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UNCERTAINTY AND SENSITIVITY ANALYSIS OF HISTORICAL VEGETATION IODINE-131 MEASUREMENTS IN 1945-1947

Hanford Environmental Dose Reconstruction Project

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This document has been reviewed and approved by the Technical Steering Panel.

J. E. Till, Chair
Technical Steering Panel
Hanford Environmental
Dose Reconstruction Project

March 9, 1994
Date

PREFACE

The purpose of the Hanford Environmental Dose Reconstruction (HEDR) Project is to estimate doses that individuals may have received from emissions of radioactive air and water from Hanford Site nuclear facilities since 1944. A major objective of the HEDR Project is to estimate doses to the thyroid of individuals who were exposed to iodine-131 by drinking milk. The milk was obtained from cows that ate vegetation contaminated by iodine-131 released into the air from Hanford facilities.

7 To support this work, HEDR Project staff developed a database of historical environmental measurements. This database includes iodine-131 concentrations for vegetation samples collected around the Hanford Site since 1945. To support this effort, staff of the HEDR Project examined the quality of historical vegetation iodine-131 measurements by reconstructing and evaluating the vegetation sampling and analysis methods used at Hanford in 1945-1947, when air emissions of iodine-131 from Hanford were at their peak (Napier 1992). This effort included compiling the radiation *counts*-per-minute per gram (cpm/g) measurements of vegetation collected in counties around the Hanford Site in the mid-1940s and estimating the uncertainties inherent in using a newly developed model to convert (using a predictive equation) those cpm/g measurements to vegetation iodine-131 concentrations in microcuries per kilogram (μCi/kg). It is anticipated that this conversion process will provide improved (less uncertain) values for vegetation iodine-131 concentrations.

8 This report focuses on 1) estimating the magnitude of uncertainty in the iodine-131 concentrations obtained using the predictive equation in Mart et al. (1993) and 2) determining which parameters in the predictive equation may need additional study to reduce those uncertainties. The report also is intended to contribute to a better understanding of the concepts, methods, and complexities involved in assessing uncertainties of model predictions. An understanding of uncertainty, how it is estimated, and what it means is

particularly important for interpreting the estimated doses to specific individuals and population groups that will be obtained by HEDR Project staff using environmental transport and dose models.

This report completes HEDR Project Milestone 0802A. It is the final report, replacing the previous version dated July 1992. Appendix C is a record of the TSP comments and BNW responses.

SUMMARY

The Hanford Environmental Dose Reconstruction (HEDR) Project is developing environmental transport and dose models to estimate the doses to individuals and populations from exposure to radionuclides released from Hanford nuclear facilities since 1944. The validity of these models will be assessed in part by comparing model predictions with environmental measurements of radionuclides. One potentially important set of environmental radionuclide measurements is those made on vegetation samples that, beginning in 1945, were collected on and around the Hanford Site. However, from October 1945 through mid-1948, the available technology permitted the vegetation samples to be measured only for total radioactivity rather than for specific radionuclides. At that time, the factors needed to convert total radioactivities to concentrations (μCi/kg) of iodine-131, the predominant radionuclide that was released into the air from Hanford stacks in the mid-1940s, were not well known or accurately quantified. A search of historical Hanford records by HEDR Project staff uncovered the original background-corrected radiation measurements made using a Geiger-Mueller (GM) detector system. The measurements were of radiation in vegetation samples collected from October 1945 through early August 1946. HEDR Project staff have developed a model that can be used to convert these radiation measurements to iodine-131 concentrations (μCi/kg). It is anticipated that this equation will be used to obtain more accurate concentrations of iodine-131 in vegetation for the purpose of validating vegetation iodine-131 concentrations that will be estimated by HEDR Project air-pathway transport models.

The iodine-131 concentrations obtained using the predictive model are uncertain to some extent due to model uncertainty as well as incomplete knowledge about which values of the model parameters should be used in the model. In this report, we estimated the magnitude of the uncertainty in the predicted iodine-131 concentrations. The uncertainty is a result of uncertainty in the parameter values. This estimate was developed for two specific vegetation

samples: a sagebrush sample collected in Richland, Washington, on December 20, 1945, and a sample of unknown species collected on the Hanford Site north of Richland on July 15, 1946. Then we used sensitivity analyses to determine which parameters in the predictive model contributed the most uncertainty to the estimated iodine-131 concentrations for these samples. The results of these analyses provide guidance on whether an attempt should be made to reduce lack of knowledge about parameter values and thereby reduce the uncertainty of estimated (predicted) vegetation iodine-131 concentrations. This report does not attempt to assess the uncertainties in iodine-131 concentrations that are related to the methods used in the mid-1940s to select, collect, and transport vegetation samples. That topic is discussed in Mart et al. (1993).

The uncertainty analyses indicate that the iodine-131 concentration for any given historical vegetation sample can be estimated to within a factor of three or less. That is, when the computed deterministic predicted concentration for any given positive (iodine-131 concentration greater than zero) vegetation sample collected from October 1945 through December 1947 is divided and then multiplied by three, the resulting interval should include the true iodine-131 concentration for the sample.

The sensitivity analyses indicate that among the 16 parameters in the predictive model, four of the five most important are related to counting-geometry and radiation-absorption factors that must be considered when converting the counts-per-minute (cpm) obtained by the GM detector system to μCi/kg of iodine-131. The other parameter among the top five is I_{cf}, which is the fraction of the vegetation radioactivity measured by the GM detector that was due to iodine-131 only. This parameter was the most important parameter for the July 15, 1946, sample. This result reflected the large uncertainty in the value of I_{cf} for this particular sample. That is, there was large uncertainty about the amount of radionuclides other than iodine-131 on the July 1946 vegetation sample. The parameter I_{cf} was only the fifth most important parameter for the December 20, 1945, sample because the uncertainty in the value of I_{cf} for that sample was small. (The historical record clearly indicates that only very small amounts of radionuclides other than iodine-131 were deposited on vegetation in December 1945.)

On the basis of the sensitivity-analysis results, one course of action would have been to conduct additional literature searches or empirical studies to obtain additional information about the five most important parameters to reduce their uncertainty, thereby reducing the uncertainty in the estimated iodine-131 concentrations obtained using the modeling equation presented in this paper as Equation (5). However, this approach was not taken for two reasons. First, it is unlikely that additional information exists to reduce parameter uncertainties sufficiently to make a substantial reduction in the uncertainty of vegetation iodine-131 concentrations.

Second, there may be no need to reduce the uncertainty of the historical vegetation iodine-131 concentrations. The primary use of the historical vegetation iodine-131 concentrations is to help validate the HEDR Project source-term, air-transport, and environmental accumulation models being used to compute vegetation iodine-131 concentrations in the study area as an intermediate step in computing doses to individuals from exposure to iodine-131 via the air pathway. The uncertainties in the predicted vegetation iodine-131 concentrations obtained on the basis of these models are likely to be very large because of the large uncertainties in some model parameter values. The uncertainties in the model predicted iodine-131 concentrations are likely to be so large that reducing the uncertainties in converting measured historical cpm/g radiation measurements to iodine-131 concentrations will not perceptibly affect the conclusions of the validation effort.

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FIGURES

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1.0 INTRODUCTION

Section 1.1 provides background information about the vegetation measurement program that was conducted at Hanford in 1945 through 1947 and related work conducted to date by the Hanford Environmental Dose Reconstruction (HEDR) Project. Section 1.2 states the purpose of this report.

1.1 BACKGROUND

Beginning in 1945, vegetation samples were collected in the Hanford environs and measured for radioactivity. From October 1945 to December 1948, the standard procedure for measuring total activity for a collected vegetation sample was to prepare a 1-g pellet of the sample, mount it on a cardboard backing, place it on the second shelf of a mica-window Geiger-Mueller (GM) detector system (Figure 1), cover the pellet with a piece of cellophane, measure the count rate (cpm/g), and correct that rate for background (counter and laboratory) activity. Then a conversion factor was used to convert the 1940s background-corrected count rate to disintegrations per minute per gram (dpm/g) of iodine-131. This dpm/g value was then divided by 2.22×10^3 to convert it to μCi/kg of iodine-131 (Mart et al. 1993).

In the mid-1940s, counting technology had not progressed to a point where it was possible to accurately determine the value of the conversion factor (Healy, Schwendiman, and Thorburn 1950) (see Sections 3.1 through 3.7). Some parameters in the factor were ignored or miscalculated, and accurate iodine-131 standards were not available. In addition, until about July 1946, the conversion of gross cpm/g data to iodine-131 μCi/kg concentrations did not take into account the iodine-131 radiological decay that occurred in the interval between when the sample was collected in the field and when it was counted in the laboratory (see Section 3.8). Also, until 1948, it was assumed that all of the activity measured on vegetation was from iodine-131 (see Section 3.9). Indeed, the fraction of total radioactivity that was due to

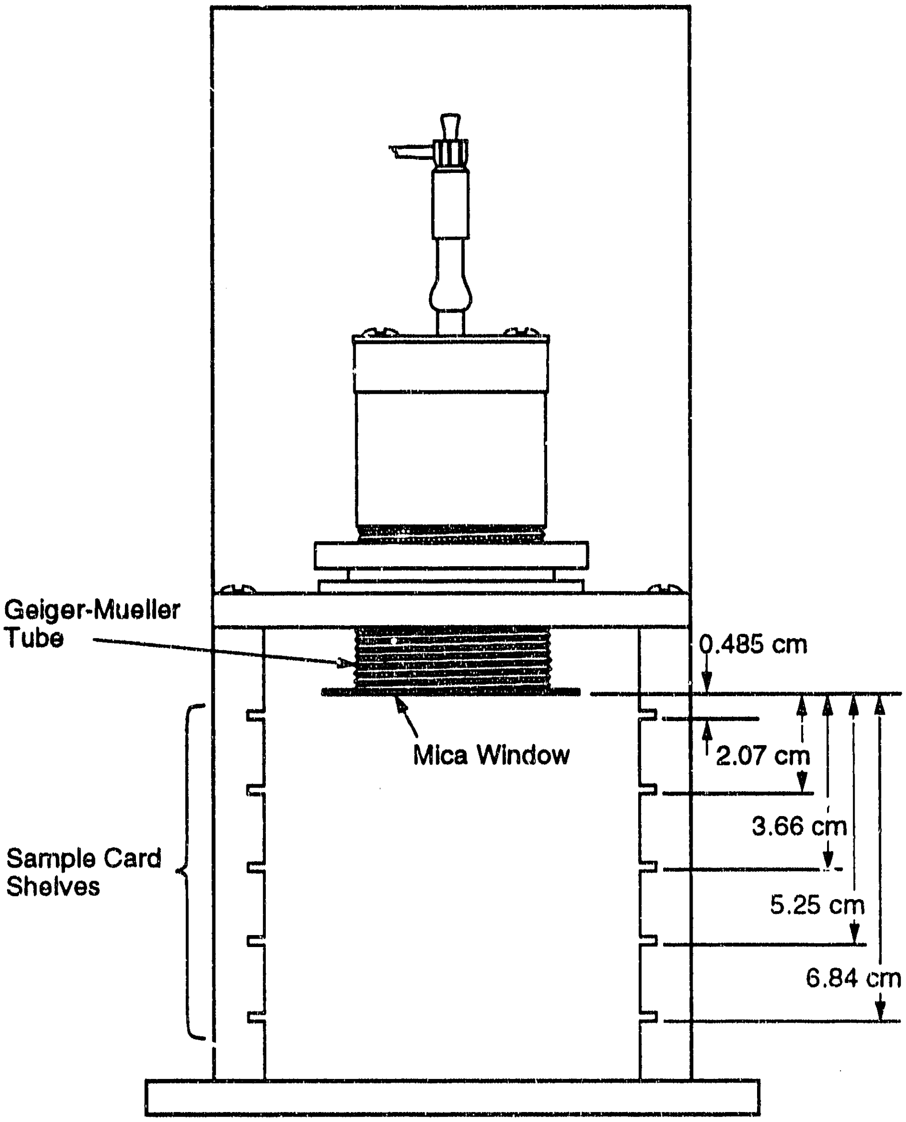


FIGURE 1. End Mica-Window Geiger-Mueller Tube Support and Shelf Assembly Used in the Mid-1940s

iodine-131 was probably very close to 1 in 1945, as indicated by decay measurements of onsite samples in February (Parker and Gamertsfelder 1945), July (Bulow 1945), and November 1945 (Healy and Eisenacher 1946). However, as time went on, other radionuclides made up a larger fraction of the activity because of 1) longer fuel cooling times (time between removal of irradiated fuel from the nuclear reactors and dissolution of the fuel in the chemical-separations facilities); 2) the installation of high-efficiency sand filters (in late 1948), fiberglass filters (in 1950), and silver reactor filters (in early 1951) in the air waste streams of chemical separation facilities to remove up to 99.99% of the iodine-131 (Burger 1991); and 3) the gradual accumulation of long-lived fission products on vegetation. As a result, the iodine-131 activities (μCi/kg) that were reported from 1945 to 1948 were biased to varying degrees. Eventually, however, more conversion factors and parameters were specifically taken into account, so that the accuracy of the reported iodine-131 activities improved. A large part of this bias was eliminated in mid-1948 when counting of vegetation pellets was supplemented by a procedure wherein iodine-131 was chemically separated from the vegetation as a silver-iodine (AgI) precipitate, which was then counted for gross activity. Beginning in December 1948, the procedure involving pellets was completely abandoned for routine analyses in favor of the AgI-precipitate procedure.

