 – this is described as resulting when "...several buckets of 20 to 40 day metal were inadvertently charged and dissolved." This is the sort of thing that is not caught by Heeb's mass balance model.

Investigation of the figure illustrates that Heeb's results during the period 1959-1960 closely match the monitored data – better than any other time period. Heeb's estimates are somewhat higher in the early 1950s than the reported values. This is reasonable, because the monitoring data were not considered to be particularly accurate before and during this period. After about 1960, the releases are quite small, and even large percentage differences in release estimate are small in terms of absolute quantity.

Just as the 1959 – 1960 concentrations of ^{131}I predicted in air can be compared to the monitoring data, so can those for later time periods. Such a comparison for the period 1959-1969 is presented in Figure 3-5. Just as the monitoring data indicate, the Warren and Heeb data provide predictions of air concentration that are very similar to the measurements in the late 1950s and early 1960s, but Heeb's estimates deviate after about 1962. After this time, the releases are very low (generally less than one curie/month), and Heeb's estimates using the fuel model are about

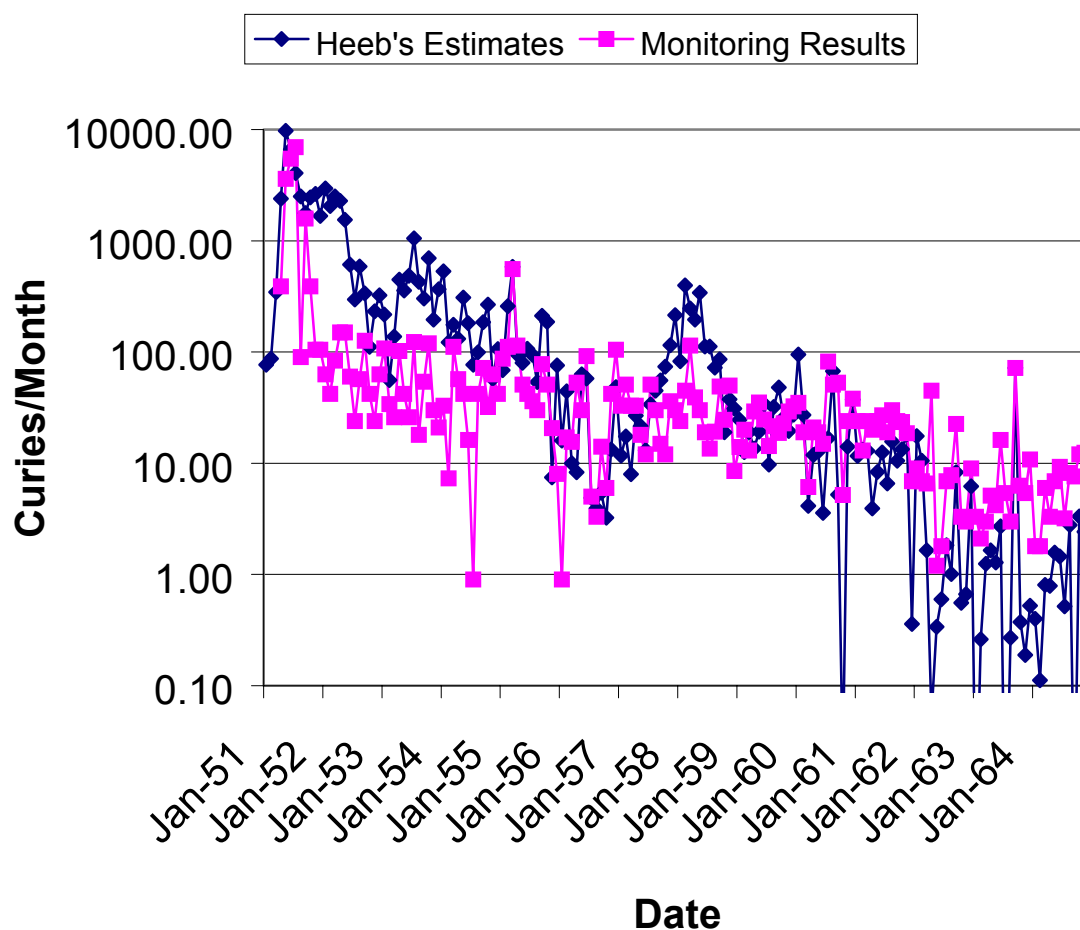


Figure 3-4. Comparison of HEDR Source Term to Monitoring Data 1951-1964.

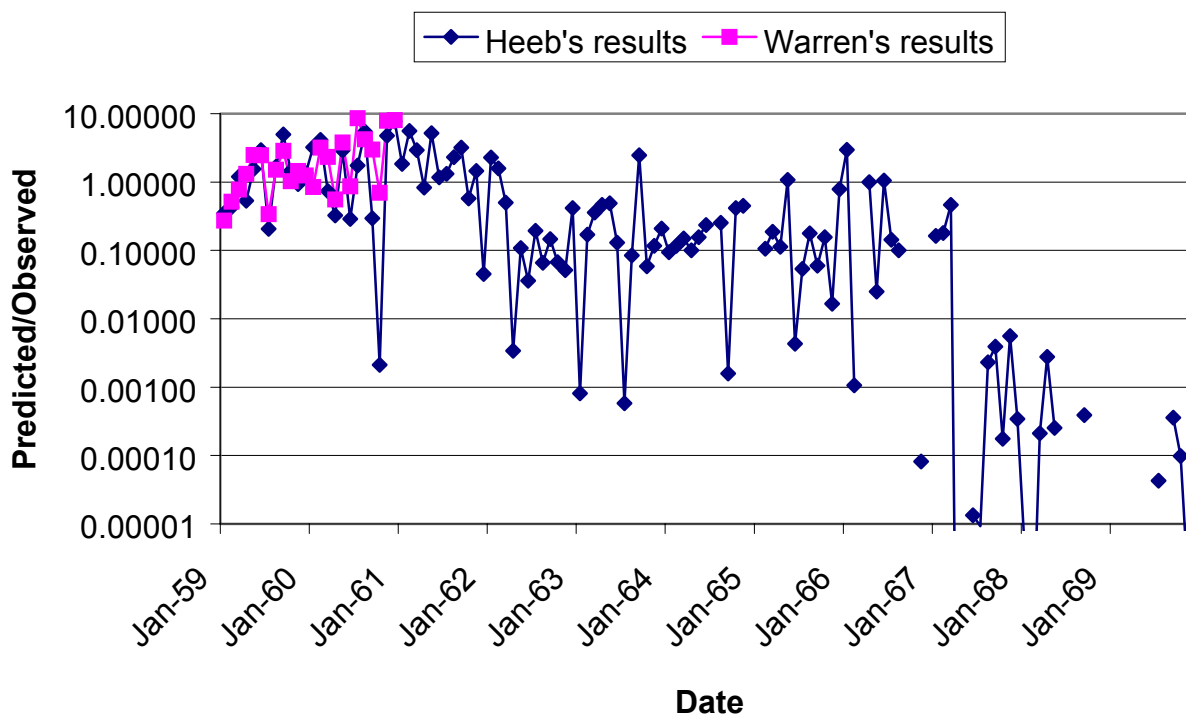


Figure 3-5. Comparison of concentrations of ^{131}I in air in North Richland predicted from release estimates to those measured, 1959 – 1970.

one-third to one-tenth what is indicated from the air measurements. The correspondence is even worse after about 1967 – but after this time, the releases are all small fractions of a curie per month, and the atmospheric monitoring results are at or below the limits of detection.

During the final decade of dissolver operations, the operators had the routine release of iodine relatively well under control. It is likely that after about 1962, the releases were dominated by unique events and abnormal operations. Therefore, Heeb's model will only reliably report a fraction of the total release after that time. This is a likely interpretation of the latter portion of the curves in Figure 3-5. What this implies is that *no* model is likely to succeed in simulating the releases in the late 1960s – they are best estimated using the stack monitoring data, with some minor adjustment to account for the inaccuracies of those systems. However, the total release estimated by Heeb after 1962 until the cessation of fuel processing in 1972 is less than 150 curies in total – less in 10 years than in any one month in 1945 through mid-1948.

3.4 Propagation of source term uncertainty

The National Academy of Sciences (NAS 1999) review of the HEDR dosimetric methods presents several assertions of underestimation of release based on an analysis by Hoffman et al (1999). One of the assertions is that “the HEDR project did not propagate the source-term uncertainties into air concentrations, ground deposition, and doses.”

The HEDR project team developed the RATCHET (Ramsdell et al. 1994) and DESCARTES (Nichols et al. 1994) computer codes to evaluate the environmental concentrations of ^{131}I from the source terms developed by Heeb (Heeb 1993, 1994). The source terms from the time period of greatest interest were developed for the T and B Plants on the basis of detailed information, and were presented hourly. The uncertainties in the releases were developed using Monte Carlo methods. Hourly meteorological data were used to estimate the atmospheric dispersion and deposition; uncertainties in the dispersion and deposition were addressed through minor variabilities in the atmospheric data, but the primary source of uncertainty in the predicted concentrations was actually the timing of the releases (generally within a few dozen hours).

However, for the time period beginning in 1950, the detailed information that allowed hourly source term reconstruction was not available. In addition, the hourly meteorological data for the Hanford Meteorological Station was also not found for the period beginning in 1950 through 1951. Therefore, two approximations had to be made, one for the source and one for the dispersion. These are described in some detail in Shipler and Napier (1994).

For the source terms, monthly estimates were developed (Heeb 1994). These were based on more general records of fuel burnup, throughput, and cooling. The batch-by-batch details that allowed the hourly estimation were not available. Thus, it was not possible to calculate the most important input in terms of dispersion and deposition – the timing of the release with respect to the wind direction.

Because neither the source term nor the meteorological data supported the hourly dispersion information from 1950 through 1951, the HEDR team decided to use surrogate information. The detailed modeling of the period December 1944 through December 1949 had provided series of 100 realizations of air concentration and deposition by day for each month. The realizations for the year 1945 were excluded, because the release histories were quite erratic at the beginning of the operation. Thus, there was a minimum of 400 realizations available for each

month. It is important to realize that a single realization includes the complete daily history for the entire month. Each of these realizations includes information on release rates, wind speeds and directions, and precipitation for an entire month. When the numerical values of air concentration and deposition rate in these realizations are divided by the appropriate monthly release rate, the result is an effective normalized dispersion factor for the month. This set of normalized dispersion factors inherently includes all uncertainties in release timing, wind speed and direction, precipitation, and plume depletion. A randomly selected set of 100 of these realizations for each month was used in the calculations for the years after 1949.

The monthly realizations from 1946 through 1949 were divided by the mean of the release rate for those months. Therefore, the mean monthly releases reported in Heeb could be used directly as inputs for the later years. Hoffman's observation is correct that the uncertainties directly associated with the later years' releases could not be directly input using this system. It was not possible to deconvolute the uncertainties in 1946 through 1949 source terms from the normalized dispersion factors. Although the uncertainties in the later years monthly releases are higher than the earlier ones (a 95% confidence level factor of 4.8 [Heeb 1994 page 4.17] versus an earlier coefficient of variation of only about 10%), this was accepted by the HEDR team. The uncertainties in the dispersion factor include the smaller coefficient of variation. The uncertainties in dispersion added by the lack of knowledge of the timing of the releases have a much larger effect than the uncertainties in the release amount, and the omission of the source term uncertainty is negligible.

The HEDR intermediate data file that contains the air concentrations and depositions input to the DESCARTES code was queried. Figure 3-6 illustrates the distribution in daily estimated concentration of ^{131}I in air in Pasco and Kennewick, Washington (a nearby node) for 1948. This set of realizations uses the full suite of information available on release rates, release times, hourly meteorology, and their associated uncertainty. Figure 3-7 illustrates the distribution in daily estimated concentrations of ^{131}I in air in Pasco and Kennewick for 1954. This set of realizations uses the mean release from Heeb (1994), and the surrogate release rates, release times, and hourly meteorology. The years 1948 and 1954 were selected for this comparison because they have releases of similar magnitude. Notice that the estimated air concentrations on any particular day span many orders of magnitude. In this figure, values less than 10^{-16} have been suppressed - which include numerous realizations of zero.

The air concentrations illustrated in Figure 3-7 have an unusual distribution for any day, with results spanning over 6 orders of magnitude. The distributions estimated using the surrogate data are similar in magnitude to those calculated using detailed data, however, there are some differences. The surrogate data have fewer zero days; the wind blows towards the location in some realizations and away from it in others. Some days may have multi-modal distributions, see for instance Figure 3-8, which compares the distributions for Day 70 (March 10 or 11, depending on leap years) of years 1948, 1951, and 1954. Notice that the detailed 1948 data indicates about a 40 percent probability of zero air concentration on this day. Notice, too, that the 1951 and 1954 results are similar to each other, differing mostly in magnitude, because both were drawn from the same set of surrogate data. Because this surrogate data includes results from 1948 as well as other years with lower probabilities of zero concentration, there is a lower chance of zero. The 1951 and 1954 results appear to have been selected from at least a high-dispersion and a low-dispersion set of possibilities, as well as a chance of zero.

Removing the small uncertainty of the 1940s source term and adding the uncertainty of the later years' source term, a lognormal distribution with a geometric standard deviation of about 2.2 (Heeb 1994), would have a very small impact on these distributions. Such an addition would be centered on the release rates used and would not shift the mean of the resulting distributions, nor noticeably effect the extremes of the distributions, as can be demonstrated with simple examples in the Excel spreadsheet add-in Crystal Ball™.

We acknowledge that the HEDR team did not do a good job of explaining and characterizing the uncertainty distribution resulting from the surrogation process used. However, it is plain from the HEDR intermediate data that this process was a success. The overall uncertainty in the daily ^{131}I environmental concentrations is quite large and encompasses any omitted uncertainty in the stack releases. We continue to believe that there is no more appropriate method available for the 1950s.

Figure 3-6. Distributions of daily estimated air concentrations at HEDR Node 443 (Pasco and Kennewick, Washington) for the year 1948.