Scientists on the HEDR Project have made a significant effort to obtain more accurate historical iodine-131 vegetation concentrations by 1) reconstructing more accurate factors for converting historical cpm/g measurements to dpm/g, 2) accounting for the radiological decay that occurred between sample collection and counting, and 3) evaluating more fully the changes over time in the proportion of the vegetation radioactivity that was due entirely to iodine-131. These efforts have been conducted primarily to provide information for comparing the historical measured values of iodine-131 to the vegetation iodine-131 concentrations (deposition patterns) that will be estimated by the air-pathway transport models being developed by HEDR Project staff. The model that was developed to obtain these more accurate concentrations is discussed briefly in this report and more thoroughly in the Mart et al. (1993).

To support this effort, parameter uncertainty analyses were conducted using computer-simulation methods (Iman and Shortencarier 1984) to assess the amount of uncertainty remaining in vegetation iodine-131 concentrations obtained using the new model. In addition, correlation-regression sensitivity analyses were conducted using the method given by Iman, Shortencarier, and Johnson (1985) to determine which parameters in the improved computational model contribute most to the uncertainty of the computed iodine-131 concentrations. These identified parameters are candidates for study if efforts are needed to reduce further the uncertainty in computed historical iodine-131 concentrations for vegetation. This report describes and presents the results of these uncertainty and sensitivity analyses.

Parameter uncertainty and sensitivity analyses have been conducted for two historical vegetation samples: one collected in Richland, Washington, on December 20, 1945, and counted the same day (Healy 1945), and one collected on the Hanford Site north of Richland on July 15, 1946, and counted the same day (Dickinson 1946). The sample collected in December 1945 was formed into a pellet by hand (a "hand-formed" pellet), whereas the sample collected on July 15, 1946, was formed into a pellet using a hand-operated press (a "press-formed" pellet). The method used to press-form pellets is described by Healy et al. (1951) and in Mart et al. (1993).

These two samples were selected for three reasons. First, both had detectable levels of activity, so that biases and uncertainties that might be present in measurements near the detection limit were avoided. (This study does not estimate iodine-131 concentration uncertainties for vegetation samples with iodine concentrations at or very close to background levels.) Second, there was a need to assess the uncertainties in iodine-131 concentrations for both hand-formed and press-formed pellets because the dimensions of the two pellet types differed somewhat (as indicated by reconstructed hand- and press-formed pellets discussed in Section A.3 in Appendix A), which would affect the values of some model parameters. Third, the December 1945 sample represents the time when almost all of the activity measured on vegetation is believed to be from iodine-131, while the July 1946 sample represents the time period when a greater proportion of the activity was due to other radionuclides.

The predictive model converts count (cpm) data to μCi/kg concentrations of iodine-131 for count data found in Hanford laboratory notebooks dated from October 1945 through December 1947. However, we note that count data have only been found for the October 1945 through August 1946 time period, except for one data sheet for December 1947. Average monthly or weekly iodine-131 activities (such as μCi/kg) have been reported in historical Hanford documents for October 1945 through December 1947. The activities that were reported in the mid-1940s may be biased in ways perhaps similar to those discussed above for the reported count data. The uncertainty in those reported activity levels is not addressed in this report since the HEDR Project has not researched how the reported monthly or weekly activities were averaged from the count data. The Mart et al. (1993) report provides a method for correcting historically reported activities for biases introduced by the historical conversion factors used. However, that report does not discuss the historical method used to compute the average activities from the count data.

The Mart et al. (1993) report provides an extensive review of historical information about vegetation collection and analysis procedures and the conversion factors used at Hanford from 1945 through 1947. The purpose of their report is to discuss in detail the rationale and development for the new computational model for converting raw counts to iodine-131 concentrations. This report does not address uncertainty in the computational model; that is, uncertainty in the form of the model equation.

1.2 PURPOSE

This report presents the methods and results of the parameter uncertainty and sensitivity analyses of the December 20, 1945, and July 15, 1946, vegetation samples for the following purposes:

1. indicating the uncertainty of iodine-131 concentrations computed using the new computational model, Equation (5), for samples collected between October 1945 and December 1947, and

2. determining which parameters in the iodine-131 computational model contribute the most uncertainty to the computed concentrations.

Those parameters in the computational model that contribute the most uncertainty are candidates for further study to reduce, if possible, the uncertainty of the estimated historical iodine-131 concentrations for vegetation obtained using the new model [Equation (5)].

1.3 ORGANIZATION OF THE REPORT

Section 2.0 describes the model used to convert cpm/g measurements to iodine-131 concentrations, as well as the technical approach used to conduct and interpret the parameter uncertainty and sensitivity analyses. Section 3.0 briefly defines and discusses each parameter in the model that is used to convert vegetation cpm/g measurements to iodine-131 concentrations. Section 4.0 presents and discusses the results of the uncertainty and sensitivity analyses. Section 5.0 discusses the quality assurance procedures and data quality objectives established for the uncertainty and sensitivity analyses, including an assessment of the extent to which these objectives have been attained. Section 6.0 gives a summary and conclusions, Section 7.0 presents recommendations for future work, and Section 8.0 is a list of references. Appendix A discusses the rationale for the choice of parameter distributions (probability density functions) that were used to model the uncertainty of model parameter values. Appendix B is a glossary of statistical terms used in this report.

2.0 TECHNICAL APPROACH

This section describes the technical approach used to assess the uncertainty of estimated iodine-131 concentrations for vegetation in the Hanford environs in the mid-1940s and to identify important parameters that would require additional study in any attempt to reduce this uncertainty.

2.1 MODEL FOR ESTIMATING VEGETATION IODINE-131 CONCENTRATIONS

Let V denote the iodine-131 concentration (μCi/kg) of a hand-formed or press-formed vegetation pellet constructed from a vegetation sample collected on or around the Hanford Site in the period October 1945 through December 1947. Then for a given vegetation pellet, V is obtained by computing

$$V = U C \qquad (1)$$

where U is the background-corrected activity (cpm/g) of the pellet and C is the total conversion factor [(μCi/kg)/(cpm/g)] that converts cpm/g of activity to μCi/kg of iodine-131. Background counts were obtained for each GM counter when no source was present, and counts were collected for a specified time period (from several minutes to several days). The background-corrected activity, U, for the pellet is obtained by computing

$$U = (G - B) / W \qquad (2)$$

where G = gross counts per minute (cpm)

B = background cpm

W = weight of the vegetation pellet (grams).

The total conversion factor, C, for the pellet is obtained by computing

$$C = \frac{1000 \text{ g/kg}}{2.22 \times 10^6 \text{ dpm}/\mu\text{Ci}} M \, D_e \, I_{cf} \tag{3}$$

$$= 0.00045 \, M \, D_e \, I_{cf}$$

where M = measurement conversion factor (dpm/cpm)

D_e = radiological decay correction factor (unitless), which accounts for losses of iodine-131 in vegetation caused by radiological decay during the interval between sample collection in the field and counting in the laboratory

I_{cf} = iodine-131 correction factor (unitless), which is the fraction of the background-corrected cpm/g activity measurement, U, that resulted from the radiological decay of iodine-131.

The factors 2.22×10^6 (dpm/μCi) and 1000 (g/kg) in Equation (3) are conversion constants required to obtain units of μCi/kg for V.

The measurement conversion factor, M, in Equation (3) is obtained by computing

$$M = 1 / (G_p \, F_d \, F_{sa} \, F_a \, F_{bs} \, F_{cel} \, E_c) \tag{4}$$

where G_p = point-source geometry parameter

F_d = sample-diameter parameter

F_{sa} = self-absorption parameter

F_a = cellophane, air, and mica-window absorption parameter

F_{bs} = backscatter parameter

F_{cel} = cellophane scatter parameter

E_c = detector sensitive-volume efficiency parameter.

All of these parameters are unitless. Portions of Equation (4) were derived by Healy, Schwendiman, and Thorburn (1950); Schwendiman (1954); and Thomas, Polinsky, and Schwendiman (1956); as discussed in the Mart et al. (1993).

Substituting Equation (4) into Equation (3), then using Equations (2) and (3) to calculate U and C in Equation (1), we obtain the equation used to compute the iodine-131 concentration (μCi/kg) of the December 20, 1945, and July 15, 1946, vegetation samples:

$$V = \frac{0.00045\,(G - B)\, D_e\, I_{cf}}{W\, G_p\, F_d\, F_{sa}\, F_a\, F_{bs}\, F_{cel}\, E_c} \tag{5}$$

All uncertainty and sensitivity analyses discussed in this report were conducted for the model given by Equation (5). Some of the parameters in Equation (5) depend on other parameters that are defined and discussed in Section 3.0 and in Appendix A. The Mart et al. (1993) report provides additional details. In particular, expressions for G_p, F_d, F_{sa}, F_a, E_c, and D_e are given by Equations (6), (9), (14), (16), (17), and (18), respectively. Hereafter, whenever we refer to "the parameters in Equation (5)," we are also including these other parameters that do not explicitly appear in Equation (5).

2.2 PARAMETER UNCERTAINTY ANALYSIS METHOD

Equation (5) is the model that is used here to compute iodine-131 concentrations, V, for vegetation samples collected between October 1945 and December 1947. The uncertainty in the computed V that is due to uncertainty about which values to use for the parameters in Equation (5) was obtained using computer-simulation parameter uncertainty analyses. The procedure that was used to conduct these simulations is given below. The uncertainty analysis computations were conducted using a computer code developed by Sandia National Laboratories (Iman and Shortencarier 1984).

2.2.1 Step-by-Step Procedure

The following steps were used in the uncertainty analysis for the two vegetation samples collected on December 20, 1945, and July 15, 1946. Additional information on methods for evaluating uncertainties in radiological assessment models is given by Hoffman and Gardner (1983). Also, Finkel (1990) gives guidance on the need for uncertainty analysis and how it can be used by decision-makers.

1. The information and data in historical Hanford reports were examined in detail for each parameter in Equation (5). On the basis of this information as well as best professional judgment, the probability density function (pdf) for each parameter in Equation (5) was specified for each specific vegetation sample. For each parameter, first the maximum conceivable range of possible applicable values for the parameter was specified, followed by specification of the central ("best estimate") value for the parameter. Then a pdf was specified that was consistent with the selected central value and range of the parameter. The pdf expresses the subjective uncertainty (due to lack of knowledge) in the true value of the parameter for the specific vegetation sample.

2. The relationships and dependencies among parameters were specified on the basis of all available information, data, and professional judgment. These relationships and dependencies were modeled using correlation coefficients or function relationships.

3. Latin Hypercube Sampling (see Appendix B) was used to generate a random value of each uncertain parameter in Equation (5) from the pdf specified for that parameter, taking into account the specified correlations and functional relationships among parameters.

4. The set of random parameter values generated in Step 3 were used in Equation (5) to compute the iodine-131 concentrations for vegetation, V, for the sample.

5. Steps 3 and 4 were repeated 1000 times to generate a subjective histogram of 1000 possible (plausible) values of V.

6. Quantitative statements were made about the effect of parameter uncertainty on computed values of the iodine-131 concentration, V.

7. Sensitivity analyses were conducted to determine which of the parameters in Equation (5) contribute the most uncertainty to the computed value of V.

8. The results and interpretation of the analyses are presented in this report.

2.2.2 <u>Comments on the Steps</u>

Comments on the steps used in the uncertainty analyses described in Section 2.2.1 are provided in this section.

1. Specification of the maximum conceivable range of possible applicable values and of the central ("best estimate") value of each parameter was done primarily by E. I. Mart, with statistical perspective provided by R. O. Gilbert. Mart extensively studied historical Hanford documents that provide information about the procedures used in the mid-1940s at Hanford to estimate vegetation iodine-131 concentrations in the Mart et al. (1993). The ranges and pdfs of the parameters in Equation (5) are given in Table A.1 in Appendix A. Appendix A gives the rationale for the pdfs selected.

   Minimal information was available for determining the pdf of most parameters. In the absence of more information, the uniform (rectangular) pdf over the maximum conceivable range was used, as suggested by the International Atomic Energy Agency (IAEA 1989, p. 33). The triangular or normal (Gaussian) pdfs were used for some parameters on the basis of professional judgment or when additional information or data were available.

   13 No attempt was made to use an interview procedure in which an expert would specify the degree of belief (in percentage) that the parameter value is not larger than specific values selected from the maximum conceivable range of the parameter specified in Step 1. This interview approach, which is recommended by IAEA (1989, p. 31) and discussed by Meyer and Booker (1991), was not used because 1) the results of this report will not impact in any critical way the achievement of the main objectives of the HEDR Project, and 2) the cost of the interview approach is high because it requires the services of a trained professional interviewer. The HEDR Project staff are addressing the issue of the extent to which a formal interview approach is needed *in other areas of the project* to elicit subjective pdfs for model parameters. The issue of how to defend model predictions based on models that require substantial subjective input is of central importance to the credibility of the HEDR Project. This issue is of greatest importance for the environmental transport and dose models being developed by HEDR Project staff.

2. The parameters DIAM and T are not independent, where DIAM is the average diameter of the vegetation pellet [introduced in Equation (10) below] and T is the thickness of the pellet. The relationship between DIAM and

T was modeled by a linear regression equation, as described in Section A.3 in Appendix A. Dependencies also occur between parameters W and G, W and T, and G and T in Equation (5), where W is the weight of the vegetation pellet, G is the total counts per minute for the vegetation sample, and T is the pellet thickness. These dependencies were modeled as correlations (ρ), as follows: ρ(W, G) = 0.90, ρ(W, T) = 0.93, and ρ(G, T) = 0.8. That is, the following correlation matrix was specified:

	W	G	T
W	1.0		
G	0.90	1.0	
T	0.93	0.80	1.0

The rationale for these correlations is given in Section A.4 in Appendix A.

These correlations apply to the ranks of the measurements (see Appendix B) (Iman and Shortencarier 1984). Rank correlations were used because they are indicators of a monotonic relationship (see Appendix B) between model parameters and the computed iodine-131 concentration. The software code by Iman and Shortencarier (1984) adjusts, if necessary, the user-specified rank correlation matrix so that it has the required mathematical property of being positive definite. This adjustment was not needed because the correlation matrix specified in this paper is positive definite, which is an indication that the specified correlations are at least mathematically reasonable.

3. The computer code by Iman and Shortencarier (1984) was used to generate the random parameter values. A comparison of Latin Hypercube Sampling with other methods for selecting values of model parameters for uncertainty analyses is provided by McKay, Beckman, and Conover (1979).

4. No comment necessary.

5. The histogram of V is subjective because the models and parameter pdfs were selected partly on the basis of professional judgment rather than entirely on hard (objective) data and information from historical Hanford documents.

   One thousand values of V were generated to ensure that good estimates would be obtained of percentiles in the tails of the histogram; e.g., the 1st and 99th percentiles. The precision with which extreme percentiles are estimated is improved when a larger number, n, of values of V is computed. See Section 5.2 for additional discussion of the accuracy and precision of percentiles of V.

is computed. See Section 5.2 for additional discussion of the accuracy and precision of percentiles of V.

6. The following type of quantitative statement about the effect of parameter uncertainty on V for a specific vegetation sample is used in this report:

   > At a subjective confidence level of 98%, the iodine-131 concentration, V, for the vegetation sample is between the 1st percentile and the 99th percentile of the distribution of 1000 computed values of V.

7. The methods used to conduct sensitivity analyses are described in Section 2.3.

8. No comment necessary.

2.3 SENSITIVITY ANALYSIS METHOD

The results of the parameter uncertainty analyses that were obtained using the code of Iman and Shortencarier (1984) were in turn used in sensitivity analyses to identify which parameters in Equation (5) contributed the most uncertainty to the computed iodine-131 concentration, V. The sensitivity analyses were conducted using the computer code by Iman, Shortencarier, and Johnson (1985). For each vegetation sample, the code made use of the 1000 sets (vectors) of randomly generated (using Latin Hypercube Sampling) parameter values and the corresponding 1000 computed values of V. The code of Iman, Shortencarier, and Johnson was used to compute the partial rank correlation coefficient (PRCC) (see Appendix B) between the computed values of V and each parameter in the equation used to compute V [Equation (5)]. The absolute values of the PRCCs were put in order from largest to smallest. Those parameters with the largest (absolute-value) PRCCs contribute most to the uncertainty in computed values of V. These important parameters are candidates for additional study should there be a need to reduce the uncertainty in computed values of V. The results of the sensitivity analyses are discussed in Section 4.2.

The code of Iman, Shortencarier, and Johnson (1985) can also compute other measures of sensitivity [standardized regression coefficients (SRC), standardized rank regression coefficients (SRCC), and partial correlation coefficients (PCC)]. However, in our judgment, little information would have been gained and considerable additional discussion would have been needed if these other measures had been used.

3.0 PARAMETERS IN THE MODEL

In this section, we describe the parameters in Equation (5), which is the equation used to compute iodine-131 concentrations for vegetation, V. Additional details on these parameters are provided in Appendix A. Table A.1 in Appendix A lists the pdfs for all parameters for which uncertainty is nonnegligible.

3.1 POINT-SOURCE GEOMETRY PARAMETER, G_p

The point-source geometry factor, G_p, accounts for the fact that only a fraction of the radiation leaving the source (vegetation pellet) travels into the solid angle subtended by the detector. Thus G_p is the fraction of particles emitted from a point source at a fixed distance from the detector that would reach the sensitive volume of the GM counter if the following effects were not present: 1) scattering of radiation into the solid angle from either the pellet, mount, or shelf arrangement, 2) absorption of radiation within the pellet, 3) sample spread, and 4) absorption of radiation in the air or by the cellophane or the counter window. These other effects are accounted for by other parameters.

For the parameter uncertainty analyses, values of G_p were calculated using the equation

$$G_p = f_1(MED) + E_1 + E_2 \qquad (6)$$

where $f_1(MED)$ = initial value of G_p for a given value of MED

$$= 10^{[0.647 \log(1/MED - 0.185) - 0.8381]} \qquad (7)$$

MED = mean effective distance (cm) from the pellet to the mica window of the detector

E_1 = uncertainty in f_1(MED) due to variability in the historical measured values of G_p that are plotted in Figure 2

E_2 = uncertainty in f_1(MED) due to Equation (7) being an imperfect fit to the measured values of G_p.

Equation (7) was developed empirically to interpolate between the historical values of G_p measured by Schwendiman (1954) for those distances from the three shelves of the GM detector assembly to the detector's mica window that are less than or equal to 2.073 cm. Interpolation was needed only for distances less than or equal to 2.073 cm because historically vegetation pellets were always counted on the second shelf of the detector assembly, which was 2.073 cm from the mica window of the detector. Figure 2 shows the values of G_p measured by Schwendiman (1954) and the curve representing Equation (7) that was fitted for distances less than 2.073 cm.

The value of MED for a specific pellet was computed using the following equation from the Mart et al. (1993) report:

$$MED = 2.073 - f\,T \tag{8}$$

where 2.073 = distance (cm) from the second shelf of the GM detector to the mica window of the detector

f = fraction of T that achieves the appropriate value of MED

T = thickness of the pellet (cm)

The concept of MED is discussed in the Mart et al. (1993) report.

The parameters E_1 and E_2 were included in Equation (6) to account for the uncertainty in the value of f_1 (MED) computed using Equation (7). Parameter E_1 models the variability in the historically measured values of G_p, whereas parameter E_2 models the uncertainty in G_p due to fitting a curved line to just the three historically measured values of G_p in Figure 2.

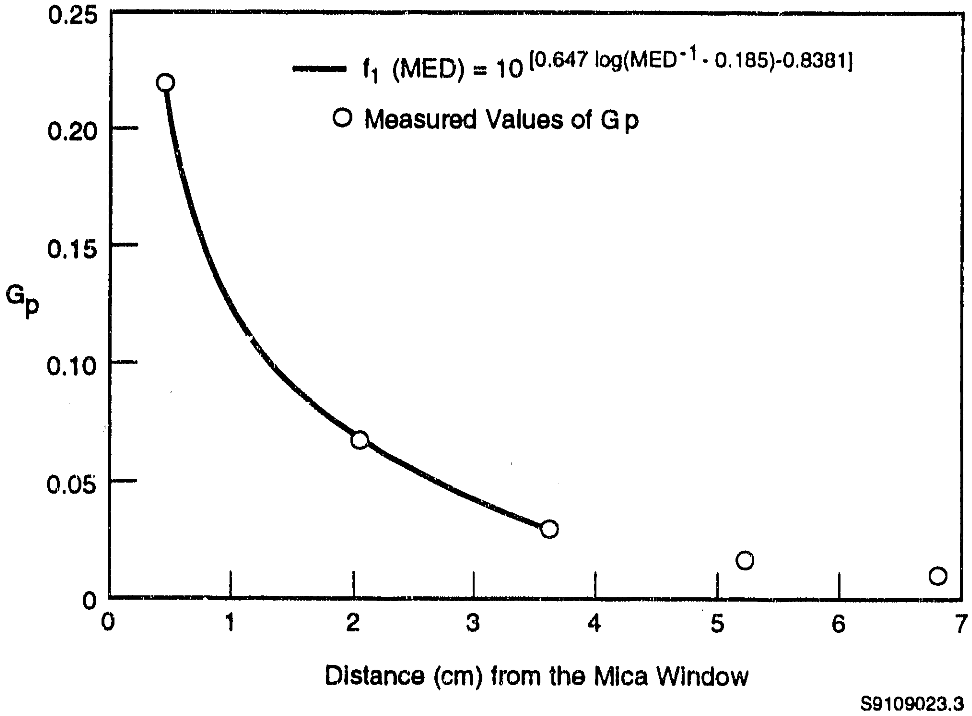


FIGURE 2. The Curve f_1(MED) [Equation (7)] Empirically Fitted to Values of G_p

We note that the assumption is made throughout this report that the GM detectors used in the mid-1940s had consistent (equal) geometries. This assumption is based on Schwendiman's observation (1954) that the error introduced by assuming an average geometry (G_p) for all beta counters (mica-window GMs) will be less than the error arising from others sources.

3.2 SAMPLE-DIAMETER PARAMETER, F_d

The sample-diameter parameter, F_d, corrects for the cpm measurement of a uniformly spread source being decreased compared to the measurement for a point source of the same activity that is centered directly under the detector. The sample-diameter parameter is the ratio of the counting rate of a uniform circular source of a given diameter to the counting rate of the same quantity of radioactive material mounted as a point source (Schwendiman 1954). For the parameter uncertainty analysis, F_d was calculated as follows:

$$F_d = f_2(MED,DIAM) + E_3 + E_4 \tag{9}$$

where DIAM = average diameter (cm) of the pellet

MED = value computed using Equation (8)

$f_2(MED,DIAM)$ = initial value of F_d

$$= 1 - (-0.4136 + 1.565 \log DIAM)\ 10^{-0.1311\ MED} \tag{10}$$

E_3 = uncertainty in $f_2(MED,DIAM)$ due to variability in the historically measured values of F_d plotted in Figure 3, and

E_4 = uncertainty in $f_2(MED,DIAM)$ due to interpolation error introduced by Equation (10).

The parameter DIAM was computed for the December 20, 1945, pellet using the equation

$$DIAM = 5.32 - 1.95\ T + e \tag{11}$$

and for the July 20, 1946, pellet using the equation

$$DIAM = 4.49 - 1.135\ T + e \tag{12}$$

The derivation of Equations (11) and (12) is discussed in Section A.3 of Appendix A.

Equation (10) was developed to allow easy interpolation between the historically measured values of F_d (plotted in Figure 3) for the specific values

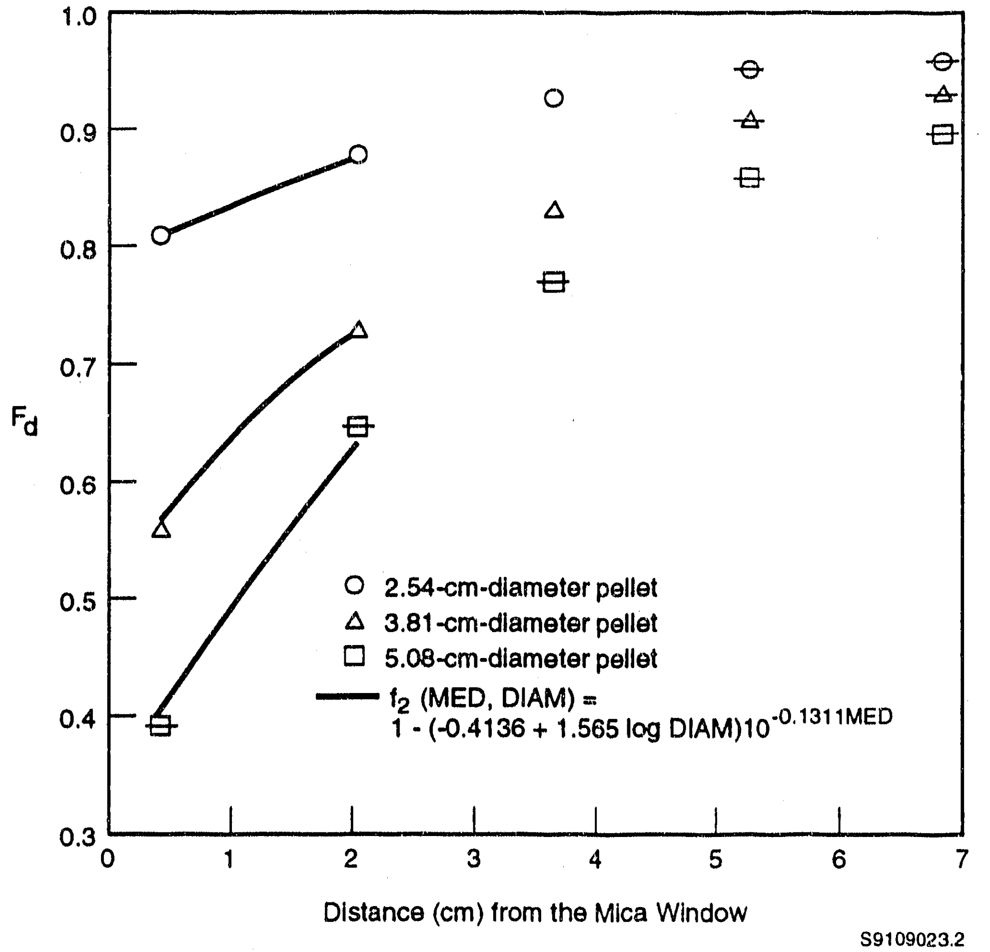


FIGURE 3. The Curve f_2(MED,DIAM) [Equation (10)] Empirically Fitted to Values of F_d Measured by Thomas, Polinsky, and Schwendiman (1956); Schwendiman (1954); and Healy, Schwendiman, and Thorburn (1950)

of MED and DIAM that apply to a specific pellet. As was discussed above for G_p, interpolation was needed only for values of MED less than or equal to 2.073 cm, the distance from the second shelf of the detector assembly to the detector mica window. Hence, the curves plotted in Figure 3 were developed to provide a good fit only to the plotted values of F_d less than or equal to 2.073 cm.