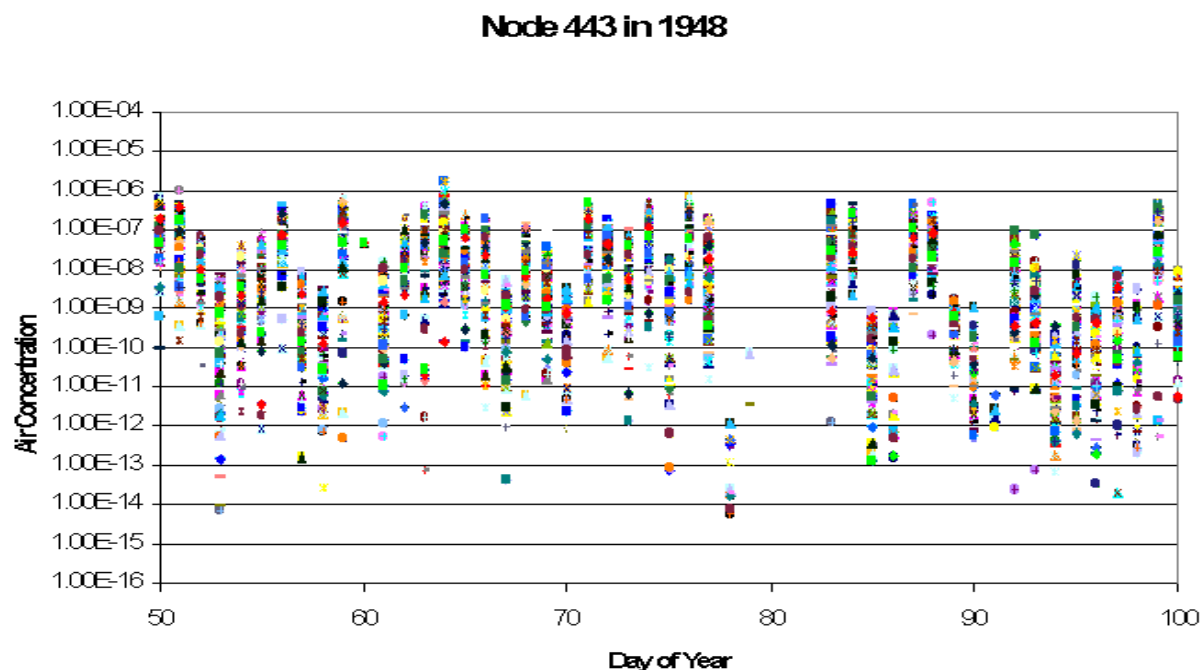


Figure 3-7. Distributions of daily estimated air concentrations at HEDR Node 443 (Pasco and Kennewick, Washington) for the year 1954.

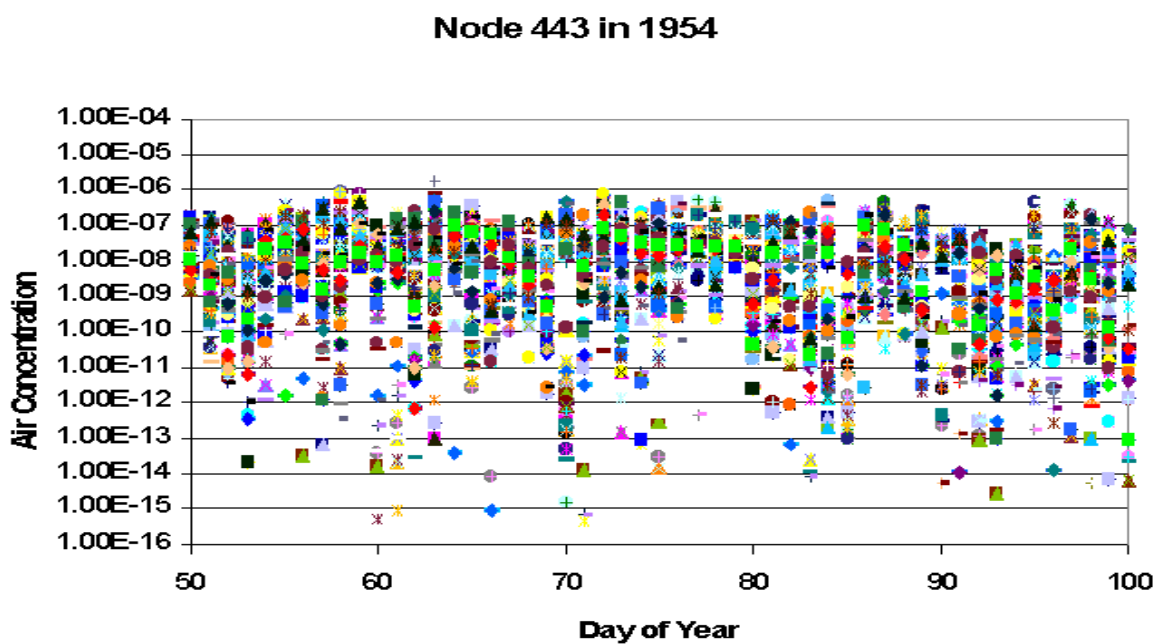
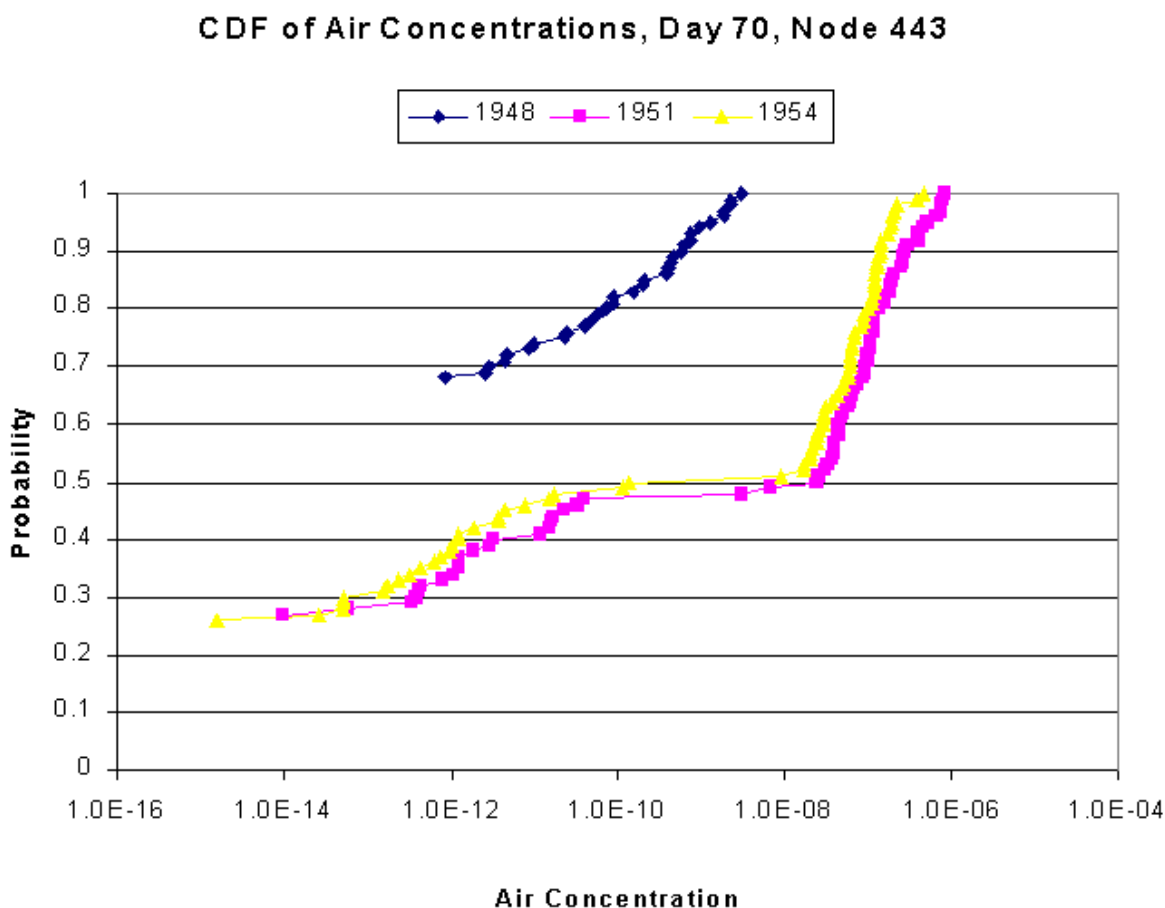


Figure 3-8. Cumulative distribution functions of estimated air concentration for HEDR Node 443 (Pasco and Kennewick) for Day 70 of three separate years.



3.5 Summary of Source Term Model Assessment

The HEDR source term was developed using a data-intensive, but relatively simple, model. As has been noted, “All models are wrong; some models are useful” (Box 1979). It is easy to disparage models piece by piece when they are assessed in a vacuum of information. However, the HEDR model is based on an enormous amount of well-defined data. In addition, it was not developed in a vacuum, either – many of the parameter selections were made with knowledge of the overall system in such a way as to reproduce that system. Individual components of the model were extensively reviewed internally, by the Technical Steering Panel, and externally.

Statistically, representing the releases using either the mean or the median of the distribution is valid; however, because the results were described as being means while actually being medians, they were used as means. The resulting initial calculations of intake for the effected time periods were therefore in error. This problem has been corrected, and all subsequent calculations use the correct inputs.

There is a large database of corroborating information. This includes historical stack monitoring and environmental samples. The collective assembly of information indicates that the HEDR model is robust, reasonably accurate, and well-suited for its task. According to some of this historical information, the HEDR model may break down in the mid- to late 1960s. However, the releases in this last period are very small.

We acknowledge that the HEDR team did not do a good job of explaining and characterizing the uncertainty distribution of the atmospheric concentration and deposition data resulting from the release-and-dispersion surrogation process used. However, it is plain from the HEDR intermediate data that this process was a success. The overall uncertainty in the daily ¹³¹I environmental concentrations is quite large and encompasses any omitted uncertainty in the stack releases.

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4. Farm Animal Feeding Regimes Used in HEDR

Output from the soil and vegetation submodel of the HEDR code DESCARTES provides the concentration of radionuclides in environmental media (soil and vegetation) at each grid node. Dairy cows and other animals are assumed to have eaten several types of diets, with a diet defined as a sum of fractional feed-type intakes. The amount of each feed type eaten by the various animals may be graphically represented as in Figure 4-1 (Beck et al. 1992). Four feeding regimes for dairy cattle were initially anticipated to be provided by the Demography, Food Consumption, and Agriculture Task: two diets related to irrigated farms and two to non-irrigated farms (Beck et al. 1992). However, the Technical Steering Panel became involved late in the project and required more feeding regimes; four for backyard (family or small farm) cows and four for commercial dairies. Milk provided by any combination of these types of cows was allowed to be combined into creamery- and grocery-supplied milk.

The use of fractional intakes of various types of feed introduces a minor complication within the animal feeding model. Each of these fractions has its own distribution. The results of the selection process of the fractions must, however, sum to 1.0, which implies a correlation structure. The means of handling this potential correlation is a simple adjustment rule because there is no strong information on possible correlations. The various fractions were drawn independently from their distributions, and the sum of the results was used to normalize each value so that the total then added to 1.0.

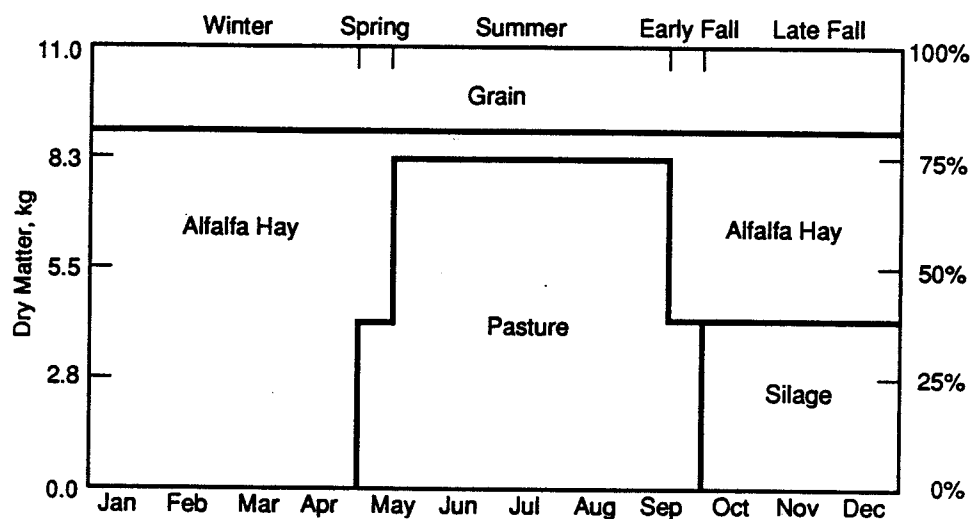


Figure 4-1. Typical cow feeding regime (Beck et al. 1992)

The quantity of a radionuclide consumed by an animal at a given location on a given day can be expressed as (Ikenberry et al. 1993)

$$A_{cons}(d,l) = \sum_{k=1}^L \sum_{t=1}^T f_{kt}^{dl} QF_t^{dl} C_{kt} e^{-\lambda_r(d-j_{kt})}$$

where $A_{cons}(d,l)$ = radionuclide consumption rate of the animal at location l on day d , Ci/d

d = current day

l = current location (where feed was eaten by animal)

L = total number of potential feed source locations

T = total number of feed types

j_{kt} = Julian day on which feed t was harvested at location k

k = location where feed was grown and harvested

$f(d,l,k,t)$ = fraction of feed type t eaten by the animal at location l during day d that was harvested at location k (from feed source/transport matrix). The sum of these fractions over all k for a given feed type, t , for the current location, l , and day d must equal 1.0.

$QF(d,l,t)$ = quantity of feed of type t that the animal at location l eats during day d (kg/d dry weight). This is from the data on feeding regimes (Beck et al. 1990).

$C(k,t)$ = radionuclide concentration (Ci/kg) in feed of type t harvested on day j at location k from soil and vegetation model

λ_{rad} = radioactive decay constant for nuclide r (d^{-1})

$(d-j_{kt})$ = decay correction time for feeds not consumed fresh (d).

The term $f(d,l,k,t)$ is a complex matrix defining what feeds were provided to animals at what times. The definitions of feed include the dates at which they were harvested or at which animals were put on to pasture. (Thus, there may be several cuttings of alfalfa, each considered to be a different "type" of feed.) The individual parameters defined above vary over time and space. The combination of amount of feed, its production history, and the dates at which the quantities and/or types change is called an animal's feeding regime.