The values of F_d in Figure 3 were taken from Healy, Schwendiman, and Thorburn (1950); Schwendiman (1954); and Thomas, Polinsky, and Schwendiman

(1956). The data from the last of these sources are believed to be the most accurate. Therefore, when data from the 1956 report were available, values of F_d provided by the other two documents were not plotted in Figure 3. Plotted points with a horizontal bar are the means of the measurements reported by Healy, Schwendiman, and Thorburn (1950) and Schwendiman (1954). The other plotted points are from Thomas, Polinsky, and Schwendiman (1956).

Equation (9) is appropriate for circular pellets in which the iodine-131 is uniformly distributed. The degree to which historical pellets were circular and uniform is not known, but the sagebrush pellets reconstructed by HEDR Project staff in FY 1990 [see discussion in Section A.3 in Appendix A and in the Mart et al. (1993) report] were not perfect circles. The amount of uncertainty in F_d resulting from pellets being noncircular and/or nonuniform is unknown and has not been taken into account here.

3.3 SELF-ABSORPTION PARAMETER, F_{sa}

10 The self-absorption parameter, F_{sa}, is a correction for absorption of radiation by the vegetation pellet itself (Schwendiman 1954). The self-absorption parameter represents that fraction of the radiation that is not absorbed by passing through the vegetation pellet and is calculated as

$$F_{sa} = \frac{1 - \exp[-(m\ D\ T)]}{m\ D\ T} \qquad (13)$$

where m = the iodine-131 beta absorption coefficient (cm^2/mg)

D = density of the pellet (mg/cm^3)

= 1000 W/(S T)

W = weight (grams) of the vegetation pellet

S = pellet surface area (cm^2)

$= \pi \, (DIAM)^2/4$

T = thickness of the pellet (cm).

The Mart et al. (1993) report discusses the assumptions underlying the model for F_{sa} given by Equation (13). *Sample uniformity also influences self-absorption, but insufficient information about the uncertainty of this parameter was available to include it in the analyses.* Substituting the formula for D (density) into Equation (13), we obtain the final equation for F_{sa}:

$$F_{sa} = \frac{(DIAM)^2 \, \{1 - \exp[-1273.24 \, m \, W/(DIAM)^2]\}}{1273.24 \, m \, W} \tag{14}$$

3.4 ABSORPTION PARAMETER, F_a

The absorption parameter, F_a, corrects for the absorption of beta particles by the air, the mica-window of the detector, and the cellophane that covered the vegetation pellet (Schwendiman 1954). The model for F_a is

$$F_a = \exp[-m \, (M_w + M_c + M_a)] \tag{15}$$

where M_w = mass thickness (mg/cm^2) of the detector window

M_c = mass thickness (mg/cm^2) of cellophane, which is assumed to be a known constant, 3.1 mg/cm^2

M_a = mass thickness (mg/cm^2) of air

$= (2.073 - T) \, (0.001205) \, (1000)$

$= 1.205 \, (2.073 - T)$

where $2.073 - T$ = distance (cm) from the top of the pellet to the detector window

0.001205 = the density of air (g/cm^3) at standard pressure and 20° temperature

and the factor 1000 converts g to mg.

The value of M_w was estimated from measurements of the mass thickness of 13 mica-window GM counters used in 1950, as discussed in Section A.9 in Appendix A.

Combining the above equations we obtain the final equation for F_a:

$$F_a = \exp\{- m [1.205 (2.073 - T) + M_w + 3.1]\} \quad (16)$$

3.5 BACKSCATTER PARAMETER, F_{bs}

The backscatter parameter, F_{bs}, accounts for the scattering back toward the counter window of beta radiation that had been moving in other directions, thereby increasing the count rate. Such scattering is typically caused by the material used to mount the sample. However, in this case, the backscatter is caused by the vegetation pellet itself rather than the cardboard mounting cards used at Hanford. The Mart et al. (1993) report discusses F_{bs} in some detail, and the data used to estimate F_{bs} are discussed in Section A.10 of Appendix A.

3.6 CELLOPHANE-SCATTERING PARAMETER, F_{cel}

Cellophane was placed directly on top of the pellet. The cellophane increased the count rate of iodine-131 by an estimated factor of 1.04, as discussed in the Mart et al. (1993) report and in Section A.11 of Appendix A.

3.7 DETECTOR SENSITIVE-VOLUME EFFICIENCY PARAMETER, E_c

The detector sensitive-volume efficiency parameter, E_c, accounts for

- the efficiency of the GM detector in detecting a pulse once a beta particle has entered the sensitive volume of the detector

- the percentage of incident gamma rays that also produce a pulse in the GM detector
- any loss of beta counts due to detector dead time, that is, when a detector is insensitive to additional pulses.

The model for E_c is

$$E_c = C_d \left(E_\beta + E_\gamma\right) \tag{17}$$

where C_d = coincidence and dead-time parameter

E_β = beta-particle detection efficiency parameter

E_γ = gamma detection efficiency parameter.

We assume that the values of these parameters are known with no uncertainty, although this assumption may not be true for E_γ with regard to low-energy gamma rays. Nonetheless, in this report, we assume that $C_d = 1$, $E_\beta = 1$, and $E_\gamma = 0$, which implies that $E_c = 1$. The rationale for these assumptions is discussed in the Mart et al. (1993) report. Also, this equation does not take into account uncertainties in the electronics of the detectors; that is, uncertainty as to whether a given pulse generated within the GM tube resulted in a registered count.

3.8 RADIOLOGICAL DECAY CORRECTION FACTOR, D_e

The radiological decay correction factor, D_e, corrects for the radiological decay of iodine-131 in vegetation that occurs during the time between sample collection in the field and counting of the vegetation pellet in the laboratory. The factor D_e is defined as

$$D_e = \exp(\lambda t) \tag{18}$$

where λ = radiological decay constant for iodine-131

= (ln 2)/(8.05 days)

= 0.086105 per day

t = length of time (days) from the time the sample is collected in the field to the time it is counted in the laboratory.

The parameter λ is a known constant. However, there is uncertainty about the best value to use for t for any given vegetation sample collected in 1945-1947. This uncertainty reflects the lack of historical Hanford records for that period to indicate the exact time of the day that samples were collected or exactly when they were counted in the laboratory. The assumptions used to approximate the uncertainties associated with t for 1945-1947 are discussed in Section A.12 in Appendix A.

3.9 IODINE-131 CORRECTION FACTOR, I_{cf}

The factor I_{cf} is that fraction of the background-corrected cpm/g measurement, U, of a vegetation pellet that resulted from iodine-131. As discussed in Section 1.1, this factor is believed to have been very close to 1 in 1945, but as time went on, other radionuclides contributed more of the beta activity of the sample. The Mart et al. (1993) report discusses what is known about the likely values of I_{cf} that apply to different periods. Table A.1 in Appendix A lists the pdfs that were used to model the uncertainty in the value of I_{cf} for the December 1945 and July 1946 vegetation samples. Three different pdfs were used for the July 1946 sample to examine how the estimated uncertainty was affected by changing the pdf. The rationale used to select the pdfs for this parameter is given in Section A.13 in Appendix A. The pdfs for I_{cf} in Table A.1 are applicable only to vegetation samples with iodine-131 activities greater than zero.

4.0 RESULTS AND DISCUSSION

The results of the uncertainty and sensitivity analyses conducted for the December 20, 1945, and the July 15, 1946, vegetation samples are presented and discussed in this section.

4.1 UNCERTAINTY ANALYSES

The results of the uncertainty analyses are presented in Section 4.1.1 in the form of histograms and confidence intervals. In Section 4.1.2, we compare the "best-estimate" [deterministic-predicted (DP)] iodine-131 concentration for both vegetation samples with the range of concentrations displayed by the histograms. In Section 4.1.3, we express the information contained in the confidence intervals in terms of multiplicative factors. This is done for the purpose of making inferences about the uncertainty of iodine-131 concentrations for 1945-1947 vegetation samples not studied in this report.

4.1.1 Histograms and Confidence Intervals

As indicated in Section 2.2, the uncertainty analysis for each vegetation sample produced 1000 values of V, the concentration of iodine-131 (μCi/kg) for the sample. A histogram was then constructed using these values. The histograms for the December 1945 and July 1946 samples are shown in Figures 4 and 5. The histograms show at a glance the range of μCi/kg values within which the true value of V is likely to lie. From Figure 4 we see that it is very unlikely that the iodine-131 concentration for the December 20, 1945, pellet could have been less than about 12 μCi/kg or more than about 40 μCi/kg, assuming of course that the distributions and correlations for the parameters in the model for V [Equation (5)], as specified in Table A.1, are appropriate. For the July 1946 sample (Figure 5), it is unlikely that the true concentration was less than about 0.7 μCi/kg or more than about 4.5 μCi/kg.

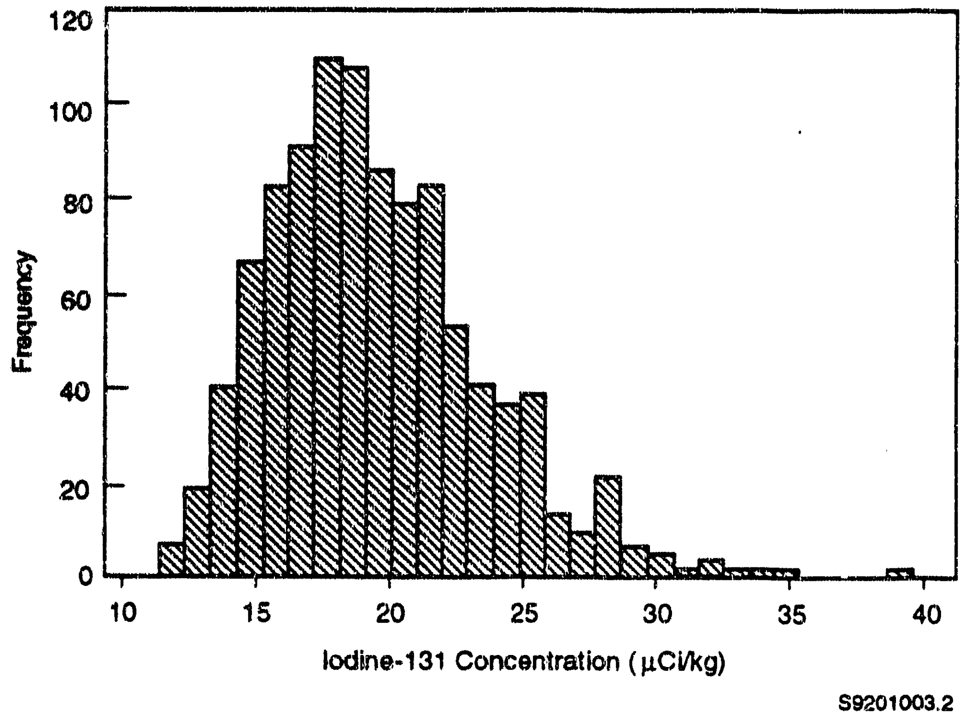


FIGURE 4. Subjective Histogram of the Iodine-131 Concentration (µCi/kg) for the Sagebrush Sample Collected on December 20, 1945, in Richland, Washington

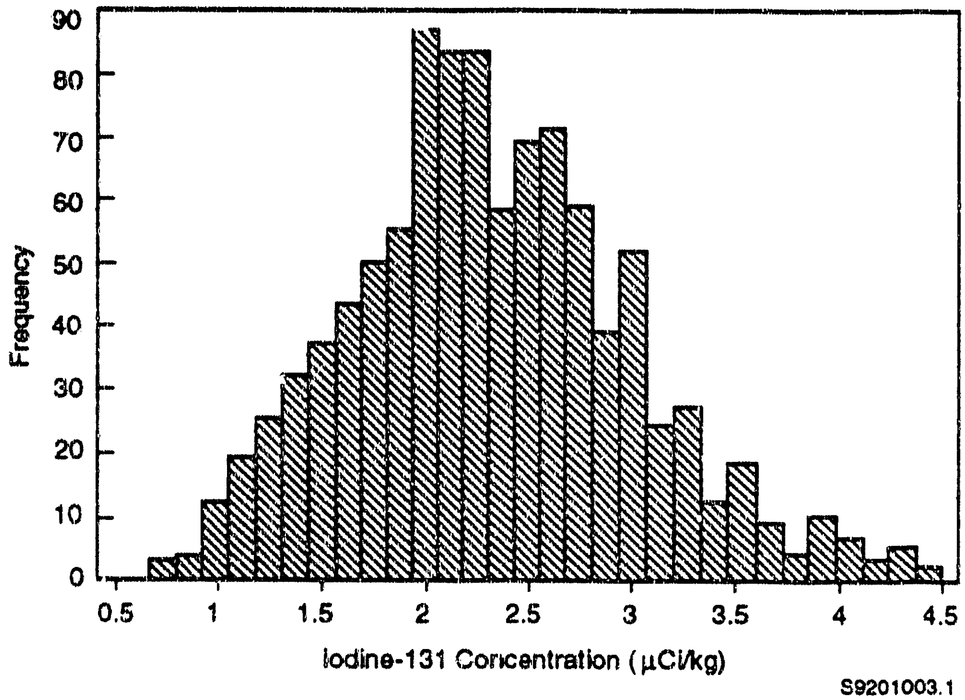
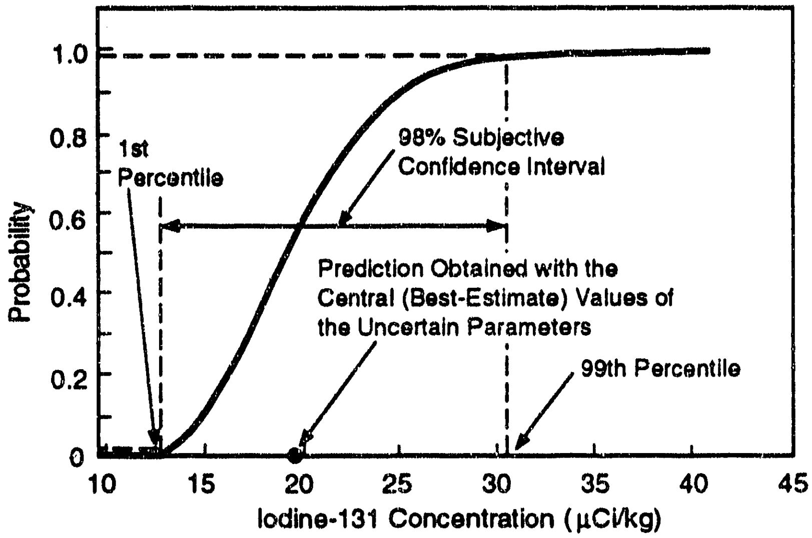


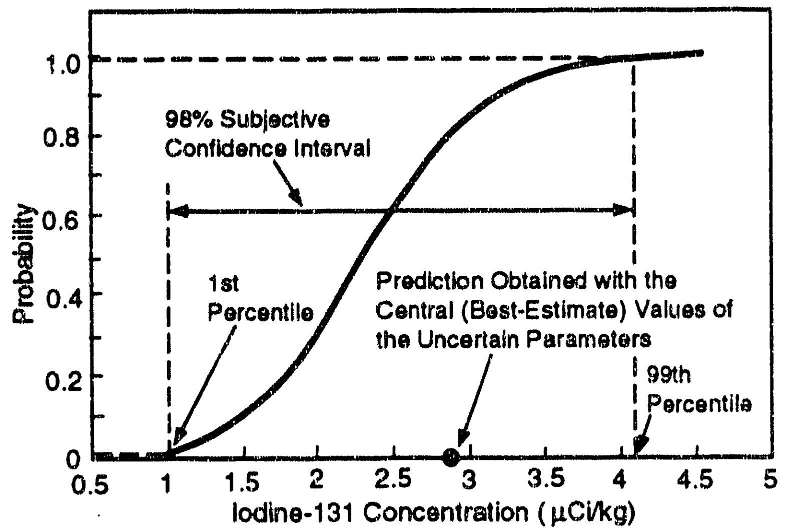
FIGURE 5. Subjective Histogram of the Iodine-131 Concentration (µCi/kg) for the Sagebrush Sample Collected on July 15, 1946, on the Hanford Site North of Richland, Washington

The histograms in Figures 4 and 5 were used to obtain the cumulative distribution functions (cdfs) shown in Figures 6 and 7. These cdfs show the probability that the true iodine-131 concentration for the two vegetation



S9201003.4

FIGURE 6. Subjective Cumulative Distribution Function of the Iodine-131 Concentration (μCi/kg) for the Sagebrush Sample Collected on December 20, 1945, in Richland, Washington



S9201003.3

FIGURE 7. Subjective Cumulative Distribution Function of the Iodine-131 Concentration (μCi/kg) for the Sagebrush Sample Collected on July 15, 1946, on the Hanford Site North of Richland, Washington

samples could have been less than or equal to any μCi/kg value specified. For example, for the December 1945 vegetation sample (Figure 6), the probability is about 0.99 (99% chance) that the iodine-131 concentration was less than or equal to 30.4 μCi/kg. That is, the 99th percentile of the distribution of V is estimated to be 30.4 μCi/kg. (See Appendix B for the definition of a percentile.)

Table 1 displays percentiles and other statistics of the 1000 values of V for the two vegetation samples. The percentiles in Table 1 can be read directly from the cdf curves in Figures 6 and 7, as illustrated in those figures by the 1st and 99th percentiles. The 98% confidence intervals for V given in Table 1 are a useful summary of the information in the histograms and the cdfs. This interval is defined by the 1st and 99th percentiles of the distribution. For the December 1945 vegetation sample, the 98% confidence interval is 13.1 to 30.4 μCi/kg, which is interpreted as follows:

> At a subjective confidence level of 98% the value of the iodine-131 concentration, V, for the December 20, 1945, vegetation sample is between 13.1 and 30.4 μCi/kg.

For the July 1946 sample the 98% confidence interval is 1.035 to 4.11 μCi/kg, which is interpreted as follows:

> At a subjective confidence level of 98% the value of the iodine-131 concentration, V, for the July 15, 1946, vegetation sample is between 1.035 and 4.11 μCi/kg.

4.1.2 Deterministic-Predicted (DP) Concentrations

In addition to percentiles and confidence intervals, Table 1 also displays the DP concentration. The DP concentration was obtained by computing the iodine-131 concentration using the central value (from Table A.1) of each parameter in Equation (5). For the December 1945 sample, the DP concentration was 19.6 μCi/kg, which is very close to both the arithmetic mean

TABLE 1. Percentiles and Other Selected Statistics for the Histogram of 1000 Possible Values of the Iodine-131 Concentrations in Vegetation (μCi/kg) for the December 20, 1945, and the July 15, 1946, Vegetation Samples

Statistics	December 20, 1945, Sample	July 15, 1946, Sample
Minimum	11.6	0.726
1st percentile	13.1	1.035
5th percentile	14.35	1.305
25th percentile	16.8	1.89
50th percentile (median)	19.3	2.31
Deterministic-predicted (DP) concentration[a]	19.6	2.88
Arithmetic mean	19.74	2.35
75th percentile	22.2	2.77
95th percentile	26.65	3.50
99th percentile	30.4	4.11
Maximum	39.3	4.38
Standard deviation	3.867	0.6629
98% Confidence interval[b]	13.1 to 30.4	1.035 to 4.11
Multiplicative uncertainty factors		
F_1[c]	1.49	2.78
F_{99}[d]	1.55	1.43
F_A[e]	1.52	2.10

(a) Computed by substituting the central value of each parameter (from Table A.1) into Equation (5), the equation for computing the iodine-131 concentration.
(b) Interval between the 1st and 99th percentiles.
(c) F_1 = DP concentration divided by the 1st percentile.
(d) F_{99} = 99th percentile divided by the DP Concentration.
(e) F_A = $(F_1 + F_{99})/2$.

(19.74 μCi/kg) and the median (19.3 μCi/kg) of the 1000 computed values of V. Hence, for the December 1945 vegetation sample, the DP concentration represents the middle or central part of the distribution of V (Figure 4). However, for the July 1946 sample, the DP value (2.88 μCi/kg) is considerably larger than either the arithmetic mean (2.35 μCi/kg) or the median (2.31 μCi/kg) (Figure 6). This result for the July 1946 vegetation sample is believed to be caused primarily by the asymmetry (negative skewness) of the triangular pdf for the parameter I_{cf} specified in Table A.1. The expression "negative skewness" means that (see Table A.1) the distance from the lower limit of I_{cf} (0.30) to the central value of I_{cf} (0.90) is much larger than the distance from the central value to the upper limit (0.95). The discrepancy between the DP concentration and the mean and median of V may also be caused to a lesser extent by the asymmetrical triangular distribution that was specified for the parameter T (pellet thickness) in Table A.1.

4.1.3 Multiplicative Factors

The information contained in the confidence interval statements can also be expressed as unitless multiplicative factors. These factors for the two vegetation samples are used here to develop a simple procedure for obtaining approximate upper and lower limits that are expected to contain (bound) the 98% confidence interval for all vegetation samples collected in the 1945-1947 period. Three multiplicative factors were computed for the two vegetation samples in Table 1:

$$F_1 = \text{DP concentration divided by the 1st percentile}$$
$$F_{99} = \text{99th percentile divided by the DP concentration}$$
$$F_A = (F_1 + F_{99})/2$$

where DP is the deterministic-predicted concentration of iodine-131, as defined in Section 4.1.2 above.

From Table 1 we see that, for the December 1945 sample, the values of F_1, F_{99}, and F_A are 1.49, 1.55, and 1.52, respectively. It follows from the definition of these factors that dividing and multiplying the DP concentration (19.6 μCi/kg) by the factor 1.5 gives, approximately, the lower and upper limits of the 98% confidence interval.

The values of F_1, F_{99}, and F_A for the July 1946 sample are 2.78, 1.43, and 2.10, respectively. By the definition of these factors, dividing the DP concentration (2.88 μCi/kg) by 2.78 gives the lower end of the 98% confidence interval (the 1st percentile), and multiplying the DP concentration by 1.43 gives the upper limit of the confidence interval (the 99th percentile).

The rationale for believing that multiplicative factors for other vegetation samples collected in the 1945-1947 period will not be substantially larger than the factors obtained above is as follows. First, for all parameters except G, B, and I_{cf}, the subjective pdfs in Table A.1 should apply to all vegetation samples. That is, the uncertainty due to lack of knowledge about the parameters is the same for all hand-formed vegetation pellets for the 1945-1947 period, and similarly for the press-formed pellets. Second, as shown by the sensitivity analyses (Section 4.2.1), parameters G and B have little influence on the uncertainty (as expressed by the pdf) of the computed iodine-131 concentration, V. Finally, the uncertainty in I_{cf} used in obtaining the results for the July 1946 vegetation sample was very large (see Table A.1). It is unlikely that the uncertainty in I_{cf} for any other vegetation sample collected in 1945-1947 would be substantially larger. In consideration of these factors, the multiplicative factors for the two vegetation samples studied in this report may be reasonably representative of factors that apply to other vegetation samples in the period from 1945 through 1947.

Based on this rationale, the values of the multiplicative factors in Table 1 suggest that a factor of 3 for the multiplicative factors F_1 and F_{99} may give quite conservative (too wide) 98% confidence intervals for most, if not all, vegetation samples collected in 1945-1947. That is, dividing and multiplying the computed DP concentration value for any sample counted in the period from October 1945 through December 1947 by 3 should result in an interval that would be highly likely to include the true iodine-131 concentration for the sample. More definitive information about the magnitude of multiplicative factors for other vegetation samples could, of course, be obtained by conducting parameter uncertainty analyses for additional samples.

4.2 SENSITIVITY ANALYSES

This section describes the sensitivity analyses conducted using the results of the uncertainty analyses discussed in Section 4.1.1.

4.2.1 Sensitivity to Individual Parameters

The 1000 possible values of iodine-131 concentrations that were computed by the uncertainty analysis for each vegetation sample were used as input to the sensitivity-analysis computer code developed by Iman, Shortencarier, and Johnson (1985). This code computes a multiple regression-correlation analysis to determine which of the parameters in Equation (5) contribute the most uncertainty to the computed iodine-131 concentrations. Those parameters with a large absolute value for the partial rank correlation coefficient (PRCC) contribute the most uncertainty to the concentrations. The parameters identified are candidates for additional study if it is necessary to reduce the uncertainty in the computed iodine-131 concentrations. The absolute values of the PRCCs for both the December 1945 and the July 1946 vegetation samples are listed in order of decreasing value in Table 2.

From Table 2, we see that the five most influential parameters (E_1, m, e, M_w, and I_{cf}) are the same for both vegetation samples, but their order is different. In particular, I_{cf} (the fraction of the background-corrected cpm/g measurement U of the sample that resulted from decay of iodine-131) is the most important parameter for the July 1946 sample, but only the fifth most important for the December 1945 sample. This difference in rank order occurs because the uncertainty in the value of I_{cf} was specified as being much larger for the July 1946 sample (ranging from 0.30 to 0.95) than for the December 1945 sample (ranging from 0.90 to 1.0; Table A.1).

Table 2 also indicates that uncertainty in the value of the parameter t (the number of days from the time the sample is collected in the field to the time it is counted in the laboratory) does not contribute greatly to the uncertainty of the iodine-131 concentration for either vegetation sample. Hence, uncertainty about the value of t is of less concern than uncertainty

TABLE 2. Partial Rank Correlation Coefficients for the Parameters in Equation (5) [that Computes the Concentration (μCi/kg) of Iodine-131] for the December 20, 1945, and the July 15, 1946, Vegetation Samples

	December 20, 1945, Sample		July 15, 1946, Sample	
Rank	Parameter	PRCC[a]	Parameter	PRCC[a]
1	E_1	-0.95	I_{cf}	0.94
2	m	0.95	m	0.87
3	e	-0.81	E_1	-0.86
4	M_w	0.59	e	-0.52
5	I_{cf}	0.50	M_w	0.34
6	F_{bs}	-0.48	F_{bs}	-0.27
7	E_3	-0.40	E_3	-0.16
8	t	0.34	t	0.16
9	F_{cel}	-0.28	F_{cel}	-0.15
10	E_2	-0.27	E_2	-0.14
11	G	0.19	G	0.12
12	E_4	-0.16	f	-0.05
13	f	-0.10	E_4	-0.02
14	B	-0.07	T	-0.02
15	W	-0.03	W	-0.01
16	T	0.04	B	0.00
$R^{2(b)}$		0.96		0.93

(a) PRCC is the partial rank correlation coefficient (see Appendix B).

(b) R^2 is the proportion of the variance of (the 1000 computed values of) V that is explained by the 16 parameters. R^2 should be close to 1 for the PRCCs to be meaningful for identifying the most influential parameters. The values 0.96 and 0.93 are considered to be acceptably close to 1.

about the correct value for I_{cf}. Uncertainties in the values of the parameters G (gross cpm), B (background cpm) and W (pellet weight) contribute very little to the uncertainty of computed iodine-131 concentrations as compared to the amount contributed by uncertainty in the other parameters.

The parameter I_{cf} is the only one of the five most influential parameters (Table 2) that appears explicitly in Equation (5). The other four appear in Equations (6), (9), (11), (12), (14), and (15), which are used to compute the factors G_p, F_d, F_{sa}, and F_a. Among the factors that appear explicitly in Equation (5), I_{cf}, G_p, F_d, F_{sa}, and F_a have the greatest impact on the uncertainty of computed values of iodine-131 concentrations.