4.1 Dairy Cattle Feeding Regimes

The feeding regimes used for cows in the HEDR representative dose calculations, and transferred to HTDS for use in the epidemiology, are fully documented by TSP member Dr. David Price (Price 1994). A copy of his report has been provided to the HTDS team. Dr. Price worked with staff of the HEDR Demography, Food Consumption, and Agriculture Task to establish the diets. He personally performed a small survey of 9 farmers from the 1940s. His information was combined with that of other sources such as the Washington Dairy Herd Improvement Association to establish the four feeding regimes for backyard (family or small farm) cows and four for commercial dairies. Sensitivity studies by Napier (1994) indicated that minor differences beyond these four major regimes did not have noticeable impact on the overall estimated milk concentrations.

In the HEDR scheme, five seasons are required to define a feeding year. The first season starts on January 1 and the last ends on December 31. The seasons are winter, spring, summer, early fall, and late fall. The start and stop times of the seasons are controlled by what are called “frost date files” in the HEDR system. The frost date files were designed to control the growing season of pasture grass and other vegetation, and were adapted, in separate runs, to control the feeding regimes as specified by Dr. Price.

Types of feed available for cows to eat in the HEDR codes included fresh pasture, grass hay, alfalfa hay, grain, silage and/or green chop. In the HEDR system, hay could be harvested several times per year, depending on location and farming practice. Additional secondary pathways of exposure to cattle included intake from deposition on stored feeds (termed “manger” intake in the codes), intake from deposition on stock water tanks, and incidental intake from soils.

The following paragraphs are adapted from Dr. Price’s report. The tables from his report are duplicated here for those who may not have access to an original copy of his report.

The HEDR dose model requires that uncertainties be specified for each variable input. This first requires that specific distribution be selected. For dry matter intakes, distributions with infinite tails such as the normal distribution were deemed non-applicable. Two distributions with finite tails were considered; the uniform and the triangular. The

triangular distribution was selected since it allows probabilities to decrease as values change from an "average". The HEDR code allows the triangular distribution to be non-symmetric. Therefore, this feature was used where appropriate. This also means that the "average" value is the mode.

The first regime for the family cow had no pasture. Since total dry matter intake is less when cows are not on pasture its mode was specified to be 9.6 kilograms throughout the year with range of 7.6 to 11.6 kilograms. Hay was specified to contribute 8.1 kilograms while grain contributed 1.5 kilograms. The range on hay was specified to vary between 7.1 and 9.1 kilograms, while that for grain was from 0.5 to 2.5 kilograms. This regime is identified in the HEDR files as BY4 (back-yard type 4).

No family cow regime contained any silage or green chop. Silage requires an appropriate, nearly air tight storage facility. None of the nine farmers interviewed fed silage or green chop. Furthermore, in 1945 it was relatively expensive to build such a facility. Machinery for green chopping was not on the market in 1945. However, hand scythes and hand corn cutters were available.

The pasture on and off dates, the seasons which meet code requirements, and the dry matter intake for family cows on irrigated pasture are shown in Table 4-1. This is HEDR type BY1. For each area there is a 15-day period where the cows adjust to being on pasture. The same adjustment period is used at the end of the pasture season. During the full pasture season, 90 percent of the dry matter intake stemmed from pasture. This was the same percentage that the experts specified for the peak non-irrigated pasture.

Even though feeding regimes are important to dose, scoping studies using the Battelle model have shown that the uncertainties associated with feeding regimes are a minor factor in the total uncertainty associated with dose. In that model, wide uncertainties have been attached to the feed-to-milk transfer factor and to the transfer factor that relates human milk consumption to thyroid dose. The uncertainties for pasture seasons (shown in parentheses, Table 4-1) were based on those expressed by the experts with slight modifications made by Dr. Price. The uncertainties allow for the possibility that nearly all dry-matter intake comes from pasture.

The feeding regimes meeting the code requirements for family cows on non-irrigated grass pasture followed by wheat stubble are given in Table 4-2. This represents both HEDR types BY2 and C1 (commercial type 1). The total dry matter intakes were allowed to decline as the pasture season progressed. This decline specified the effect of the deterioration in non-irrigated pasture over the season. In addition to the decline in total dry matter intake, the amount of hay fed was increased as pastures deteriorated. The decline in the percent of dry matter intake from pasture was specified to be in agreement with the opinions of the experts. The percent of dry matter from pasture varied from 75 percent in the first two months of the pasture season to about 32 percent in the last two months.

The pasture on and off dates were those given by the three experts. The uncertainties allowed the percent of dry matter from pasture to be as high at 84 percent in the first two months of the pasture season to as low as about 15 percent in the last two months. The uncertainties allowed the possibility of no grain being fed during the pasture season.

The feeding regimes for family cows on non-irrigated pasture with no wheat or stubble pasture are specified in Table 4-3. This is HEDR type BY3. The dates cows were taken off pasture represent a combination of the opinions of the three experts. The dates on pasture were those specified by the experts.

The non-irrigated pasture regimes with no wheat or stubble were similar to those with stubble. The major differences were an earlier off date and less dry matter intake from pasture during the latter part of the pasture season.

Pasture on and off dates for commercial dairies with cows on irrigated pasture (Table 4-4, HEDR type C2) were identical to those for the family cow. The dry matter intakes for the commercial operations were higher as estimated in the previous section. Unlike the family cow, some hay was fed while cows were on full pasture. The amount of dry matter from pasture was specified to be consistent with expert opinion. That is, the percent of dry matter from irrigated pasture was specified to be 75 percent, the same as the percentage from peak non-irrigated pasture.

Silage was included in the commercial irrigated regimes during the autumn months. No silage was specified for other seasons. Due to storage time, its contribution to dose in other seasons would be negligible.

The commercial feeding regimes with non-irrigated pastures did not include silage (Table 4-5, HEDR type C3, and Table 4-6, HEDR type C4). In the HEDR area, it is not feasible to raise corn without irrigation. Feeding of grass silage was limited during the 1945-1951 period.

The two commercial feeding regimes for non-irrigated pasture use the same pasture on and off dates and seasons as these regimes for the family cow. The percentage of dry matter intake from pasture is the same as the commercial irrigated regime for the peak pasture season. The percentages then decline over the season as specified by the experts. Hay is used to supplement pasture and grain throughout the pasture season.

For non-irrigated pasture with stubble, 43 percent of the dry matter intake came from pasture. This is the same percentage as that for non-irrigated pasture without stubble. This contrasts with 74 percent for irrigated pasture.

Under irrigated family cow regimes, the percent of dry matter intake from the various pasture regimes over the entire year for the various areas range from 38 to 53 percent. With the uncertainties, this figure can range between 28 to 63 percent. The between area differences are the result of the longer pasture seasons in the warmer areas of the HEDR domain.

The percent dry matter for the non-irrigated pastures is quite constant across areas. Pasture season begins earlier in the warmer areas, but it also ends at an earlier date. In addition, pasture quality declines more rapidly over the year. The ranges in dry matter intake within a given geographic area are wider for non-irrigated pasture than for irrigated pasture. This depicts the wide variation both in size of pasture and in moisture conditions that exist within a given geographic area.

The percent dry matter intakes from pasture for the commercial operations are all lower than those for the family cow. The differences between areas and within areas are similar to those for the family cow.

4.2 Feeding Regimes for Other Farm Animals

Other farm animals for which concentrations of ^{131}I were calculated in the DESCARTES code are beef cattle (for meat), chickens (for meat and eggs), and goats (for milk). It appears that the HEDR feeding regimes for these animals have never been formally published. Therefore, the original data input files for the DESCARTES calculations used by the CIDER code were recovered, and the contents put in a form parallel to the tables generated by Dr. Price. Significantly less effort went into the generation of these input selections, and there is only a single variant for each animal. However, the season lengths for each animal are tied to the same regions as the dairy cattle, and thus there are regional variations in the feeding regimes that vary through the year.

Table 4-7 presents the basic feeding regime for beef cattle. As with the dairy cattle, the ranges for each feed type are uniform and constrained to a range of maximum values. Intakes of hay are further broken down into alfalfa hay and grass hay. Grass hay was an option available for all feeding regimes; however, it was not selected by Dr. Price for any of the back yard or commercial dairy cow feeding regimes. Hay in all of the dairy cattle feeding regime tables refers to alfalfa hay. Not shown in the table are additional small intakes via drinking water from stock tanks, consumption of dirt along with the feed, and fallout onto the manger.

Table 4-8 presents the basic feeding regime for poultry. Laying hens and frying hens are assumed to eat the same diet. As with the dairy cattle, the ranges for each feed type are uniform and constrained to a range of maximum values. Not shown in the table are additional small intakes via drinking water from stock tanks, and consumption of dirt along with the feed.

Table 4-9 presents the basic feeding regime for dairy goats. Unlike with the other animal types, only the ranges for the pasture feed type are uniform, the others are assigned a triangular distribution as indicated. All intakes are constrained to a range of maximum values. Not shown in the table are additional small intakes via drinking water from stock tanks, and consumption of dirt along with the feed.

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Table 4-1 : Feeding Regimes for Family Cows; Irrigated Pasture

I. Areas: Yakima Valley, Lewiston, Walla Walla, Umatilla, Central Basin, Ringold

Season	Start Date	No. Days	Dry Matter Intake			Total
			Pasture	Hay	Grain	
A	1/1	90 (+/-15)	0	8.1 (+/-1)	1.5 (+/-1)	9.6 (+/-2)
B	4/1 (+/-15)	15	6.6 (+/-2)	3.3 (+/-2)	1.1 (+/-1)	11.0 (+/-2)
C	B+15 days	184 (+/-30)	9.9 (+/-1)	0	1.1 (+/-1)	11.0 (+/-2)
D	E-15 days	15	6.6 (+/-2)	3.3 (+/-2)	1.1 (+/-1)	11.0 (+/-2)
E	11/1 (+/-15)	61 (+/-15)	0	8.1 (+/-1)	1.5 (+/-1)	9.6 (+/-2)

II. Areas: Spokane, Pullman

Season	Start Date	No. Days	Dry Matter Intake			Total
			Pasture	Hay	Grain	
A	1/1	120 (+/-15)	0	8.1 (+/-1)	1.5 (+/-1)	9.6 (+/-2)
B	5/1 (+/-15)	15	6.6 (+/-2)	3.3 (+/-2)	1.1 (+/-1)	11.0 (+/-2)
C	B+15 days	138 (+/-30)	9.9 (+/-1)	0	1.1 (+/-1)	11.0 (+/-2)
D	E-15 days	15	6.6 (+/-2)	3.3 (+/-2)	1.1 (+/-1)	11.0 (+/-2)
E	10/15 (+/-15)	77 (+/-15)	0	8.1 (+/-1)	1.5 (+/-1)	9.6 (+/-2)

III. Areas: Colville

Season	Start Date	No. Days	Dry Matter Intake			Total
			Pasture	Hay	Grain	
A	1/1	125 (+/-15)	0	8.1 (+/-1)	1.5 (+/-1)	9.6 (+/-2)
B	5/5 (+/-15)	15	6.6 (+/-2)	3.3 (+/-2)	1.1 (+/-1)	11.0 (+/-2)
C	B+15 days	133 (+/-30)	9.9 (+/-1)	0	1.1 (+/-1)	11.0 (+/-2)
D	E-15 days	15	6.6 (+/-2)	3.3 (+/-2)	1.1 (+/-1)	11.0 (+/-2)
E	10/15 (+/-15)	77 (+/-15)	0	8.1 (+/-1)	1.5 (+/-1)	9.6 (+/-2)

IV. Areas: Okanogan

Season	Start Date	No. Days	Dry Matter Intake			Total
			Pasture	Hay	Grain	
A	1/1	120	0	8.1	1.5	9.6
		(+15)		(+1)	(+1)	(+2)
B	5/1	15	6.6	3.3	1.1	11.0
	(+15)		(+2)	(+2)	(+1)	(+2)
C	B+15 days	123	9.9	0	1.1	11.0
		(+30)	(+1)		(+1)	(+2)
D	E-15 days	15	6.6	3.3	1.1	11.0
			(+2)	(+2)	(+1)	(+2)
E	10/1	92	0	8.1	1.5	9.6
	(+15)	(+15)		(+1)	(+1)	(+2)

V. Areas: Wenatchee, Pomeroy, Lacrosse

Season	Start Date	No. Days	Dry Matter Intake			Total
			Pasture	Hay	Grain	
A	1/1	110	0	8.1	1.5	9.6
		(+15)		(+1)	(+1)	(+2)
B	4/20	15	6.6	3.3	1.1	11.0
	(+15)		(+2)	(+2)	(+1)	(+2)
C	B+15 days	153	9.9	0	1.1	11.0
		(+30)	(+1)		(+1)	(+2)
D	E-15 days	15	6.6	3.3	1.1	11.0
			(+2)	(+2)	(+1)	(+2)
E	10/20	72	0	8.1	1.5	9.6
	(+15)	(+15)		(+1)	(+1)	(+2)

VI. Areas: Pendleton

Season	Start Date	No. Days	Dry Matter Intake			Total
			Pasture	Hay	Grain	
A	1/1	105	0	8.1	1.5	9.6
		(+15)		(+1)	(+1)	(+2)
B	4/15	15	6.6	3.3	1.1	11.0
	(+15)		(+2)	(+2)	(+1)	(+2)
C	B+15 days	153	9.9	0	1.1	11.0
		(+30)	(+1)		(+1)	(+2)
D	E-15 days	15	6.6	3.3	1.1	11.0
			(+2)	(+2)	(+1)	(+2)
E	10/15	77	0	8.1	1.5	9.6
	(+15)	(+15)		(+1)	(+1)	(+2)

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VII. Areas: Dayton

<u>Season</u>	<u>Start Date</u>	<u>No. Days</u>	<u>Dry Matter Intake</u>			<u>Total</u>
			<u>Pasture</u>	<u>Hay</u>	<u>Grain</u>	
A	1/1	105 (+15)	0	8.1 (+1)	1.5 (+1)	9.6 (+2)
B	4/15 (+15)	15	6.6 (+2)	3.3 (+2)	1.1 (+1)	11.0 (+2)
C	B+15 days	169 (+30)	9.9 (+1)	0	1.1 (+1)	11.0 (+2)
D	E-15 days	15	6.6 (+2)	3.3 (+2)	1.1 (+1)	11.0 (+2)
E	11/1 (+15)	61 (+15)	0	8.1 (+1)	1.5 (+1)	9.6 (+2)

VIII. Areas: Kittitas Valley

<u>Season</u>	<u>Start Date</u>	<u>No. Days</u>	<u>Dry Matter Intake</u>			<u>Total</u>
			<u>Pasture</u>	<u>Hay</u>	<u>Grain</u>	
A	1/1	100 (+15)	0	8.1 (+1)	1.5 (+1)	9.6 (+2)
B	4/10 (+15)	15	6.6 (+2)	3.3 (+2)	1.1 (+1)	11.0 (+2)
C	B+15 days	174 (+30)	9.9 (+1)	0	1.1 (+1)	11.0 (+2)
D	E-15 days	15	6.6 (+2)	3.3 (+2)	1.1 (+1)	11.0 (+2)
E	11/1 (+15)	61 (+15)	0	8.1 (+1)	1.5 (+1)	9.6 (+2)

Table 4-2 : Feeding Regimes for Family Cows; Nonirrigated Pasture, with Stubble.