4.2.2 Effect of Reducing the Uncertainty of Parameters

This section considers whether efforts should be made to reduce the uncertainty of model parameters to in turn reduce the uncertainty of historical vegetation iodine-131 concentrations.

Parameter I_{cf}

In Section 4.2.1, it was shown that the computed iodine-131 concentration for the July 1946 vegetation sample [obtained using Equation (5)] was most sensitive to the parameter I_{cf}. In this section we address the question:

> If the value of the parameter I_{cf} was known with greater certainty, would that cause a substantial reduction in the uncertainty of the computed iodine-131 concentration for the July 1946 sample?

To address this question, the parameter uncertainty analyses for the July sample were repeated, keeping all parameter specifications the same except for the lower limit for the distribution of I_{cf}. First, this lower limit was changed from 0.3 to 0.5, and then to 0.7. By increasing the value of the lower limit of I_{cf} while keeping the central value and upper limit unchanged, the amount of uncertainty of I_{cf} was reduced.

The percentiles and summary statistics for the histograms of iodine-131 concentrations for the three cases (lower limit of I_{cf} equal to 0.3, 0.5, and 0.7) are shown in Table 3. The uncertainty in the computed iodine-131 concentration, as estimated by the width of the 98% confidence interval, decreased 12% (from 3.08 to 2.69) when the lower limit of I_{cf} was increased from 0.3 to 0.5. No further decrease in the width occurred when the lower limit of I_{cf} was increased to 0.7.

The last column of Table 3 gives results for the case when <u>all</u> uncertainty in I_{cf} was eliminated; i.e., when the central value of I_{cf} (0.9) was used in Equation (5) to compute iodine-131 concentration for all 1000 cases. For this case, the width of the 98% confidence interval for the computed

TABLE 3. Percentiles and Other Selected Statistics for the Histogram of 1000 Possible Values of Iodine-131 Concentrations (μCi/kg) for the July 15, 1946, Vegetation Sample When the Lower Limit of the Triangular Distribution of the Parameter I_{cf} Was Set Equal to 0.3, 0.5, and 0.7

Statistics	Lower Limit of Distribution of I_{cf} 0.3	0.5	0.7	0.9[a]
Minimum	0.726	1.3	1.60	1.8
1st percentile	1.035	1.46	1.74	1.92
5th percentile	1.305	1.69	1.98	2.1
25th percentile	1.89	2.10	2.38	2.54
50th percentile (median)	2.31	2.52	2.70	2.89
Deterministic-predicted (DP) concentration[b]	2.88	2.88	2.88	2.88
Arithmetic mean	2.35	2.57	2.79	2.96
75th percentile	2.77	2.96	3.14	3.32
95th percentile	3.50	3.73	3.83	4.00
99th percentile	4.11	4.15	4.45	4.43
Maximum	3.38	4.59	4.86	4.92
Standard deviation	0.6629	0.604	0.573	0.5763
98% Confidence interval[c]	1.035 to 4.11	1.46 to 4.15	1.74 to 4.45	1.92 to 4.43
Width of 98% confidence interval	3.08	2.69	2.71	2.51
Multiplicative uncertainty factors				
F_1[d]	2.78	1.98	1.66	1.50
F_{99}[e]	1.43	1.44	1.54	1.54
F_A[f]	2.10	1.71	1.60	1.52

(a) Both lower limit and upper limit of I_{cf} were set equal to 0.90 so that there was no uncertainty in I_{cf}; i.e., the central value of I_{cf} (0.9) was used to compute each of the 1000 values of V.

(b) Computed by substituting the central value of each parameter (Table A.1) in the equation for computing V.

(c) Interval between the 1st and 99th percentiles.

(d) F_1 = DP concentration divided by the 1st percentile.

(e) F_{99} = 99th percentile divided by the DP concentration.

(f) $F_A = (F_1 + F_{99})/2$.

iodine-131 concentration decreased 18% (from 3.08 to 2.51). This result illustrates that the estimates of uncertainty of computed iodine-131 concentrations can be noticeably affected if uncertainties in influential parameters are completely ignored.

These results also have implications regarding the usefulness of expending funds to attempt to reduce the uncertainty in I_{cf} in order to reduce the uncertainty in computed historical iodine-131 concentrations for vegetation. As the results in Table 3 show, uncertainty of the iodine-131 concentration for the July 1946 sample, as measured by the width of the 98% confidence interval, can be reduced a maximum of approximately 18%. Of course, to achieve this reduction would require removing <u>all</u> uncertainty in the value of I_{cf}, which is impossible. Based on the results in Table 3, it might be reasonable to expect perhaps a 10% reduction in the uncertainty of the computed iodine-131 concentration of the July 1946 vegetation sample if the uncertainty of I_{cf} could be reduced by 30% or so. It is probably not possible, however, to achieve that much reduction in the uncertainty of I_{cf}, regardless of the amount of funds expended. Also, it is debatable whether expending funds in an attempt to obtain only a 10% reduction in the uncertainty of the computed iodine-131 concentration is warranted.

<u>Parameters in M [Measurement Conversion Factor; Equation (4)]</u>

The uncertainty analysis of the July 15, 1946, vegetation sample was repeated for a case with no uncertainty in any of the parameters (such as G_p, F_d, F_a, and F_{sa}) in Equation (4) that are needed to convert counts-per-minute to disintegrations-per-minute. For this case, a reduction in the multiplicative factor F_A from 2.1 to 1.8 occurred. Also, the width of the 98% subjective confidence interval was reduced from 3.08 (Table 3) to 1.92. However, this amount of reduction in uncertainty is again beyond what can be achieved in practice, since it is impossible that uncertainties caused by lack of knowledge can be reduced to zero.

4.2.3 Discussion

On the bases of the results in Section 4.2.1, one might conclude that additional literature searches or empirical studies should be conducted to obtain additional information about the top five most important parameters to reduce their uncertainty, thereby reducing the uncertainty in the estimated iodine-131 concentrations obtained using the modeling equation presented in this paper as Equation (5). However, this approach is not recommended for two reasons. First, it is unlikely that additional information exists to reduce parameter uncertainties sufficiently to make a substantial reduction in the uncertainty of iodine-131 concentrations for vegetation.

Second, there may be no need to reduce the uncertainty of the historical iodine-131 concentrations for vegetation. The most likely use that will be made of the historical iodine-131 concentration for vegetation will be to help validate the HEDR Project source-term, air-transport, and environmental-accumulation models that are needed to compute iodine-131 concentrations for vegetation in the study area as an intermediate step in computing doses to individuals from exposure to iodine-131 via the air pathway. The uncertainties in the predicted iodine-131 concentrations for vegetation obtained on the basis of these complex models are likely to be very large because of the large uncertainties in some model parameter values. The uncertainties in the model-predicted iodine-131 concentrations are likely to be so large that reducing the uncertainties in converting measured historical cpm/g radiation measurements to iodine-131 concentrations will not perceptibly affect the conclusions of the validation effort.

There may be some limited value to conducting additional uncertainty and sensitivity analyses on other vegetation samples collected in the 1945-1947 period to confirm that the results obtained in this report are representative of most samples. Also, because the results of this report apply, strictly speaking, to sagebrush samples only, efforts could be made to evaluate uncertainties for other species of vegetation. However, the funds these studies would require might be better used to increase, if possible, our knowledge about uncertainty for parameters in the source-term, air-transport, environmental-pathways, and dose models that have a major impact on the estimated thyroid doses of individuals.

5.0 QUALITY ASSURANCE AND DATA QUALITY OBJECTIVES

The uncertainty and sensitivity analyses were conducted and this report was prepared according to HEDR Quality Assurance (QA) Plan OHE-3, Revision 4, issued June 21, 1991. The following PNL QA procedures were used for the uncertainty analyses: SCP-70-312 (Determination of Software Requirements), SCP-70-315 (Conversion Testing, Verification, and/or Validation of Software), SCP-70-316 (Software Application Control), and PAP-70-301 (Hand Calculations, General).

Project files will be sent to the HEDR Project Record Center upon completion of this report in accordance with the Project's QA plan. Drafts of this document have undergone internal PNL technical review. Review comments were satisfactorily resolved, and there were no controversial resolutions to the comments.

The data quality objectives that were adopted for this study are given in Section 5.1, and the level to which they have been achieved is evaluated in Section 5.2.

5.1 DATA QUALITY OBJECTIVES

5.1.1 Accuracy

The qualitative accuracy objective is to quantify as accurately as possible the uncertainties of computed iodine-131 concentrations for vegetation, V, for the two vegetation samples examined in this report. This qualitative objective will be achieved by using appropriate models, estimating the uncertainties of model parameters, and appropriately propagating the uncertainties of those parameters through the models.

The quantitative accuracy objective is that the 1st through 99th percentiles of the probability distribution functions (pdfs) of the model parameters differ by less than 5% from the percentiles of the specified pdfs in Table A.1 for those parameters.

5.1.2 Precision

The objective is that two pdfs generated using uncertainty analysis for the same model and model parameter distributions should not vary by more than 5% for representative percentiles in the range from the 1st to the 99th percentile.

5.1.3 Completeness

The objective is to conduct uncertainty and sensitivity analyses for both hand-formed and press-formed vegetation pellets, the two types of pellets used in the 1945-1947 time period.

5.1.4 Representativeness

The objective is that the models developed to convert historical vegetation beta activities to iodine-131 concentrations should be accepted by peer reviewers as being appropriate. That is, the models should adequately represent the procedures that were used for preparing vegetation pellets and measuring radiation during the period from October 1945 through December 1947.

5.1.5 Comparability

The objective is to make the uncertainty and sensitivity analyses in this report comparable by consistently using the same uncertainty and sensitivity methods (outlined in Sections 2.2 and 2.3) throughout the report.

5.2 ATTAINMENT OF DATA QUALITY OBJECTIVES

5.2.1 Accuracy

The attainment of this objective was assessed qualitatively by peer reviews. The quantitative objective was assessed by determining whether selected representative percentiles in the range from the 1st through the 99th, of the probability distribution functions (pdfs) for three representative model parameters [generated using the code by Iman and Shortencarier (1984)], differed by less than 5% from the percentiles of the specified pdfs in Table A.1 for these three parameters. Table 4 displays the percentiles and other statistics of the specified pdf (from Table A.1) and of the generated pdf for the following three model parameters: I_{cf} for the July 1946 sample for the case where the minimum value was set at 0.30, e for the December 1945 vegetation sample, m for both samples. These parameters were

TABLE 4. Percentiles and Other Selected Statistics for the Specified (Table A.1) and Generated[a] Probability Density Functions of Parameters I_{cf}, e, and m in the Model [Equation (5)] for Iodine-131 Concentrations in Vegetation

	I_{cf}[b] (triangular pdf)		e[c] (normal pdf)		m[d] (uniform pdf)	
Statistics	Specified	Generated	Specified	Generated	Specified	Generated
Minimum	0.30	0.318	-0.8100	-0.81	0.0295	0.0295
1st percentile	0.362	0.361	-0.6094	-0.609	0.0296	0.0296
5th percentile	0.440	0.440	-0.4310	-0.431	0.0302	0.0302
25th percentile	0.612	0.612	-0.1767	-0.1765	0.0330	0.033
50th percentile	0.742	0.742	0.0000	0.00012	0.0365	0.0365
Mean	0.7166	0.7167	0.0000	-0.00006	0.0365	0.0365
75th percentile	0.841	0.841	0.1767	0.1765	0.040	0.040
95th percentile	0.910	0.910	0.4310	0.431	0.0428	0.0428
99th percentile	0.932	0.932	0.6094	0.6125	0.04336	0.04335
Maximum	0.95	0.949	0.8100	0.81	0.0435	0.0435
Standard deviation	0.148	0.148	0.262	0.262	0.00404	0.00404

(a) 1000 generated values of the parameter.
(b) I_{cf} is the fraction of the background-corrected vegetation-sample beta activity that is due to iodine-131.
(c) e is an additive random error term that models the uncertainty in approximating the diameter of vegetation pellets using the linear regression of pellet diameter on pellet thickness [Equations (11) and (12)].
(d) m is the iodine-131 beta absorption coefficient [Equation (13)].

selected because 1) they were identified (Section 4.2) as being relatively large contributors to the uncertainty in computed iodine-131 concentrations and 2) their specified pdfs (Table A.1) represent the three different distributions of pdfs used in this report: triangular, normal (Gaussian), and uniform (rectangular). It is clear from Table 4 that the percentiles and statistics for the pdfs that were generated are in close agreement with those for the specified (target) pdfs. Moreover, the percent difference in the specified and generated percentiles were less than 1% for all percentiles. Hence, the data quality objective for accuracy has been attained.

5.2.2 Precision

The data quality objective for precision was that two pdfs generated using uncertainty analysis for the same model and model parameter distributions should not vary by more than 5% for selected representative percentiles in the range from the 1st to the 99th percentile. The attainment of this data quality objective was assessed by repeating the uncertainty analysis for the December 20, 1945, vegetation sample with a new sequence of random numbers. The new sequence was obtained by using a different random number seed in the code by Iman and Shortencarier (1984) to start the random number sequence.

The percentiles and statistics that describe the 1000 values of iodine-131 concentrations obtained in the new uncertainty analysis are shown in Table 5, along with the results for the original uncertainty analysis from Table 1. The percent relative standard deviations for the percentiles are all less than 5%. Hence, the precision data quality objective was achieved. (The percent relative standard deviation is 100 times the standard deviation divided by the mean.) The relative standard deviations for the other statistics were also less than 5% with the exception of the maximum value of V. The two maximum values (39.3 and 32.4 μCi/Kg) differed by 18% and had a percent relative standard deviation of 13.6%. However, because the distribution of the maximum order statistic has a wide variability (large uncertainty) thisdifference is maximum values is not an unusual result. Given the very

TABLE 5. Percentiles and Other Selected Statistics for Two Histograms of 1000 Possible Values of the Iodine-131 Concentrations in Vegetation (μCi/kg) as Obtained Using Two Sequences of Random Parameter Values for the December 20, 1945, Vegetation Sample

Statistics	Original Uncertainty Analysis[(a)]	Duplicate Uncertainty Analysis
Number of values of V[(b)]	1000	1000
Minimum	11.6	11.9
1st percentile	13.1	13.05
5th percentile	14.35	14.2
25th percentile	16.8	16.85
50th percentile (median)	19.3	19.3
Deterministic-predicted concentration value[(c)]	19.6	19.6
Arithmetic mean	19.74	19.74
75th percentile	22.2	22.0
95th percentile	26.65	26.55
99th percentile	30.4	29.95
Maximum	39.3	32.4
Standard deviation	3.867	3.829
98% Confidence interval[(d)]	13.1 to 30.4	13.05 to 29.95
Multiplicative uncertainty factors		
F_1[(e)]	1.49	1.50
F_{99}[(f)]	1.55	1.53
F_A[(g)]	1.52	1.52

(a) The results for this case are from Table 1.
(b) Number of values of V (iodine-131 concentrations) that were computed.
(c) Computed by substituting the central value of each parameter in Equation (5), the equation for computing V.
(d) Interval between the 1st and 99th percentiles.
(e) F_1 = DP concentration divided by the 1st percentile.
(f) F_{99} = 99th percentile divided by the DP concentration.
(g) $F_A = (F_1 + F_{99})/2$.

small relative standard deviations in Table 5, there is no reason to believe that a replication of the uncertainty analyses described in this report would result in histograms of iodine-131 concentrations that would lead to different conclusions and recommendations.

5.2.3 Completeness, Representativeness, and Comparability

The completeness objective was attained because uncertainty and sensitivity analyses for both hand-formed and press-formed vegetation pellets were conducted. The representativeness objective was attained to the extent of the peer reviews conducted for this report. However, further verification of this objective will be assessed by peer reviews of the report by Mart et. al. (1993), which is currently in preparation. The comparability objective was also verified by peer reviews of this report.

6.0 SUMMARY AND CONCLUSIONS

The Mart et al. (1993) report describes a model for converting GM detector measurements (cpm/g) of historical Hanford vegetation samples to concentrations of iodine-131 (μCi/kg). This model, Equation (5), which is expected to be applied to individual vegetation samples, has a number of parameters. Because of a lack of knowledge about the correct value of these parameters for a given sample, there is uncertainty in the computed iodine-131 concentration for each sample. The uncertainties of these parameters are specified as probability density functions (pdfs), which are listed in Table A.1 in Appendix A. These pdfs were used as input to a computer code (Iman and Shortencarier 1984) that was used to estimate the uncertainty of the iodine-131 concentration computed using Equation (5). This uncertainty is characterized by the histograms of 1000 possible (plausible) iodine-131 concentration values generated by the uncertainty analysis for each of the vegetation samples. For each sample, this histogram expresses the uncertainty in the predicted iodine-131 concentration that is due to uncertainties in the model parameters. The model itself is assumed to be known.

Uncertainty analyses were conducted for two specific vegetation samples: a sagebrush sample collected and counted on December 20, 1945, and a sample of unknown species collected and counted on July 15, 1946. The histograms of the 1000 computed values for iodine-131 concentrations for these two samples are summarized in Table 1 and displayed in Figures 4 and 5. The uncertainty for each vegetation sample is described by both the 98% confidence interval for the concentration value and by a unitless multiplicative uncertainty factor. The multiplicative factor is useful for summarizing and comparing results for different vegetation samples. From Table 1 it was found, using the upper and lower limits of the 98% confidence interval, that the multiplicative uncertainty for the December 1945 iodine-131 concentration was approximately 1.5. That is, the lower and upper limits were a factor of approximately 1.5 smaller and larger, respectively, than the deterministic-predicted (DP) concentration.

For the July 1946 sample, the upper limit of the 98% confidence interval was a factor of 1.4 larger than the DP concentration, and the lower limit was a factor of 2.8 less than the DP concentration. This difference in factors for the December 1945 and July 1946 vegetation samples reflects the fact that the uncertainty in the iodine correction factor I_{cf} was substantially larger for the July 1946 sample than for the December 1945 sample. The factors for the July sample (1.4 and 2.8) were unequal because the pdf of I_{cf} for that sample was asymmetrical (higher probability of extremely low values than of extremely high values of I_{cf}).

In addition to the parameter uncertainty analyses, sensitivity analyses were conducted to determine which parameters[a] in Equation (5) contribute the most to the uncertainty of the iodine-131 concentration value for each vegetation sample. The sensitivity analyses (Section 4.2) indicated that E_1, m, e, M_w, and I_{cf} were the most influential parameters[b] for both the December and July vegetation samples. However, the parameter I_{cf} contributed the most uncertainty to the iodine-131 concentration for the July 1946 sample only. The analyses also showed that the parameter t (time between sample collection in the field and beta counting in the laboratory) was not highly influential for either sample. Also, parameters G (gross GM detector cpm), B (background cpm), and W (vegetation pellet weight) had very minor influences on the uncertainty. These results suggest that the parameter I_{cf} is the most important candidate for further study, followed by E_1, m, e, and M_w.

The results (Section 4.2.2) suggest that if all of the uncertainty in I_{cf} was removed for the July 1946 vegetation sample, the multiplicative uncertainty factors 1.4 and 2.8 would reduce to a single factor of about 1.5. That is, when all uncertainty in I_{cf} was removed, the 98% subjective confidence interval was from 1.92 to 4.43 μCi/kg, in contrast to 1.035 to 4.11 μCi/kg calculated when I_{cf} was assigned the original (more realistic) uncertainty.

(a) The reader should recall that some of these parameters depend on other parameters defined in Equations (6), (9), (14), (16), (17), and (18).

(b) For definitions of these parameters, see Appendix A and Section 3.0.

This result suggests that even if the uncertainty in I_{cf} were reduced to zero, which is impossible to achieve, the confidence intervals for iodine-131 concentrations would not change drastically. Hence, further study to reduce the uncertainty of I_{cf} would not have been cost effective. Since I_{cf} is the most important parameter for the July 1946 sample, further study to reduce uncertainty in the remaining parameters also would not have been cost effective. Also, it may not be possible to reduce uncertainty in the other parameters to any extent.

7.0 RECOMMENDATIONS FOR FUTURE WORK

A major goal of the HEDR Project is to estimate the iodine-131 dose to the thyroid of specific individuals and population groups who were exposed to iodine-131 in the 1944-1990 period. Those doses will be estimated using the air pathway dose computer model HEDRIC (Hanford Environmental Dose Reconstruction Integrated Codes). HEDRIC contains an environmental accumulation model (DESCARTES) that computes historical measurements of iodine-131 concentrations for vegetation. Because of the large uncertainty that is present in modeling the amount of iodine-131 released from Hanford stacks and the dispersion of that iodine-131 to vegetation around the Hanford Site, the uncertainties in DESCARTES' estimated iodine-131 concentrations for vegetation are also likely to be very large. The uncertainties in iodine-131 concentrations of historical vegetation samples that are computed in this report (Section 4.1) using Equation (5) are expected to be much smaller. In this situation, there appears to be little incentive to conduct studies to try to reduce the uncertainty of parameters in Equation (5). Instead, efforts should be focused on developing improved pdfs for parameters in the source-term, air-transport, environmental-accumulation, and dose models that contribute the most uncertainty to estimated thyroid doses of individuals. This development process is being evaluated as part of the HEDR Project Milestone 0803A letter report: Project Sensitivity Uncertainty Analyses Plan.

Because uncertainty and sensitivity analyses are such an important part of the procedures being developed to estimate doses received by specific individuals and populations, the HEDR Project is currently examining two questions:

1. What level of effort should be devoted to quantifying the uncertainty in the source-term, air-transport, environmental-accumulation, and dose models?

2. To what extent are formal, structured, interview methods for eliciting information from experts concerning model and model-parameter uncertainties needed to ensure the credibility and defensibility of HEDR Project dose estimates?

The first question addresses the issue of uncertainty about models (equations) rather than uncertainty about which parameter values to use in the model. The analyses conducted in this report estimate uncertainty due solely to lack of knowledge about which parameter values to use. An additional component of uncertainty is that due to uncertainty about which model form or structure to use. The predictive models used in this report (Sections 2.1 and 3.0), which are from the Mart et al. (1993) report, are considered to be known with certainty. Of course, model uncertainty (as distinct from parameter uncertainty) does indeed exist. Indeed, the models described in the Mart et al. (1993) report have not yet been formally reviewed by the HEDR Project because that report is still in preparation. However, the issue of model uncertainty was not addressed for the models here because the results of this report will not directly affect the main objective of the HEDR Project, which is to estimate doses to individuals and groups. Staff of the HEDR Project are considering how to resolve the issue of model uncertainty for the source-term, air-transport, environmental-accumulation, and dose models (equations). These models are vitally important for the success of the HEDR Project.

As concerns the second question, no attempt was made here to use a structured interview procedure, such as those discussed by Meyer and Booker (1991) and IAEA (1989, p. 31), for eliciting information about the uncertainty of model-parameter values. This approach was not used because of the time and expense that would have been required, and because such an approach was not considered essential to achieve the goals of this report. However, HEDR Project staff are addressing the issue of the extent to which a formal interview approach is needed to elicit information about models and probability density functions for model parameters. The methods for eliciting and analyzing expert judgment discussed by Meyer and Booker (1991) are currently being evaluated. The issue of how to defend model predictions based on models that require substantial subjective input is of central importance to the credibility of the HEDR Project. This issue is of greatest importance for the source-term, air-transport, environmental-accumulation, and dose models. The defensibility and credibility of the estimated doses for individuals and groups will depend in large part on the credibility of the procedures used to elicit uncertainty information from experts.

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APPENDIX A

RATIONALE FOR THE CHOICE OF PARAMETER DISTRIBUTIONS

APPENDIX A

RATIONALE FOR THE CHOICE OF PARAMETER DISTRIBUTIONS

This appendix gives the rationale for the choice of the probability density function (pdf) for each parameter in Equation (5), the equation that was used to compute iodine-131 concentrations, V. The forms of the pdf (normal, triangular, or uniform) and the minimum, central, and maximum values for each pdf are given in Table A.1.

A.1 GROSS COUNTS PER MINUTE, G (cpm)

For both vegetation samples studied in this report, a large number of beta-particle counts were obtained during the time (t_g minutes) that the vegetation pellets were counted in the GM detector. Hence, the gross count rate, G, for each pellet is known (NCRP 1985) to be well approximated by a normal (Gaussian) distribution with mean G and standard deviation $(G/t_g)^{1/2}$. For the December 20, 1945, pellet, Healy (1945) reports that G = 711 cpm and t_g = 5 minutes, which implies that the mean and standard deviation (SD) of G are 711 and $(711/5)^{1/2}$ = 11.9 cpm, respectively. For the July 15, 1946, pellet, Dickinson (1946) reports that G = 132 cpm and t_g = 16 minutes, which implies that the mean and SD of G for this pellet are 132 and $(132/16)^{1/2}$ = 2.87 cpm, respectively. For both samples, the 0.1 and 99.9 percentiles of G, which are required input to the uncertainty analysis computer code (Iman and Shortencarier 1984), were computed as follows:

$$0.1 \text{ Percentile} = \text{mean} - 3.09 \text{ SD} \qquad (A.1)$$

$$99.9 \text{ Percentile} = \text{mean} + 3.09 \text{ SD} \qquad (A.2)$$

Using these formulas we obtain (see also Table A.1):

	0.1 Percentile	99.9 Percentile
December 20, 1945, sample:	674 cpm	748 cpm
July 15, 1946, sample:	123 cpm	141 cpm

When the computer code by Iman and Shortencarier (1984) selects random values from a normal distribution, no values are selected outside the range given by the 0.1 and 99.9 percentiles. That is, the computer code truncates the low probability tails of normal distributions. Since G has a normal distribution, the code does not select any random values of G outside the range given by the 0.1 and 99.9 percentiles. The other distributions used in this report (uniform and triangular) are not truncated by the code since they have well defined minimums and maximums.

A.2 BACKGROUND COUNTS PER MINUTE, B (cpm)

The numbers of background counts obtained during the background counting time (t_b minutes) for the pellets were large enough to indicate that B is well approximated by the normal distribution, with mean and SD equal to B and $(B/t_b)^{1/2}$, respectively (NCRP 1985). For the December 20, 1945 pellet, B = 23.4 cpm and t_b = 30 minutes, which implies that the mean and SD of B are 23.4 and $(23.4/30)^{1/2}$ = 0.883 cpm, respectively. For the July 15, 1946 pellet, B = 31.5 cpm and t_b = 2160 minutes (36 hours), which implies that the mean and SD of B for this pellet are 31.5 and $(31.5/2160)^{1/2}$ = 0.121 cpm, respectively. The 0.1 and 99.9 percentiles of B, the values of which are given in Table A.1, were computed as they were for G above, and the computer code truncated the normal distributions of B at the 0.1 and 99.9 percentiles.