I. Areas: Yakima Valley, Lewiston, Walla Walla, Umatilla, Central Basin, Ringold

Season	Start Date	No. Days	Dry Matter Intake			Total
			Pasture	Hay	Grain	
A	1/1	90	0	8.1	1.5	9.6
		(+15)		(+1)	(+1)	(+2)
B	4/1	61	8.25	1.75	1.0	11.0
	(+15)		(+1)	(+1)	(+1)	(+2)
C	B+61 days	92	5.57	3.93	1.0	10.5
		(+30)	(-2.4+3.2)	(-2.4+3.2)	(+1)	(+2)
D	E-61 days	61	3.25	5.35	1.0	9.6
			(-2+3.5)	(-2+3.5)	(+1)	(+2)
E	11/1	61	0	8.1	1.5	9.6
	(+15)	(+15)		(+1)	(+1)	(+2)

II. Areas: Spokane, Pullman

Season	Start Date	No. Days	Dry Matter Intake			Total
			Pasture	Hay	Grain	
A	1/1	120	0	8.1	1.5	9.6
		(+15)		(+1)	(+1)	(+2)
B	5/1	61	8.25	1.75	1.0	11.0
	(+15)		(+1)	(+1)	(+1)	(+2)
C	B+61 days	62	8.32	3.18	1.0	10.5
		(+30)	(-2+3)	(-2+3)	(+1)	(+2)
D	E-61 days	61	3.74	4.86	1.0	9.6
			(-2+3)	(-2+3)	(+1)	(+2)
E	11/1	61	0	8.1	1.5	9.6
	(+15)	(+15)		(+1)	(+1)	(+2)

III. Areas: Collville

Season	Start Date	No. Days	Dry Matter Intake			Total
			Pasture	Hay	Grain	
A	1/1	125	0	8.1	1.5	9.6
		(+15)		(+1)	(+1)	(+2)
B	5/5	61	8.25	1.75	1.0	11.0
	(+15)		(+1)	(+1)	(+1)	(+2)
C	B+61 days	57	6.4	3.1	1.0	10.5
		(+30)	(-2+3)	(-2+3)	(+1)	(+2)
D	E-61 days	61	3.91	4.69	1.0	9.6
			(-2+3)	(-2+3)	(+1)	(+2)
E	11/1	61	0	8.1	1.5	9.6
	(+15)	(+15)		(+1)	(+1)	(+2)

IV. Areas: Okanogan

<u>Season</u>	<u>Start Date</u>	<u>No. Days</u>	<u>Dry Matter Intake</u>			<u>Total</u>
			<u>Pasture</u>	<u>Hay</u>	<u>Grain</u>	
A	1/1	120	0	8.1	1.5	9.6
		(+15)		(+1)	(+1)	(+2)
B	5/1	61	8.25	1.75	1.0	11.0
	(+15)		(+1)	(+1)	(+1)	(+2)
C	B+61 days	62	6.3	3.2	1.0	10.5
		(+30)	(-2+3)	(-2+3)	(+1)	(+2)
D	E-61 days	61	3.76	4.84	1.0	9.6
			(-2+3)	(-2+3)	(+1)	(+2)
E	11/1	61	0	8.1	1.5	9.6
	(+15)	(+15)		(+1)	(+1)	(+2)

V. Areas: Wenatchee, Pomeroy, Lacrosse

<u>Season</u>	<u>Start Date</u>	<u>No. Days</u>	<u>Dry Matter Intake</u>			<u>Total</u>
			<u>Pasture</u>	<u>Hay</u>	<u>Grain</u>	
A	1/1	110	0	8.1	1.5	9.6
		(+15)		(+1)	(+1)	(+2)
B	4/20	61	8.25	1.75	1.0	11.0
	(+15)		(+1)	(+1)	(+1)	(+2)
C	B+61 days	72	6.0	3.5	1.0	10.5
		(+30)	(-2.3+3.1)	(-2.3+3.1)	(+1)	(+2)
D	E-61 days	61	3.58	5.02	1.0	9.6
			(-2+3.1)	(-2+3.1)	(+1)	(+2)
E	11/1	61	0	8.1	1.5	9.6
	(+15)	(+15)		(+1)	(+1)	(+2)

VI. Areas: Pendleton

<u>Season</u>	<u>Start Date</u>	<u>No. Days</u>	<u>Dry Matter Intake</u>			<u>Total</u>
			<u>Pasture</u>	<u>Hay</u>	<u>Grain</u>	
A	1/1	105	0	8.1	1.5	9.6
		(+15)		(+1)	(+1)	(+2)
B	4/15	61	8.25	1.75	1.0	11.0
	(+15)		(+1)	(+1)	(+1)	(+2)
C	B+61 days	77	5.87	3.63	1.0	10.5
		(+30)	(-2.3+3.1)	(-2.3+3.1)	(+1)	(+2)
D	E-61 days	61	3.5	5.1	1.0	9.6
			(-2+3.3)	(-2+3.3)	(+1)	(+2)
E	11/1	61	0	8.1	1.5	9.6
	(+15)	(+15)		(+1)	(+1)	(+2)

VII. Areas: Dayton

<u>Season</u>	<u>Start Date</u>	<u>No. Days</u>	<u>Dry Matter Intake</u>			<u>Total</u>
			<u>Pasture</u>	<u>Hay</u>	<u>Grain</u>	
A	1/1	105	0	8.1	1.5	9.6
		(+15)		(+1)	(+1)	(+2)
B	4/15	61	8.25	1.75	1.0	11.0
	(+15)		(+1)	(+1)	(+1)	(+2)
C	B+61 days	77	5.87	3.63	1.0	10.5
		(+30)	(-2.3+3.1)	(-2.3+3.1)	(+1)	(+2)
D	E-61 days	61	3.5	5.1	1.0	9.6
			(-2+3.2)	(-2+3.2)	(+1)	(+2)
E	11/1	61	0	8.1	1.5	9.6
	(+15)	(+15)		(+1)	(+1)	(+2)

VIII. Areas: Kittitas Valley

<u>Season</u>	<u>Start Date</u>	<u>No. Days</u>	<u>Dry Matter Intake</u>			<u>Total</u>
			<u>Pasture</u>	<u>Hay</u>	<u>Grain</u>	
A	1/1	100	0	8.1	1.5	9.6
		(+15)		(+1)	(+1)	(+2)
B	4/10	61	8.25	1.75	1.0	11.0
	(+15)		(+1)	(+1)	(+1)	(+2)
C	B+61 days	82	5.76	3.74	1.0	10.5
		(+30)	(-2.3+3.1)	(-2.3+3.1)	(+1)	(+2)
D	E-61 days	61	3.4	5.2	1.0	9.6
			(-2+3.3)	(-2+3.3)	(+1)	(+2)
E	11/1	61	0	8.1	1.5	9.6
	(+15)	(+15)		(+1)	(+1)	(+2)

Table 4-3: Feeding Regimes for Family Cows; Nonirrigated Pasture, No Wheat or Stubble.

I. Areas: Yakima Valley, Lewiston, Walla Walla, Umatilla, Central Basin, Ringold

Season	Start Date	No. Days	Dry Matter Intake			Total
			Pasture	Hay	Grain	
A	1/1	90	0	8.1	1.5	9.6
		(+15)		(+1)	(+1)	(+2)
B	4/1	61	8.25	1.75	1.0	11.0
	(+15)		(+1)	(+1)	(+1)	(+2)
C	B+61 days	61	6.35	3.15	1.0	10.5
		(+30)	(-2+3)	(-2+3)	(+1)	(+2)
D	E-61 days	61	1.9	6.7	1.0	9.6
			(-1.9+3.5)	(-1.9+3.5)	(+1)	(+2)
E	10/1	92	0	8.1	1.5	9.6
	(+15)	(+15)		(+1)	(+1)	(+2)

II. Areas: Spokane, Pullman

Season	Start Date	No. Days	Dry Matter Intake			Total
			Pasture	Hay	Grain	
A	1/1	120	0	8.1	1.5	9.6
		(+15)		(+1)	(+1)	(+2)
B	5/1	61	8.25	1.75	1.0	11.0
	(+15)		(+1)	(+1)	(+1)	(+2)
C	B+61 days	31	7.4	2.1	1.0	10.5
		(+30)	(-2+2.4)	(-2+2.4)	(+1)	(+2)
D	E-61 days	61	4.1	4.5	1.0	9.6
			(-2+3.4)	(-2+3.4)	(+1)	(+2)
E	10/1	92	0	8.1	1.5	9.6
	(+15)	(+15)		(+1)	(+1)	(+2)

III. Areas: Collville

Season	Start Date	No. Days	Dry Matter Intake			Total
			Pasture	Hay	Grain	
A	1/1	125	0	8.1	1.5	9.6
		(+15)		(+1)	(+1)	(+2)
B	5/5	61	8.25	1.75	1.0	11.0
	(+15)		(+1)	(+1)	(+1)	(+2)
C	B+61 days	31	7.4	2.1	1.0	10.5
		(+30)	(-2+2.4)	(-2+2.4)	(+1)	(+2)
D	E-61 days	61	4.1	4.5	1.0	9.6
			(-2+3.4)	(-2+3.4)	(+1)	(+2)
E	10/5	87	0	8.1	1.5	9.6
	(+15)	(+15)		(+1)	(+1)	(+2)

IV. Areas: Okanogan

<u>Season</u>	<u>Start Date</u>	<u>No. Days</u>	<u>Dry Matter Intake</u>			<u>Total</u>
			<u>Pasture</u>	<u>Hay</u>	<u>Grain</u>	
A	1/1	120	0	8.1	1.5	9.6
		(+15)		(+1)	(+1)	(+2)
B	5/1	61	8.25	1.75	1.0	11.0
	(+15)		(+1)	(+1)	(+1)	(+2)
C	B+61 days	31	7.4	2.1	1.0	10.5
		(+30)	(-2+2.4)	(-2+2.4)	(+1)	(+2)
D	E-61 days	61	4.1	4.5	1.0	9.6
			(-2+3.4)	(-2+3.4)	(+1)	(+2)
E	10/1	92	0	8.1	1.5	9.6
	(+15)	(+15)		(+1)	(+1)	(+2)

V. Areas: Wenatchee, Pomeroy, Lacrosse

<u>Season</u>	<u>Start Date</u>	<u>No. Days</u>	<u>Dry Matter Intake</u>			<u>Total</u>
			<u>Pasture</u>	<u>Hay</u>	<u>Grain</u>	
A	1/1	110	0	8.1	1.5	9.6
		(+15)		(+1)	(+1)	(+2)
B	4/20	61	8.25	1.75	1.0	11.0
	(+15)		(+1)	(+1)	(+1)	(+2)
C	B+61 days	61	6.35	3.15	1.0	10.5
		(+30)	(-2+3)	(-2+3)	(+1)	(+2)
D	E-61 days	61	1.9	6.7	1.0	9.6
			(-1.9+3.5)	(-1.9+3.5)	(+1)	(+2)
E	10/20	72	0	8.1	1.5	9.6
	(+15)	(+15)		(+1)	(+1)	(+2)

VI. Areas: Pendleton

<u>Season</u>	<u>Start Date</u>	<u>No. Days</u>	<u>Dry Matter Intake</u>			<u>Total</u>
			<u>Pasture</u>	<u>Hay</u>	<u>Grain</u>	
A	1/1	105	0	8.1	1.5	9.6
		(+15)		(+1)	(+1)	(+2)
B	4/15	61	8.25	1.75	1.0	11.0
	(+15)		(+1)	(+1)	(+1)	(+2)
C	B+61 days	61	6.35	3.15	1.0	10.5
		(+30)	(-2+3)	(-2+3)	(+1)	(+2)
D	E-61 days	61	1.9	6.7	1.0	9.6
			(-1.9+3.5)	(-1.9+3.5)	(+1)	(+2)
E	10/15	77	0	8.1	1.5	9.6
	(+15)	(+15)	43	(+1)	(+1)	(+2)

VII. Areas: Dayton

<u>Season</u>	<u>Start Date</u>	<u>No. Days</u>	<u>Dry Matter Intake</u>			<u>Total</u>
			<u>Pasture</u>	<u>Hay</u>	<u>Grain</u>	
A	1/1	105	0	8.1	1.5	9.6
		(+15)				
B	4/15	61	8.25	(+1)	(+1)	(+2)
	(+15)			1.75	1.0	11.0
C	B+61 days	77	(+1)	(+1)	(+1)	(+2)
			5.87	3.63	1.0	10.5
D	E-61 days	(+30)	(-2.3+3.1)	(-2.3+3.1)	(+1)	(+2)
		61	3.5	5.1	1.0	9.6
E	11/1	61	(-2+3.2)	(-2+3.2)	(+1)	(+2)
	(+15)	(+15)	0	8.1	1.5	9.6
				(+1)	(+1)	(+2)

VIII. Areas: Kittitas Valley

<u>Season</u>	<u>Start Date</u>	<u>No. Days</u>	<u>Dry Matter Intake</u>			<u>Total</u>
			<u>Pasture</u>	<u>Hay</u>	<u>Grain</u>	
A	1/1	100	0	8.1	1.5	9.6
		(+15)				
B	4/10	61	8.25	(+1)	(+1)	(+2)
	(+15)			1.75	1.0	11.0
C	B+61 days	82	(+1)	(+1)	(+1)	(+2)
			5.76	3.74	1.0	10.5
D	E-61 days	(+30)	(-2.3+3.1)	(-2.3+3.1)	(+1)	(+2)
		61	3.4	5.2	1.0	9.6
E	11/1	61	(-2+3.3)	(-2+3.3)	(+1)	(+2)
	(+15)	(+15)	0	8.1	1.5	9.6
				(+1)	(+1)	(+2)

Table 4-4: Feeding Regimes for Commercial Production;
Irrigated Pasture

I. Areas: Yakima Valley, Lewiston, Walla Walla, Umatilla,
Central Basin, Ringold

Season	Start Date	No. Days	Dry Matter Intake			Total
			Pasture	Hay	Grain	
A	1/1	90	0	9.9	1.7	11.6
		(+-15)		(+-1)	(+-1)	(+-2)
B	4/1	15	8.45	3.25	1.3	13.0
	(+-15)		(+-1)	(+-1)	(+-1)	(+-2)
C	B+15 days	184	9.75	1.95	1.3	13.0
		(+-30)	(+-1)	(+-1)	(+-1)	(+-2)
D	E-15 days	15	8.45	3.25	1.3	13.0
			(+-1)	(+-1)	(+-1)	(+-2)
E	11/1	61	0	4.95	1.7	11.6
	(+-15)	(+-15)		(+-1)	(+-1)	(+-2)

Season E should include 4.95(+1) of silage.

II. Areas: Spokane, Pullman

Season	Start Date	No. Days	Dry Matter Intake			Total
			Pasture	Hay	Grain	
A	1/1	120	0	9.9	1.7	11.6
		(+-15)		(+-1)	(+-1)	(+-2)
B	5/1	15	8.45	3.25	1.3	13.0
	(+-15)		(+-1)	(+-1)	(+-1)	(+-2)
C	B+15 days	138	9.75	1.95	1.3	13.0
		(+-30)	(+-1)	(+-1)	(+-1)	(+-2)
D	E-15 days	15	8.45	3.25	1.3	13.0
			(+-1)	(+-1)	(+-1)	(+-2)
E	10/15	77	0	4.95	1.7	11.6
	(+-15)	(+-15)		(+-1)	(+-1)	(+-2)

Season E should include 4.95(+1) of silage.

III. Areas: Colville

Season	Start Date	No. Days	Dry Matter Intake			Total
			Pasture	Hay	Grain	
A	1/1	125	0	9.9	1.7	11.6
		(+-15)		(+-1)	(+-1)	(+-2)
B	5/5	15	8.45	3.25	1.3	13.0
	(+-15)		(+-1)	(+-1)	(+-1)	(+-2)
C	B+15 days	133	9.75	1.95	1.3	13.0
		(+-30)	(+-1)	(+-1)	(+-1)	(+-2)
D	E-15 days	15	8.45	3.25	1.3	13.0
			(+-1)	(+-1)	(+-1)	(+-2)
E	10/15	77	0	4.95	1.7	11.6
	(+-15)	(+-15)		(+-1)	(+-1)	(+-2)

Season E should include 4.95(+1) of silage.

IV. Areas: Okanogan

<u>Season</u>	<u>Start Date</u>	<u>No. Days</u>	<u>Dry Matter Intake</u>			<u>Total</u>
			<u>Pasture</u>	<u>Hay</u>	<u>Grain</u>	
A	1/1	120	0	9.9	1.7	11.6
		(+15)		(+1)	(+1)	(+2)
B	5/1	15	8.45	3.25	1.3	13.0
	(+15)		(+1)	(+1)	(+1)	(+2)
C	B+15 days	123	9.75	1.95	1.3	13.0
		(+30)	(+1)	(+1)	(+1)	(+2)
D	E-15 days	15	8.45	3.25	1.3	13.0
			(+1)	(+1)	(+1)	(+2)
E	10/1	92	0	4.95	1.7	11.6
	(+15)	(+15)		(+1)	(+1)	(+2)

Season E should include 4.95(+1) of silage.

V. Areas: Wenatchee, Pomeroy, Lacrosse

<u>Season</u>	<u>Start Date</u>	<u>No. Days</u>	<u>Dry Matter Intake</u>			<u>Total</u>
			<u>Pasture</u>	<u>Hay</u>	<u>Grain</u>	
A	1/1	110	0	9.9	1.7	11.6
		(+15)		(+1)	(+1)	(+2)
B	4/20	15	8.45	3.25	1.3	13.0
	(+15)		(+1)	(+1)	(+1)	(+2)
C	B+15 days	153	9.75	1.95	1.3	13.0
		(+30)	(+1)	(+1)	(+1)	(+2)
D	E-15 days	15	8.45	3.25	1.3	13.0
			(+1)	(+1)	(+1)	(+2)
E	10/20	72	0	4.95	1.7	11.6
	(+15)	(+15)		(+1)	(+1)	(+2)

Season E should include 4.95(+1) of silage.

VI. Areas: Pendleton

<u>Season</u>	<u>Start Date</u>	<u>No. Days</u>	<u>Dry Matter Intake</u>			<u>Total</u>
			<u>Pasture</u>	<u>Hay</u>	<u>Grain</u>	
A	1/1	105	0	9.9	1.7	11.6
		(+15)		(+1)	(+1)	(+2)
B	4/15	15	8.45	3.25	1.3	13.0
	(+15)		(+1)	(+1)	(+1)	(+2)
C	B+15 days	153	9.75	1.95	1.3	13.0
		(+30)	(+1)	(+1)	(+1)	(+2)
D	E-15 days	15	8.45	3.25	1.3	13.0
			(+1)	(+1)	(+1)	(+2)
E	10/15	77	0	4.95	1.7	11.6
	(+15)	(+15)		(+1)	(+1)	(+2)

Season E should include 4.95(+1) of silage.

VII. Areas: Dayton

<u>Season</u>	<u>Start Date</u>	<u>No. Days</u>	<u>Dry Matter Intake</u>			<u>Total</u>
			<u>Pasture</u>	<u>Hay</u>	<u>Grain</u>	
A	1/1	105	0	9.9	1.7	11.6
		(+-15)		(+-1)	(+-1)	(+-2)
B	4/15	15	8.45	3.25	1.3	13.0
	(+-15)		(+-1)	(+-1)	(+-1)	(+-2)
C	B+15 days	169	9.75	1.95	1.3	13.0
		(+-30)	(+-1)	(+-1)	(+-1)	(+-2)
D	E-15 days	15	8.45	3.25	1.3	13.0
			(+-1)	(+-1)	(+-1)	(+-2)
E	11/1	61	0	4.95	1.7	11.6
	(+-15)	(+-15)		(+-1)	(+-1)	(+-2)

Season E should include 4.95(+1) of silage.

VIII. Areas: Kittitas Valley

<u>Season</u>	<u>Start Date</u>	<u>No. Days</u>	<u>Dry Matter Intake</u>			<u>Total</u>
			<u>Pasture</u>	<u>Hay</u>	<u>Grain</u>	
A	1/1	100	0	9.9	1.7	11.6
		(+-15)		(+-1)	(+-1)	(+-2)
B	4/10	15	8.45	3.25	1.3	13.0
	(+-15)		(+-1)	(+-1)	(+-1)	(+-2)
C	B+15 days	174	9.75	1.95	1.3	13.0
		(+-30)	(+-1)	(+-1)	(+-1)	(+-2)
D	E-15 days	15	8.45	3.25	1.3	13.0
			(+-1)	(+-1)	(+-1)	(+-2)
E	11/1	61	0	4.95	1.7	11.6
	(+-15)	(+-15)		(+-1)	(+-1)	(+-2)

Season E should include 4.95(+1) of silage.

Table 4-5: Feeding Regimes for Commercial Production;
Nonirrigated Pasture, No Wheat or Stubble

I. Areas: Yakima Valley, Lewiston, Walla Walla, Umatilla,
Central Basin, Ringold

<u>Date</u>	<u>Start</u> <u>Days</u>	<u>No.</u> <u>Pasture</u>	<u>Dry Matter Intake Season</u>			
			<u>Hay</u>	<u>Grain</u>	<u>Total</u>	
A	1/1	90	0	9.9	1.7	11.6
		(+/-15)		(+/-1)	(+/-1)	(+/-2)
B	4/1	61	9.1	2.6	1.3	13.0
	(+/-15)		(+/-1)	(+/-1)	(+/-1)	(+/-2)
C	B+61 days	61	5.62	5.58	1.3	12.5
		(+/-30)	(-2+2.5)	(-2+2.5)	(+/-1)	(+/-2)
D	E-61 days	61	1.17	9.13	1.3	11.6
			(-1+3.5)	(-1+2.5)	(+/-1)	(+/-2)
E	10/1	92	0	9.90	1.7	11.6
	(+/-15)	(+/-15)		(+/-1)	(+/-1)	(+/-2)

II. Areas: Spokane, Pullman

<u>Season</u>	<u>Start</u> <u>Date</u>	<u>No.</u> <u>Days</u>	<u>Dry Matter Intake</u>			<u>Total</u>
			<u>Pasture</u>	<u>Hay</u>	<u>Grain</u>	
A	1/1	120	0	9.8	1.7	11.6
		(+/-15)		(+/-1)	(+/-1)	(+/-2)
B	5/1	61	9.1	2.6	1.3	13.0
	(+/-15)		(+/-1)	(+/-1)	(+/-1)	(+/-2)
C	B+61 days	31	6.87	4.33	1.3	12.5
		(+/-30)	(-2+1.6)	(-2+1.6)	(+/-1)	(+/-2)
D	E-61 days	61	3.0	7.3	1.3	11.6
			(-1.2+3.5)	(-1.2+3.5)	(+/-1)	(+/-2)
E	10/1	92	0	9.9	1.7	11.6
	(+/-15)	(+/-15)		(+/-1)	(+/-1)	(+/-2)

III. Areas: Colville

<u>Season</u>	<u>Start</u> <u>Date</u>	<u>No.</u> <u>Days</u>	<u>Dry Matter Intake</u>			<u>Total</u>
			<u>Pasture</u>	<u>Hay</u>	<u>Grain</u>	
A	1/1	125	0	9.9	1.7	11.6
		(+/-15)		(+/-1)	(+/-1)	(+/-2)
B	5/5	61	9.1	2.6	1.3	13.0
	(+/-15)		(+/-1)	(+/-1)	(+/-1)	(+/-2)
C	B+61 days	31	6.87	4.33	1.3	12.5
		(+/-30)	(-2+1.6)	(-2+1.6)	(+/-1)	(+/-2)
D	E-61 days	61	3.0	7.3	1.3	11.6
			(-1.2+3.5)	(-1.2+3.5)	(+/-1)	(+/-2)
E	10/5	87	0	9.9	1.7	11.6
	(+/-15)	(+/-15)		(+/-1)	(+/-1)	(+/-2)

IV. Areas: Okanogan

Season	Start Date	No. Days	Dry Matter Intake			Total
			Pasture	Hay	Grain	
A	1/1	120	0	9.9	1.7	11.6
		(+-15)		(+-1)	(+-1)	(+-2)
B	5/1	61	9.1	2.6	1.3	13.0
	(+-15)		(+-1)	(+-1)	(+-1)	(+-2)
C	B+61 days	31	6.87	4.33	1.3	12.5
		(+-30)	(-2+1.6)	(-2+1.6)	(+-1)	(+-2)
D	E-61 days	61	3.0	7.3	1.3	11.6
			(-1.2+3.5)	(-1.2+3.5)	(+-1)	(+-2)
E	10/1	92	0	9.9	1.7	11.6
	(+-15)	(+-15)		(+-1)	(+-1)	(+-2)

V. Areas: Wenatchee, Pomeroy, Lacrosse

Season	Start Date	No. Days	Dry Matter Intake			Total
			Pasture	Hay	Grain	
A	1/1	115	0	9.9	1.7	11.6
		(+-15)		(+-1)	(+-1)	(+-2)
B	4/20	61	9.1	2.6	1.3	13.0
	(+-15)		(+-1)	(+-1)	(+-1)	(+-2)
C	B+61 days	61	5.62	5.58	1.3	12.5
		(+-30)	(-2+2.5)	(-2+2.5)	(+-1)	(+-2)
D	E-61 days	61	1.17	9.13	1.3	11.6
			(-1+3.5)	(-1+2.5)	(+-1)	(+-2)
E	10/20	72	0	9.90	1.7	11.6
	(+-15)	(+-15)		(+-1)	(+-1)	(+-2)

VI. Areas: Pendleton

Season	Start Date	No. Days	Dry Matter Intake			Total
			Pasture	Hay	Grain	
A	1/1	105	0	9.9	1.7	11.6
		(+-15)		(+-1)	(+-1)	(+-2)
B	4/15	61	9.1	2.6	1.3	13.0
	(+-15)		(+-1)	(+-1)	(+-1)	(+-2)
C	B+61 days	61	5.62	5.58	1.3	12.5
		(+-30)	(-2+2.5)	(-2+2.5)	(+-1)	(+-2)
D	E-61 days	61	1.17	9.13	1.3	11.6
			(-1+3.5)	(-1+2.5)	(+-1)	(+-2)
E	10/15	77	0	9.90	1.7	11.6
	(+-15)	(+-15)		(+-1)	(+-1)	(+-2)

VII. Areas: Dayton

<u>Season</u>	<u>Start Date</u>	<u>No. Days</u>	<u>Dry Matter Intake</u>			<u>Total</u>
			<u>Pasture</u>	<u>Hay</u>	<u>Grain</u>	
A	1/1	105 (+-15)	0	9.9 (+-1)	1.7 (+-1)	11.6 (+-2)
B	4/15 (+-15)	61	9.1 (+-1)	2.6 (+-1)	1.3 (+-1)	13.0 (+-2)
C	B+61 days	61 (+-30)	5.62 (-2+2.5)	5.58 (-2+2.5)	1.3 (+-1)	12.5 (+-2)
D	E-61 days	61	1.17 (-1+3.5)	9.13 (-1+2.5)	1.3 (+-1)	11.6 (+-2)
E	10/15 (+-15)	77 (+-15)	0	9.90 (+-1)	1.7 (+-1)	11.6 (+-2)

VIII. Areas: Kittitas Valley

<u>Season</u>	<u>Start Date</u>	<u>No. Days</u>	<u>Dry Matter Intake</u>			<u>Total</u>
			<u>Pasture</u>	<u>Hay</u>	<u>Grain</u>	
A	1/1	100 (+-15)	0	9.9 (+-1)	1.7 (+-1)	11.6 (+-2)
B	4/10 (+-15)	61	9.1 (+-1)	2.6 (+-1)	1.3 (+-1)	13.0 (+-2)
C	B+61 days	61 (+-30)	5.62 (-2+2.5)	5.58 (-2+2.5)	1.3 (+-1)	12.5 (+-2)
D	E-61 days	61	1.17 (-1+3.5)	9.13 (-1+2.5)	1.3 (+-1)	11.6 (+-2)
E	10/10 (+-15)	82 (+-15)	0	9.90 (+-1)	1.7 (+-1)	11.6 (+-2)

Table 4-6: Feeding Regimes for Commercial Production;
Nonirrigated Pasture, with Stubble

I. Areas: Yakima Valley, Lewiston, Walla Walla, Umatilla,
Central Basin, Ringold

Season	Start Date	No. Days	Dry Matter Intake			Total
			Pasture	Hay	Grain	
A	1/1	90	0	9.9	1.7	11.6
		(+15)		(+1)	(+1)	(+2)
B	4/1	61	9.1	2.6	1.3	13.0
	(+15)		(+1)	(+1)	(+1)	(+2)
C	B+61 days	92	4.73	8.47	1.3	12.5
		(+30)	(-2.4+2.8)	(-2.4+2.8)	(+1)	(+2)
D	E-61 days	61	2.5	7.8	1.3	11.6
			(-2+3.3)	(-2+3.3)	(+1)	(+2)
E	11/1	61	0	9.9	1.7	11.6
	(+15)	(+15)		(+1)	(+1)	(+2)

II. Areas: Spokane, Pullman

Season	Start Date	No. Days	Dry Matter Intake			Total
			Pasture	Hay	Grain	
A	1/1	120	0	9.9	1.7	11.6
		(+15)		(+1)	(+1)	(+2)
B	5/1	61	9.1	2.6	1.3	13.0
	(+15)		(+1)	(+1)	(+1)	(+2)
C	B+61 days	62	5.56	5.64	1.3	12.5
		(+30)	(-2+2.5)	(-2+2.5)	(+1)	(+2)
D	E-61 days	61	2.75	7.55	1.3	11.6
			(-2+3)	(-2+3)	(+1)	(+2)
E	11/1	61	0	9.9	1.7	11.6
	(+15)	(+15)		(+1)	(+1)	(+2)

III. Areas: Colville

Season	Start Date	No. Days	Dry Matter Intake			Total
			Pasture	Hay	Grain	
A	1/1	125	0	9.9	1.7	11.6
		(+15)		(+1)	(+1)	(+2)
B	5/5	61	9.1	2.6	1.3	13.0
	(+15)		(+1)	(+1)	(+1)	(+2)
C	B+61 days	57	5.69	5.51	1.3	12.5
		(+30)	(-2+2.4)	(-2+2.4)	(+1)	(+2)
D	E-61 days	61	2.88	7.42	1.3	11.6
			(-2+3)	(-2+3)	(+1)	(+2)
E	11/1	61	0	9.9	1.7	11.6
	(+15)	(+15)		(+1)	(+1)	(+2)

IV. Areas: Okanogan

Season	Start Date	No. Days	Dry Matter Intake			Total
			Pasture	Hay	Grain	
A	1/1	120	0	9.9	1.7	11.6
		(+-15)		(+-1)	(+-1)	(+-2)
B	5/1	15	8.45	3.25	1.3	13.0
	(+-15)		(+-1)	(+-1)	(+-1)	(+-2)
C	B+15 days	123	9.75	1.95	1.3	13.0
		(+-30)	(+-1)	(+-1)	(+-1)	(+-2)
D	E-15 days	15	8.45	3.25	1.3	13.0
			(+-1)	(+-1)	(+-1)	(+-2)
E	10/1	92	0	4.95	1.7	11.6
	(+-15)	(+-15)		(+-1)	(+-1)	(+-2)

Season E should include 4.95(+1) of silage.

V. Areas: Wenatchee, Pomeroy, Lacrosse

Season	Start Date	No. Days	Dry Matter Intake			Total
			Pasture	Hay	Grain	
A	1/1	110	0	9.9	1.7	11.6
		(+-15)		(+-1)	(+-1)	(+-2)
B	4/20	15	8.45	3.25	1.3	13.0
	(+-15)		(+-1)	(+-1)	(+-1)	(+-2)
C	B+15 days	153	9.75	1.95	1.3	13.0
		(+-30)	(+-1)	(+-1)	(+-1)	(+-2)
D	E-15 days	15	8.45	3.25	1.3	13.0
			(+-1)	(+-1)	(+-1)	(+-2)
E	10/20	72	0	4.95	1.7	11.6
	(+-15)	(+-15)		(+-1)	(+-1)	(+-2)

Season E should include 4.95(+1) of silage.

VI. Areas: Pendleton

Season	Start Date	No. Days	Dry Matter Intake			Total
			Pasture	Hay	Grain	
A	1/1	105	0	9.9	1.7	11.6
		(+-15)		(+-1)	(+-1)	(+-2)
B	4/15	15	8.45	3.25	1.3	13.0
	(+-15)		(+-1)	(+-1)	(+-1)	(+-2)
C	B+15 days	153	9.75	1.95	1.3	13.0
		(+-30)	(+-1)	(+-1)	(+-1)	(+-2)
D	E-15 days	15	8.45	3.25	1.3	13.0
			(+-1)	(+-1)	(+-1)	(+-2)
E	10/15	77	0	4.95	1.7	11.6
	(+-15)	(+-15)		(+-1)	(+-1)	(+-2)

Season E should include 4.95(+1) of silage.

VII. Areas: Dayton

<u>Season</u>	<u>Start Date</u>	<u>No. Days</u>	<u>Dry Matter Intake</u>			<u>Total</u>
			<u>Pasture</u>	<u>Hay</u>	<u>Grain</u>	
A	1/1	105	0	9.9	1.7	11.6
		(+-15)		(+-1)	(+-1)	(+-2)
B	4/15	61	9.1	2.6	1.3	13.0
	(+-15)		(+-1)	(+-1)	(+-1)	(+-2)
C	B+61 days	61	5.62	5.58	1.3	12.5
		(+-30)	(-2+2.5)	(-2+2.5)	(+-1)	(+-2)
D	E-61 days	61	1.17	9.13	1.3	11.6
			(-1+3.5)	(-1+2.5)	(+-1)	(+-2)
E	10/15	77	0	9.90	1.7	11.6
	(+-15)	(+-15)		(+-1)	(+-1)	(+-2)

VIII. Areas: Kittitas Valley

<u>Season</u>	<u>Start Date</u>	<u>No. Days</u>	<u>Dry Matter Intake</u>			<u>Total</u>
			<u>Pasture</u>	<u>Hay</u>	<u>Grain</u>	
A	1/1	100	0	9.9	1.7	11.6
		(+-15)		(+-1)	(+-1)	(+-2)
B	4/10	61	9.1	2.6	1.3	13.0
	(+-15)		(+-1)	(+-1)	(+-1)	(+-2)
C	B+61 days	61	5.62	5.58	1.3	12.5
		(+-30)	(-2+2.5)	(-2+2.5)	(+-1)	(+-2)
D	E-61 days	61	1.17	9.13	1.3	11.6
			(-1+3.5)	(-1+2.5)	(+-1)	(+-2)
E	10/10	82	0	9.90	1.7	11.6
	(+-15)	(+-15)		(+-1)	(+-1)	(+-2)

Table 4-7. Feeding Regimes for Beef Cattle, Intakes in kg/day of dry matter. All distributions are uniform.

Season	Pasture	Alfalfa Hay	Grass Hay	Grain	Total
Winter	0 – 2	0 – 7.5	0 – 7.5	0 – 1.5	8.5 – 15
Spring	0.5 – 2.5	0 – 4.5	0 – 2	0 – 4.5	7.5 – 12
Summer	1 – 8	0 – 2	0	0 – 3	6.5 – 10
Early Fall	1 – 4	0 – 2	0 – 2	0 – 6	7.5 – 13
Late Fall	0 – 1.5	0 – 4.5	0 – 4.5	0 – 7	8 – 13

Table 4-8. Feeding Regimes for Poultry, Intakes in kg/day of dry matter. All distributions are uniform.

Season	Pasture	Alfalfa Hay	Grass Hay	Grain	Total
Winter	0 – 0.03	0 – 0.01	0	0.04 – 0.10	0.06 – 0.16
Spring	0.01 – 0.04	0.005 – 0.01	0	0.03 – 0.10	0.05 – 0.15
Summer	0.02 – 0.05	0.005 – 0.01	0	0.02 – 0.07	0.04 – 0.11
Early Fall	0.01 – 0.05	0.005 – 0.01	0	0.02 – 0.08	0.04 – 0.12
Late Fall	0 – 0.04	0 – 0.01	0	0.03 – 0.10	0.05 – 0.15

Table 4-9. Feeding Regimes for Dairy Goats, Intakes in kg/day of dry matter. Distributions for Pasture and Total are uniform, all others are triangular; values presented are the minimum, mode, and maximum of the distribution.

Season	Pasture	Alfalfa Hay	Grass Hay	Grain	Total
Winter	0	0.9 – 1.4 – 1.6	0	0.8 – 2 – 3.2	1.2 – 4.5
Spring	0.6 – 1.0	0.9 – 1.4 – 1.6	0	0.8 – 2 – 3.2	1.2 – 4.5
Summer	0.6 – 1.0	0.9 – 1.4 – 1.6	0	0.8 – 2 – 3.2	1.2 – 4.5
Early Fall	0.6 – 1.0	0.9 – 1.4 – 1.6	0	0.8 – 2 – 3.2	1.2 – 4.5
Late Fall	0	0.9 – 1.4 – 1.6	0	0.8 – 2 – 3.2	1.2 – 4.5

5. Feed-to-Milk Transfer

The factors relating transfer of ^{131}I from cows' feed to milk are described in Snyder et al. (1994). Based on review of historical reports, Snyder et al. defined a range for the parameter F_m , the feed-to-milk transfer coefficient for individual cows, with a median of 0.0092 day/liter and a geometric standard deviation of 2.1. The mean value of this distribution was applied to herds of cows, which is a surrogate for estimating the milk from each cow and then pooling it at a collection center. The mean value of the distribution is 0.012 day/liter.

The National Academy of Sciences review of the Hanford Thyroid Disease Study dose methodology suggests that the HEDR values "seem to be too high by a factor of about 2" compared with other values used in recent studies with which the NAS authors are familiar. They do note, however, that "this is an open issue, in that the measured values of this transfer coefficient vary over a large range for reasons that remain largely unexplained."

The relationship of the various available data sets on the feed-to-milk transfer coefficient was discussed in one of the last HEDR Project public meetings in Seattle. The subject was extensively discussed in that meeting by external reviewers and the public, and these values were accepted and used by the HEDR team.

At the Seattle meeting, additional reviews of this coefficient published by other groups were discussed. One of the most interesting was prepared as a joint effort between the U.S. Nuclear Regulatory Commission and the Commission of European Communities (NRC/EC 1997). This study grew out of an attempt to develop credible and traceable uncertainty distributions for the input variables in environmental assessment computer codes being developed by these entities. The study used expert elicitation methods to determine the ranges and bounds for a number of parameters, one of which was the feed-to-milk transfer coefficient for individual cows. For this multinational study, an elicitation procedure was developed, tested and clarified. Internationally recognized experts were selected using a common set of criteria. Probability training exercises were conducted to establish ground rules and set the initial and boundary conditions. The experts developed their distributions independently of each other. For the feed-to-milk transfer factor, 10 experts provided inputs. The experts were asked to provide their estimates of the fifth percentile, median, and ninety-fifth percentile values for the parameter. They provided

extensive rationale and supporting references, which are included in the final report. The raw estimates for each expert are provided in Table 5-1, along with the corresponding HEDR values (derived at the appropriate percentiles from the distribution in Snyder et al. 1994).

The NRC/EC report also developed an aggregated ranges provided by the experts into a single cumulative distribution. The overall ranges of distributions described by the various experts are compared to the aggregated value and to the HEDR distribution in Figure 1. (Note that the experts were only asked to provide 5% to 95% ranges, the HEDR distribution was truncated at the 1 and 99% levels). From Figure 5-1, it can be seen that the HEDR distribution generally falls within the upper portion of the ranges defined by the experts. The lower half of the HEDR range is somewhat higher, up to a factor of 5 higher than the experts' aggregated value at the 5% value. However, the upper portion of the range is essentially the same, from about the 50% to the 95% values. The HEDR values are actually lower than the experts' aggregate value beyond about the 85th percentile

The HEDR model used a herd-averaged transfer value to describe the general transfer of ¹³¹I in milk within the commercial milk distribution system. This is because pooling milk from many individual cows has the result of averaging the transfer factor. The HEDR herd-averaged value was obtained from the distribution of individual cows' transfer factors. The average of the HEDR distribution is 0.012 day/liter, which was assigned a

Table 5-1. Various experts' estimates of the ¹³¹I feed-to-milk transfer factor, d/L (NRC/EC 1997)

<i>Expert</i>	<i>5th percentile</i>	<i>Median</i>	<i>95th percentile</i>
H	0.001	0.01	0.04
I	0.001	0.007	0.03
J	0.001	0.01	0.04
K	0.001	0.01	0.035
L	0.001	0.011	0.034
M	0.001	0.005	0.01
N	0.0005	0.005	0.05
O	0.002	0.004	0.01
P	0.002	0.004	0.018
Q	0.002	0.01	0.02
HEDR	0.0028	0.0092	0.032

small uncertainty of a standard deviation of 0.002 day/liter. This value may be compared with the average of the expert elicitation process described above. The average of the expert elicitation process is about 0.015 day/liter. It may also be compared against other comparable values used in recent assessments. The International Union of Radioecologists (IUR/IAEA 1994) reports that the range of minimum to maximum values of F_m reported in the radioecological literature is about 1×10^{-3} to 3.5×10^{-2} day/liter. The IUR considers a “typical” value, i.e., one most likely to occur, to be about 0.01 day/liter. Studies referenced in the NRC/EC (1997) study include some for the computer codes ECOSYS (Muller et al. 1993) and MARC (Jones, Mansfield, and Crick 1995). These are both post-Chernobyl studies that attempted to review the pertinent literature. The HEDR herd distribution is compared to the ECOSYS, MARC, and NRC/EC values in Figure 5-2. The mean value for the ECOSYS distribution is 0.0055 day/liter, and for the MARC distribution is 0.011 day/liter. It can be seen that the HEDR, IUR/IAEA, and MARC results are all very close; the ECOSYS result is about one-half these others – and close to the results referenced in the National Academy review.

The HEDR value is also similar to that used in the estimation of iodine exposures from Nevada Test Site fallout in the PATHWAY model (Whicker and Kirchner 1987; Whicker et al. 1996). A mean of the transfer factor of 0.0084 day/liter can be derived for this model (Breshears et al. 1989), with a lognormal distribution with a 95% confidence interval from 0.005 to 0.14.

All of the studies described here were performed after the Chernobyl accident in 1986 and included post-Chernobyl results in their determination of distributions. It has been noted that the Chernobyl situation appears to be unique, and that concentrations of ^{131}I observed in milk after the accident were somewhat lower than expected on the basis of previous measurements (Kirchner 1994). In light of the recent studies, it appears possible that the distribution selected by HEDR could possibly have included some lower values with low probabilities, but that the average and upper range is in line with much of current understanding. However, when using parameters with relatively wide distributions, the average result is dominated by the higher values, which would not change were the HEDR selection to have included more low values.

Overall, the selection made appears to have been reasonable and prudent, particularly in light of pressure at the time from the public and the HEDR Technical Steering Panel to have higher values (see for example Price 1994, where herd-averaged values of 0.0126 for commercial and 0.0139 for backyard cows is suggested).

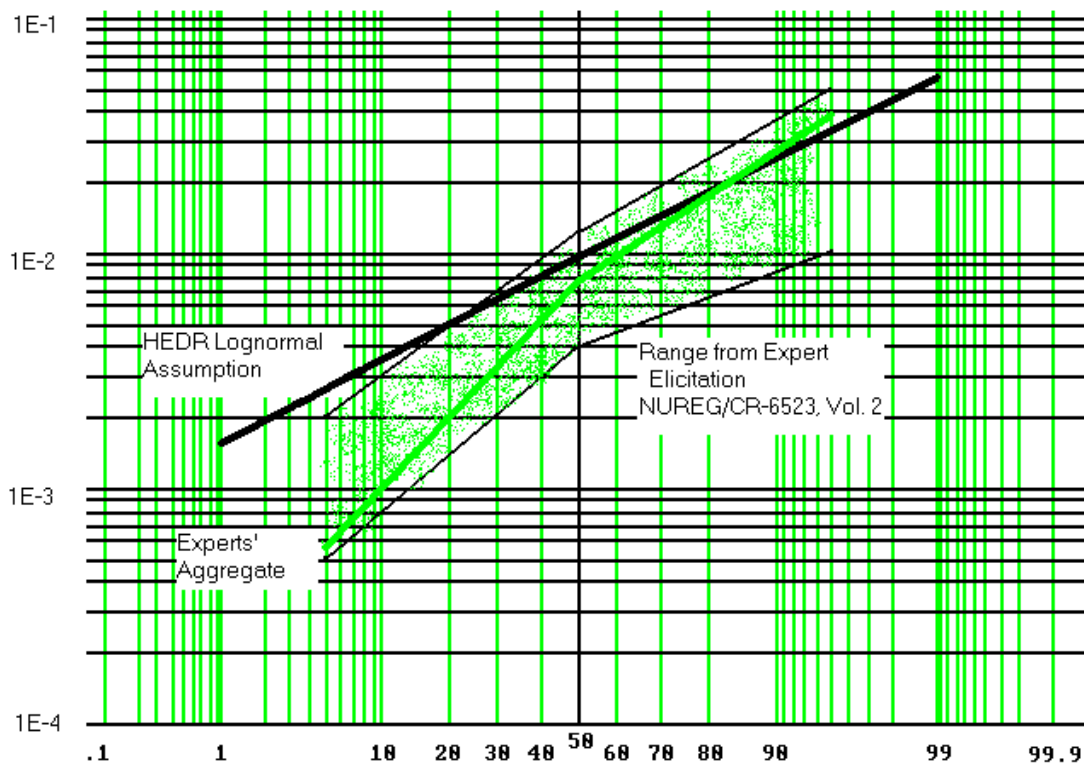


Figure 5-1. Comparison of HEDR feed-to-milk transfer factor to that developed through expert elicitation

5.1 References for Section 5

Breshears, D.D., T.B. Kirchner, M.D. Otis, and F.W. Whicker, 1989. "Uncertainty in Predictions of Fallout Radionuclides in Foods and of Subsequent Ingestion," *Health Physics*; 57(6):943-953

International Union of Radioecologists and International Atomic Energy Agency (IUR/IAEA), 1994. *Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Temperate Environments*, Technical Reports Series No. 364, IAEA, Vienna.

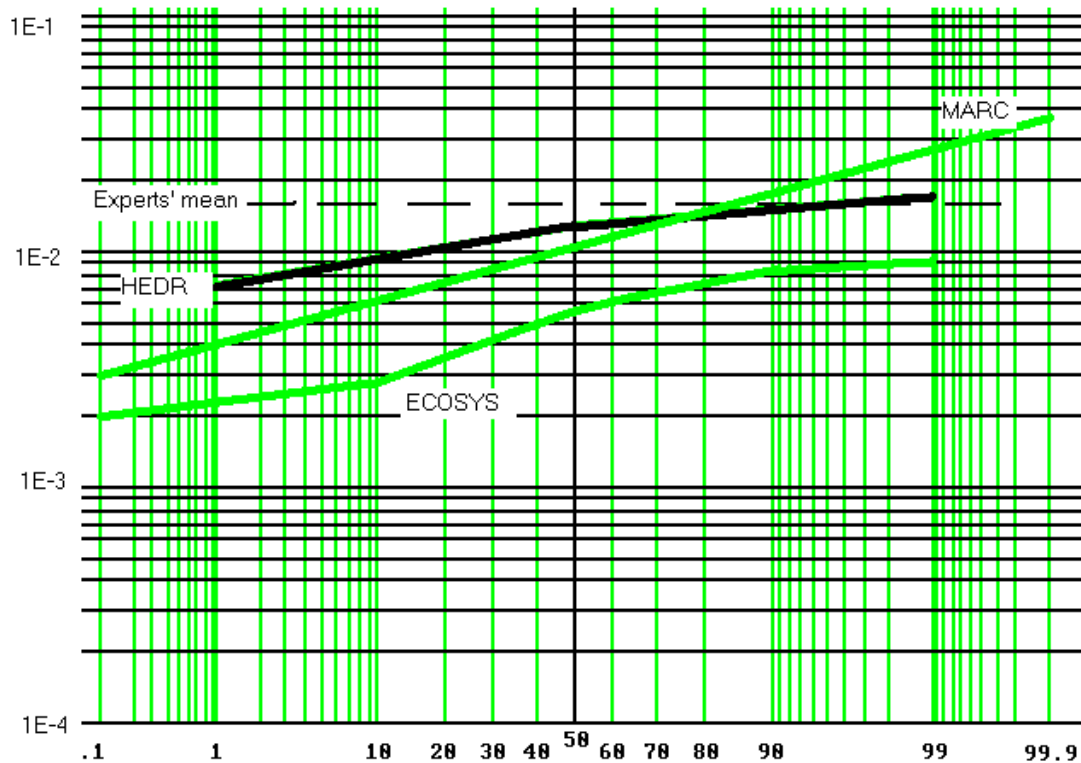


Figure 5-2. Comparison of HEDR feed-to-milk transfer factor with those used in other recent assessments

Jones, J.A., P.A. Mansfield, and M.J. Crick. 1995. Uncertainty Analysis of the Predicted Consequences of Nuclear Accidents using the NRPB Code MARC-2A, NRPB-R274, Chilton, England

Kirchner, G. 1994. "Transport of Iodine and Cesium Via the Grass-Cow-Milk Pathway After the Chernobyl Accident," Health Physics;66(6):653-665

Muller, H., W. Friedland, et al., "Uncertainty in the Ingestion Dose Calculation," Radiation Protection Dosimetry, 50 (1-4), 353-357, 1993.

Price, D.W. 1994. Dairy Cow Feeding Regimes for Representative Doses, Special Report, Technical Steering Panel of the Hanford Environmental Dose Reconstruction Project

Snyder, S.F., W.T. Farris, B.A. Napier, T.A. Ikenberry, and R.O. Gilbert. 1994. Parameters Used in the Environmental Pathways and Radiological Dose Modules (DESCARTES, CIDER, and CRD) of the Hanford Environmental Dose Reconstruction Integrated Codes (HEDRIC). PNWD-2023 HEDR Rev. 1, Battelle Pacific Northwest Laboratories, Richland, Washington

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- Whicker, F.W., T.B. Kirchner, L.R. Anspaugh, and Y.C. Ng, 1996. "Ingestion of Nevada Test Site Fallout: Internal Dose Estimates," *Health Physics*;71(4):477-486
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6. Fetal Dose Conversion Factors

The National Academy of Sciences review of the HTDS dosimetry results noted that the uncertainty estimates accompanying the individual HTDS doses appeared to be too low. The geometric standard deviations of some doses were estimated to be as low as 1.4, while the geometric standard deviation (GSD) of the dose conversion factors themselves was about 2.0 (Snyder et al. 1994). The NAS reviewers noted that the doses estimated for reference individuals in the HEDR project had uncertainties with GSDs of 2 or greater (Farris et al. 1994). The NAS recommended that the HTDS authors explain why the uncertainty ranges were so narrow for this class of doses.

This comment induced the HTDS staff to review the input parameters used in the calculations. All dose conversion factor values that were used are documented in Snyder et al. (1994). All of the internal dose conversion factors in Snyder et al. (1994) have GSDs of 2 or greater, with one exception. The exception is the prenatal dose factor – the one applied to individuals in the period prior to birth. The description of that factor implied a GSD of 2 would be appropriate, but a triangular approximation using one-half to twice the central value was used (Snyder et al. 1994, page 6.58). Because none of the reference dose calculations prepared for the HEDR final reports used this parameter, this had no impact on the HEDR calculations and the parameter as input to the codes was not seriously reviewed. The HTDS staff acquired the HEDR code CIDER with its associated databases, and also did not seriously question this selection until it was pointed out by the NAS. This narrow distribution would result in overall narrowed uncertainties for individuals who were primarily exposed *in utero*.

Upon the discovery of the nature of this parameter by HTDS, the remaining HEDR staff prepared a new input file of the prenatal dose factors using the central value of Snyder et al. supplemented with a GSD of 2. This updated file was supplied in February 2000 to staff of the Fred Hutchinson Cancer Research Center, the Centers for Disease Control and Prevention, and the Individual Dose Assessment project. It has been used for all subsequent calculations and recalculations.

6.1 References for Section 6

Snyder, S.F., W.T. Farris, B.A. Napier, T.A. Ikenberry, and R.O. Gilbert. 1994. Parameters Used in the Environmental Pathways and Radiological Dose Modules (DESCARTES, CIDER, and CRD) of the Hanford Environmental Dose Reconstruction Integrated Codes (HEDRIC). PNWD-2023 HEDR Rev. 1, Battelle Pacific Northwest Laboratories, Richland, Washington

Farris, W.T., B.A. Napier, T.A. Ikenberry, J.C. Simpson, and D.B. Shipler. 1994. Atmospheric Pathway Dosimetry Report, 1944-1992, Hanford Environmental Dose Reconstruction Project, PNWD-2228 HEDR, Battelle Pacific Northwest Laboratories, Richland, Washington

7. CIDER modifications

Several small changes were made to the CIDER (Ouderkirk and Eslinger 1993; Eslinger et al. 1994) dose calculation computer code.

7.1 Hardware requirements for new version of CIDER.

The original version of the CIDER code was developed for the large HEDR Sun computer. That machine was decommissioned after the HEDR project ended, and neither Battelle Pacific Northwest Laboratories nor Fred Hutchinson Cancer Research Center Hanford Thyroid Disease Study (HTDS) have comparable machines available. Battelle has implemented other modules of the HEDR codes on a PC with capabilities that are modest by current standards (512 MB of memory, 18GB hard drive [much less is required to run CIDER], 233 Mhz). It was agreed that further revisions would be made on a PC version, which HTDS could then run in-house. This benefits HTDS by removing the difficulties inherent in transferring scenario files and dose estimation results back and forth from the Centers for Disease Control and Prevention (CDC) system. It should also be a fairly simple matter for HTDS to identify or acquire a PC adequate to run the new version of CIDER. The adoption of a PC-based version will also be generally beneficial by providing a more portable system. However it will also require CDC to adopt the new version as the current standard.

7.2 Internal correlations

The original CIDER code performed no stochastic variable selection; all realizations of all parameters were input from externally created files. This was done for simplicity in CIDER and for repeatability of the calculations. This has no influence on any individual dose calculation; however, when analyzing the entire set of HTDS subjects, it can result in undesirable internal correlations between individuals. The correlations occur because the random variables are always selected in the same order for the realizations, which causes statistically-observable patterns in the results. The patterns are artifacts of the calculation process that interfere with the overall analyses. The CIDER code was modified to allow randomization of the order of selection of stochastic dose conversion factors. The same external files are accessed, but the order of use of the values is now permuted on the basis of an input key, which may be made unique for every person.

7.3 Uncertainties in Reported Dietary Intakes

The National Academy of Science review of the HTDS noted that “The HTDS did not take into account the uncertainties associated with the recall – 5 decades after the period of exposure – of the origin of milk, the milk consumption rate, or changes in residence. That is a serious flaw of the methodology...” The HTDS protocol was widely debated when it was designed, and public sentiment at the time was strongly against any modification of the reported values. Therefore, at the Technical Steering Panel’s direction, the CIDER code was designed to accept the respondents’ input without modifications.

No data are available from the Computer-Aided Telephone Interview (CATI) to assess the uncertainties in the reported information. The largest set of detailed information on American food consumption patterns as functions of age, sex, location, and lifestyle come from the U.S. Department of Agriculture 1977-78 Nationwide Food Consumption Survey (USDA 1983). This information was adapted for the CIDER code and, through a backcasting technique, a series of default reference diets were prepared (Anderson 1993). These reference diets were used for all HEDR project example calculations, and were used to support the HTDS calculations for foods not reported by the HTDS respondents. Essentially all that is available about the variability of American intakes of various foods is summarized in the reference diet tables.

A practical method for assigning uncertainties to the dietary factors in CIDER is to apply the uncertainty for dietary factors from the reference diets used in default calculations to the reported values from the CATI. However this approach applies only to dietary consumption data, since the use of reference diet value sets $\{R_{p,1}, \dots, R_{p,100}\}$ is already built into CIDER. This does not apply to the remaining input parameters: distributions of milk/food products among sources, residence history (locations and periods of residence), family cow feeding regimes, and breast-feeding characteristics (yes/no, wean date). Major structural modifications of CIDER would be required to incorporate uncertainty of these input parameters. Therefore it was agreed that only dietary factors would be addressed.

Several ideas were developed for incorporating uncertainties about dietary consumption levels reported from the CATI for HTDS participants. There is no simple and

direct way to do this, because the data were collected with the explicit intention of using it directly. It was determined that the most defensible approach would be the simplest approach that allowed investigation of the impact of various options on the final dose/response results. In a telephone conversation with Dr. Ken Kopecky, FHCRC, on July 28, 2000, the following approach was outlined. The purpose of this approach is to allow a wide degree of flexibility in modeling these uncertainties, so that their impact on HTDS dose estimates and dose response results can be explored.

The approach that was implemented proceeds as follows:

Specify a scaling factor $SF_0 \geq 0$, which controls the handling of reported consumption values of 0: if $SF_0 = 0$, no uncertainty will be applied to reported values of 0; if $SF_0 > 0$, then uncertainty will be applied.

Specify the value of two parameters:

- $SF \geq 0$, a scaling factor for the application of reference diet uncertainties, and
- $G \geq 0$, a geometric standard deviation for the application of lognormal uncertainties.

For each of these parameters, specifying a value of 0 indicates that the corresponding uncertainty will not be applied to the reported consumption values. Since at most one type of uncertainty will be applied, an error is reported and processing stops if both SF and G are assigned values greater than 0. The possible combinations of the three parameters are summarized in Table 7-1.

The implementation of the transformation proceeds as follows:

If $SF > 0$ and $G = 0$, reference diet uncertainties are obtained by transforming the reported consumption value R_p into 100 realizations $r_{p,1}, \dots, r_{p,100}$ as

$$r_{p,i} = \begin{cases} SF_0 \times m_p \times (R_{p,j[i]} / m_p)^{SF} & \text{if } R_p = 0 \\ R_p \times (R_{p,j[i]} / m_p)^{SF} & \text{if } R_p > 0 \end{cases}$$

where

$$i = 1, \dots, 100,$$

$\{R_{p,1}, \dots, R_{p,100}\}$ is the reference diet, indexed by realizations 1, ..., 100,

Table 7-1. CIDER Input Options for Handling Uncertainties in Reported Consumption

SF_0	SF	G	Handling of uncertainty and reported values of 0
0	0	0	No uncertainty is applied to any reported consumption values; all reported values (including 0s) are left unchanged
> 0	0	0	No uncertainty is applied to reported consumption values; reported values of 0 are replaced with positive values with no uncertainty
0	> 0	0	Reference diet uncertainties are applied to reported consumption values > 0; reported values of 0 are left as 0 with no uncertainty
> 0	> 0	0	Reference diet uncertainties are applied to reported consumption values > 0, and to positive values substituted for reported values of 0
0	0	> 0	Lognormal uncertainties are applied to reported consumption values > 0; reported values of 0 are left as 0 with no uncertainty
> 0	0	> 0	Lognormal uncertainties are applied to reported consumption values > 0, and to positive values substituted for reported values of 0
0	> 0	> 0	Not permissible
> 0	> 0	> 0	Not permissible

$\{j[1], \dots, j[100]\}$ is a pseudorandomly generated permutation of the indices 1, ..., 100, and

m_p is the mean of $R_{p,1}, \dots, R_{p,100}$.

Note that this transformation has the following effects:

- If the reported value R_p is positive, then $r_{p,i} = 0$ whenever $R_{p,j[i]} = 0$. In other words, any zeroes present in the reference diet will be reflected in the uncertainty applied to the reported value.

- If the reported value R_p is zero and $SF_0 > 0$, then R_p is replaced by $SF_0 \times m_p$, which can be made “small” by a sufficiently small choice of SF_0 . As above, any zeroes present in the reference diet will be reflected in the uncertainty applied to the reported value.
- If $SF_0 = 0$, then no uncertainty is applied to reported values of zero (i.e., $R_p = 0$ is transformed into $r_{p,1} = r_{p,2} = \dots = r_{p,100} = 0$).
- If $SF > 0$, then the GSD of $r_{p,1}, \dots, r_{p,100}$ for $R_p > 0$ (and for all R_p if $SF_0 > 0$) is g^{SF} where g is the GSD of the reference diet $\{R_{p,1}, \dots, R_{p,100}\}$; thus if $SF = 1$, the uncertainty about reported consumption values has the same GSD as the corresponding reference diet.

If $SF = 0$ and $G > 0$, reference diet uncertainties are obtained by transforming the reported consumption value R_p as

$$r_{p,i} = \begin{cases} S_i \times SF_0 \times m_p & \text{if } R_p = 0 \\ S_i \times R_p & \text{if } R_p > 0 \end{cases}$$

where

$\{S_1, \dots, S_{100}\}$ is a set of pseudorandomly generated realizations of a lognormally distributed random variable with mean 1 and geometric standard deviation G .

Note that if $SF_0 > 0$, then $r_{p,i} > 0$ for all i ; in other words, all of the realizations $r_{p,i}$ are positive, even if the reported consumption value is 0. If $SF_0 = 0$, then $r_{p,i} > 0$ for all i if $R_p > 0$, while $r_{p,i} = 0$ for all i if $R_p = 0$; that is the realizations $r_{p,i}$ are all either 0 or positive, depending on whether R_p is 0 or positive, respectively.

The lognormal variates $S_1, \dots, S_{100}$ are generated as a new set of 100 realizations $\{S_1, \dots, S_{100}\}$ each time.

A minor difficulty with the two approaches defined above is that in the reference diets there are some food types for which all default realizations are zero. That is, no person in 1977 of that age/sex/season/urbanization combination reported eating that particular food. As a result, the mean of the reference diet distribution is zero, which would cause problems with undefined variables for some combinations of input. Therefore, an additional step of establishing surrogate diets for those few food categories was undertaken. The cases of all-zero food consumption occur only for some combinations of age/season for very young children. The only foods for which the problem occurs are leafy vegetables, eggs, and

poultry. Because there are always combinations of age/sex/season/urbanization that are closely related (rural versus urban, or summer versus fall) that do have non-zero results, it was felt better to use the closest approximation than to attempt to create another diet category. A diet surrogate matrix was established that cross-referenced each food type in each reference diet with either itself or a similar non-zero set of entries. This matrix was added to the internal CIDER data so that the several versions of the diet file would not need to be changed. The matrix is only invoked when one or more of SF_0 , SF , or G is non-zero. The contents and format of the addition are shown in Table 7-2. Entries are indexed by row and column; entries indicate which reference diet the code should access when looking for a non-zero set of data for a particular food type. Note that only 12 transfers are indicated.

The algorithms and options described above were added to the CIDER code. The resulting changes were tested independently and together, and the results compared to equivalent results from the original, unmodified code. Additional observational and hand-calculation tests were made to ensure that the code processes the options correctly. Additional tests were run by FHCRC staff to verify the changes. Code development and testing records have been maintained and are available in project records.

7.3 References for Section 7

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- Eslinger, P.W., K.S. Lessor, and S.J. Ouder Kirk. 1994. User Instructions for the CIDER Dose Code. PNWD-2252 HEDR, Battelle Pacific Northwest Laboratories, Richland, Washington.
- Ouder Kirk, S.J., P.W. Eslinger. 1993. Software Design Description for the CIDER Dose Estimation Computer Code, Battelle Pacific Northwest Laboratories, Richland, Washington.
- U.S. Department of Agriculture (USDA). 1983. Food Consumption: Households in the United States, Seasons, and Years 1977-1978. National Food Consumption Survey 1977-1978, Report No. H-6, Human Nutrition Information Service, Consumer Nutrition Division. U.S. Government Printing Office, Washington, D.C.

Table 7-2. Non-zero diet pointers for reference diet file

1. f-milk	2. s-milk	3. l-veg	4. o-veg	5. fruit	6. grain	7. eggs	8. beef	9. poultry
1	1	1	1	1	1	1	1	1
2	2	17*	2	2	2	107	2	2
3	3	3	3	3	3	3	3	3
4	4	4	4	4	4	4	4	4
5	5	5	5	5	5	5	5	5
6	6	6	6	6	6	6	6	6
7	7	7	7	7	7	7	7	7
8	8	8	8	8	8	8	8	8
9	9	9	9	9	9	9	9	9
10	10	10	10	10	10	10	10	10
11	11	11	11	11	11	11	11	11
12	12	12	12	12	12	12	12	12
13	13	13	13	13	13	13	13	13
14	14	14	14	14	14	14	14	14
15	15	15	15	15	15	15	15	15
16	16	16	16	16	16	16	16	16
17	17	17	17	17	17	77	17	17
18	18	18	18	18	18	18	18	18
19	19	19	19	19	19	19	19	19
20	20	20	20	20	20	20	20	20
21	21	21	21	21	21	21	21	21
22	22	22	22	22	22	22	22	22
23	23	23	23	23	23	23	23	23
24	24	24	24	24	24	24	24	24
25	25	25	25	25	25	25	25	25
26	26	26	26	26	26	26	26	26
27	27	27	27	27	27	27	27	27
28	28	28	28	28	28	28	28	28
29	29	29	29	29	29	29	29	29
30	30	30	30	30	30	30	30	30
31	31	31	31	31	31	31	31	31
32	32	17	32	32	32	92	32	32
33	33	33	33	33	33	33	33	33
34	34	34	34	34	34	34	34	34
35	35	35	35	35	35	35	35	35
36	36	36	36	36	36	36	36	36
37	37	37	37	37	37	37	37	37
38	38	38	38	38	38	38	38	38
39	39	39	39	39	39	39	39	39
40	40	40	40	40	40	40	40	40
41	41	41	41	41	41	41	41	41
42	42	42	42	42	42	42	42	42
43	43	43	43	43	43	43	43	43
44	44	44	44	44	44	44	44	44
45	45	45	45	45	45	45	45	45
46	46	46	46	46	46	46	46	46
47	47	17	47	47	47	107	47	47
48	48	48	48	48	48	48	48	48

1. f-milk	2. s-milk	3. l-veg	4. o-veg	5. fruit	6. grain	7. eggs	8. beef	9. poultry
49	49	49	49	49	49	49	49	49
50	50	50	50	50	50	50	50	50
51	51	51	51	51	51	51	51	51
52	52	52	52	52	52	52	52	52
53	53	53	53	53	53	53	53	53
54	54	54	54	54	54	54	54	54
55	55	55	55	55	55	55	55	55
56	56	56	56	56	56	56	56	56
57	57	57	57	57	57	57	57	57
58	58	58	58	58	58	58	58	58
59	59	59	59	59	59	59	59	59
60	60	60	60	60	60	60	60	60
61	61	61	61	61	61	61	61	61
62	62	62	62	62	62	107	62	62
63	63	108	63	63	63	63	63	63
64	64	64	64	64	64	64	64	64
65	65	65	65	65	65	65	65	65
66	66	66	66	66	66	66	66	66
67	67	67	67	67	67	67	67	67
68	68	68	68	68	68	68	68	68
69	69	69	69	69	69	69	69	69
70	70	70	70	70	70	70	70	70
71	71	71	71	71	71	71	71	71
72	72	72	72	72	72	72	72	72
73	73	73	73	73	73	73	73	73
74	74	74	74	74	74	74	74	74
75	75	75	75	75	75	75	75	75
76	76	76	76	76	76	76	76	76
77	77	92	77	77	77	77	77	77
78	78	78	78	78	78	78	78	78
79	79	79	79	79	79	79	79	79
80	80	80	80	80	80	80	80	80
81	81	81	81	81	81	81	81	81
82	82	82	82	82	82	82	82	82
83	83	83	83	83	83	83	83	83
84	84	84	84	84	84	84	84	84
85	85	85	85	85	85	85	85	85
86	86	86	86	86	86	86	86	86
87	87	87	87	87	87	87	87	87
88	88	88	88	88	88	88	88	88
89	89	89	89	89	89	89	89	89
90	90	90	90	90	90	90	90	90
91	91	91	91	91	91	91	91	91
92	92	92	92	92	92	92	92	92
93	93	93	93	93	93	93	93	93
94	94	94	94	94	94	94	94	94
95	95	95	95	95	95	95	95	95
96	96	96	96	96	96	96	96	96
97	97	97	97	97	97	97	97	97
98	98	98	98	98	98	98	98	98

1. f-milk	2. s-milk	3. l-veg	4. o-veg	5. fruit	6. grain	7. eggs	8. beef	9. poultry
99	99	99	99	99	99	99	99	99
100	100	100	100	100	100	100	100	100
101	101	101	101	101	101	101	101	101
102	102	102	102	102	102	102	102	102
103	103	103	103	103	103	103	103	103
104	104	104	104	104	104	104	104	104
105	105	105	105	105	105	105	105	105
106	106	61	106	106	106	106	106	106
107	107	92	107	107	107	107	107	107
108	108	108	108	108	108	108	108	108
109	109	109	109	109	109	109	109	109
110	110	110	110	110	110	110	110	110
111	111	111	111	111	111	111	111	111
112	112	112	112	112	112	112	112	112
113	113	113	113	113	113	113	113	113
114	114	114	114	114	114	114	114	114
115	115	115	115	115	115	115	115	115
116	116	116	116	116	116	116	116	116
117	117	117	117	117	117	117	117	117
118	118	118	118	118	118	118	118	118
119	119	119	119	119	119	119	119	119
120	120	120	120	120	120	120	120	120

* Shaded cells indicate sets of all-zero consumption realizations, and the entries therein indicate to which alternative set of data the CIDER code refers.