TABLE A.1. Probability Density Functions for Parameters in Equation (5) Used to Compute Vegetation Iodine-131 Activities (μCi/kg) for a Vegetation Sample Collected and Counted on December 20, 1945, and a Vegetation Sample Collected and Counted on July 15, 1946

Parameter	Pellet	pdf	Minimum	Central Value[a]	Maximum
G[b] (gross cpm)	12/20/45[c]	Normal	674[d]	711	748[e]
	7/15/46[c]	Normal	123[d]	132.4	141[e]
B (bckg cpm)	12/20/45	Normal	20.7[d]	23.4	26.1[e]
	7/15/46	Normal	31.1[d]	31.5	31.9[e]
I_{cf}	12/20/45	Triangular	0.90	0.98	1.0
	7/15/46	Triangular	0.30	0.90	0.95
	7/15/46	Triangular	0.50	0.90	0.95
	7/15/46	Triangular	0.70	0.90	0.95
T[b] (thickness, cm)	HFP[f]	Triangular	0.300	0.578	0.762
	PFP[f]	Triangular	0.381	0.551	0.737
e	HFP	Normal	-0.81[d]	0.0	0.81[e]
	PFP	Normal	-0.56[d]	0.0	0.56[e]
f	HFP	Uniform	0.67	0.70	0.73
	PFP	Triangular	0.70	0.72	0.73
t (days)	All[g]	Uniform	0.0417	0.333	0.625
W[a] (weight, grams)	All	Uniform	0.90	1	1.10
E_1	All	Uniform	-0.0173	0.0	0.0173
E_2	All	Uniform	-0.00173	0.0	0.00173
E_3	All	Uniform	-0.0173	0.0	0.0173
E_4	All	Uniform	-0.00953	0.0	0.00953
m (mg/cm^3)	All	Uniform	0.0295	0.0365	0.0435
M_w (mg/cm^2)	All	Uniform	2.33	3.68	5.03
F_{bs}	All	Uniform	1.06	1.10	1.14
F_{cel}	All	Uniform	1.02	1.04	1.06

(a) Mean of the distribution for each parameter except f (for the July 15, 1946, sample), I_{cf}, and T, for which the mode was used.
(b) Correlation between W and G was 0.90; correlation between W and T was 0.93; correlation between G and T was 0.80. These correlations applied to both hand-formed and press-formed pellets.
(c) 12/20/45 and 7/15/46 are the dates that the two samples were collected and counted.
(d) 0.10th percentile of the distribution.
(e) 99.9th percentile of the distribution.
(f) HFP = all hand-formed vegetation pellets in 1945-1946;
PFP = all press-formed vegetation pellets in 1946-1947.
(g) All vegetation pellets in 1945-1947.

A.3 THICKNESS (T) AND AVERAGE DIAMETER (DIAM) OF THE VEGETATION PELLET (cm)

The thickness (T) and average diameter (DIAM) of a vegetation pellet are parameters in the equation for calculating the self-absorption parameter, F_{sa} [Equation (14)]. Unfortunately, the historical Hanford documents reviewed by the HEDR Project contained only limited information about the actual dimensions of vegetation pellets constructed from early 1945 through 1947, and the original pellets no longer exist.

To obtain estimates of pellet dimensions for the historical pellets, HEDR Project staff constructed several prototype 1-g pellets of green sagebrush and dried cheatgrass in 1989-1990. These prototypes were sent for evaluation to several veteran Hanford employees who worked in the environmental sampling program in the 1940s. There was some disagreement on the cheatgrass pellet, but the veterans' consensus was that the sagebrush pellets generally resembled those made in the 1940s, although they were too perfectly shaped. One person thought that the constructed pellets should contain more leaves. Another person thought that stems should be included in the constructed pellets. Apparently, the historical pellets were more crudely formed because they tried to minimize the handling of the samples.

Based on these comments, HEDR Project staff collected green sagebrush samples monthly for about a year and constructed hand-formed and press-formed pellets using the procedures outlined in the historical documents. The majority of these pellets contained both leaves and small stems. Some pellets also contained flowers or parts of flowers. Fifty-five hand-formed and 55 press-formed 1-g sagebrush pellets were constructed from September 1989 to July 1990 (ten pellets of each type in September, and usually five pellets of each type in other months).

Calipers were used to measure the thickness and diameter of these reconstructed pellets. A single measurement of the thickness (T) was made for each pellet. The diameter was measured at four evenly spaced points (~45 degrees apart) around the pellet surface, and DIAM was computed as the arithmetic average of these four measurements. For each type of pellet, the 55 values of T were plotted as a histogram. Using the shape of this histogram as a guide, the triangular distribution was selected for the pdf for both hand-formed and press-formed pellets. The particular triangular distributions that were selected are given in Table A.1.

If we assume that all 1-g pellets have the same density, the dimensions T and DIAM should be related (in general, larger DIAM implies smaller T). Accordingly, a linear regression analysis of DIAM on T was performed so that the parameter DIAM in the equation for F_{sa} [Equation (14)] could be replaced with an equation that contained only the parameter T plus a random error term e that would model the random deviations from the fitted line. This approach was preferred to the alternative approach of retaining both DIAM and T in the expressions for F_{sa}, specifying pdfs for both DIAM and T, and also specifying the correlation between DIAM and T. The regression approach was judged to be more direct and easier to understand and interpret.

A.3.1 Hand-Formed Pellets

The following regression approach was used for the hand-formed pellets. First, the value of DIAM was plotted against the value of T for each of the 55 reconstructed vegetation pellets. Then, a simple linear regression equation was fit to the data using the software PROC REGRESS in a commercial software package by the Statistical Analysis System (SAS 1985a,b). The regression equation gave the following model:

$$DIAM = 5.32 - 1.95\,T + e \qquad (A.3)$$

where e is a variable that models the random deviations of the plotted points about the straight line. The coefficient of determination (R^2) for the regression (see Appendix B) was only 0.22; i.e., only 22% of the variability in DIAM was explained by the variation in T. Nevertheless, the relationship was judged to be useful because the estimated slope of the line [Equation (A.3)] was negative (-1.95) so that the value of DIAM predicted by Equation (A.3) decreases as T increases.

The parameter e was assumed to be normally distributed with a mean of 0 and a SD of 0.262 cm. The normal distribution was selected because the Kolomogorov goodness-of-fit test used by the SAS (1985a,b) statistical software routine PROC UNIVARIATE indicated a very small likelihood that e was not normally distributed. The SD of e was estimated from the regression analysis to be 0.262 cm.

The normal distribution of e was truncated at the 0.1 and 99.9 percentiles of the distribution by the uncertainty analysis computer code (Iman and Shortencarier 1984). These percentiles were computed using Equation (A.1) and Equation (A.2), and are shown in Table A.1.

In summary, each value of DIAM used in the uncertainty analyses was obtained by first randomly selecting a value of T from its triangular distribution and a value of e from its truncated normal distribution (Table A.1). Then these values T and e were used to compute DIAM using Equation (A.3). This process was repeated for each of the 1000 iterations of the code.

A.3.2 Press-Formed Pellets

The same procedure that was used for hand-formed pellets was also used to estimate the linear relationship between DIAM and T for press-formed pellets. The simple linear regression equation that was fit to the data was

$$\text{DIAM} = 4.49 - 1.135\,T + e \qquad \text{(A.4)}$$

The value of R^2 was 0.096, meaning that about 10% of the variability in DIAM was explained by the variability in T, which indicates that the parameter e varies over a wide range. That is, Equation (A.4) does not give a very precise estimate of DIAM. The test for normality (the same test as was used for hand-formed pellets) indicated it was reasonable to assume that the parameter e was normally distributed. The SD of e was estimated from the regression analysis to be 0.181. Hence, e was assumed to be normally distributed with mean 0 and SD 0.181. The 0.1 and 99.9 percentiles of the normal distribution of e were estimated using Equations (A.1) and (A.2). These percentiles are given in Table A.1.

A.4 WEIGHT OF THE PELLET, W (g)

In this report, it has been assumed that both the December 1945 and the July 1946 pellets weighed 1 g. The rationale for this selection is discussed in the Mart et al. (1993) report. The measurements of W are assumed to have a uniform distribution with lower and upper limits of 0.9 and 1.1 grams, respectively (Table A.1). That is, we have assumed that the actual pellet weight was equally likely to have been any value from 0.9 to 1.1 g, with no possibility that the pellet weight could have been outside that range. These limits were used because veteran Hanford employees indicated that the weighing balances that were used in the mid-1940s were notched in 0.1-g increments. The uniform distribution was selected because no historical information has been found regarding the actual measurement-error distribution.

We assume that the weight, W, and the total beta counts per minute, G, of a specific pellet have a correlation of 0.90. This correlation was selected subjectively on the basis of information reported by Healy and Eisenacher (1946). They counted an unspecified number of samples weighing less than 1 g to determine the effect of sample size on the counting rate (cpm). They found that the cpm was nearly proportional to the pellet weight. The correction factor for a 0.5-g sample was 1.7 instead of the expected value of 2.0 that would apply for the proportional case. For a 0.25-g sample, the correction factor was 3.3 instead of the expected value of 4.0. Pellets of different weight have different values for the parameters G_p, F_d, F_{sa}, and F_a, which may account for the nonproportionality observed by Healy and Eisenacher.

The raw data that were the basis for Healy and Eisenacher's conclusions were not in their report and have not been found. We note that heavier pellets will tend to absorb more of their own radiation than lighter pellets, which will tend to reduce somewhat the value of G and the correlation between W and G.

The weight, W, is also correlated with the thickness, T, of the pellet; heavier pellets tend to be thicker. The correlations here were estimated using sagebrush vegetation pellets constructed in January 1990 by HEDR Project staff to investigate the relationship between pellet weight and dimension (thickness and diameter). Five pellets of each type (hand- and press-formed) were formed for 0.5-, 0.75-, 1.0-, 1.25-, 1.5-, 1.75-, and 2.0-g weights, for a total of 35 pellets of each type. The resulting calculated correlation between W and T was 0.93 for both hand-formed and press-formed pellets.

Since W and G as well as W and T have positive correlations (of assumed values 0.90 and 0.93, respectively), it follows that G and T also have a positive correlation. (Note that a larger T implies more self absorption, which somewhat reduces the value of G and the positive correlation between T and G.) Moreover, since T is correlated with G via the correlations of both T and G with W, it is reasonable to assume that the correlation between T and G is less than the correlation between W and G or W and T. With that assumption, a correlation of 0.8 between T and G was selected subjectively. A subjective selection was necessary because it is not possible to compute the correlation between T and G merely on the basis of specified correlations between W and G and between W and T.

The above correlations were specified as input to the uncertainty-analysis computer code (Iman and Shortencarier 1984). The code did not have to adjust these correlations because the specified correlation matrix was positive definite.

A.5 FRACTION, f [from Equation (8)]

The uniform distribution was selected for the pdf of f for the December 20, 1945, vegetation sample because minimal information was available for this parameter. [Recall that f is the fraction of T (pellet thickness) that achieves the appropriate value of MED.] The mean of f was specified to be 0.70 based on the calculations made in the Mart et al. (1993) report. The lower and upper limits for f were subjectively specified as 0.67 and 0.73 on the basis of professional judgment.

For the July 15, 1946, vegetation sample, the subjectively specified values for the minimum, central (best-estimate), and maximum values were 0.70, 0.72, and 0.73, respectively. A triangular pdf was selected because available information was minimal and because the central value (0.72) was not midway between the minimum and maximum values.

A.6 UNCERTAINTY PARAMETERS E_1 AND E_2 ASSOCIATED WITH G_p

The uniform distribution was selected for the pdf of E_1 and E_2, which are the uncertainty parameters associated with computing G_p [Equation (6)]. The uniform distribution was selected because minimal information was available about these parameters.

Each uniform distribution was assumed to have a mean of 0, which implies that Equation (6) neither underestimates nor overestimates G_p consistently. The SD that was assumed to apply to E_1 was 0.01, which was reported by Schwendiman (1954) for a measured G_p value of 0.22 for shelf 1 of the beta counter. Schwendiman obtained this value by measuring G_p for different beta counters. Because of a lack of data, we assume that the SD of 0.01 also applies to G_p values for the second shelf of the counter. Using a mean of 0 and a SD of 0.01, the minimum and maximum values of E_1 are -0.0173 and 0.0173, respectively, as computed using the formulas

$$\max = \text{mean} + (3)^{1/2}\ \text{SD}$$

$$\min = \text{mean} - (3)^{1/2}\ \text{SD}$$

These formulas were obtained by solving for max and min the following formulas that give the mean and SD of the uniform distribution [from Iman and Shortencarier (1984)]:

$$\text{mean} = (\min + \max) / 2$$

$$\text{SD} = (\max - \min) / (12)^{1/2}$$

The SD of E_2 was assumed to be 0.001, which was the value obtained by computing the SD of the differences between the measured and modeled [Equation (7)] values of G_p for shelf-distance values of 0.485, 2.073, and 3.66 cm (see Figure 2). (The measured and modeled values of G_p for shelf distances of 5.25 and 6.84 cm were not used to estimate the SD because the lower shelves were not used in 1945-1947.) Even though the shelf distance 3.66 cm was not used in 1945-1947, values of G_p for that distance were used to estimate the SD of E_2 because the measured G_p for distance 3.66 cm was used to estimate the curve that relates G_p to distance (Figure 2 of this report). Assuming a uniform distribution for E_2 with a mean of 0 and a SD of 0.001, the minimum and maximum values of E_2 were computed to be -0.00173 and 0.00173, respectively. These values were computed using the formulas given above for maximum and minimum.

A.7 UNCERTAINTY PARAMETERS E_3 AND E_4 ASSOCIATED WITH F_d

The uniform distribution was selected for the pdfs for E_3 and E_4 because minimal information was available about these parameters. The mean of each pdf was assumed to be 0, which implies that Equation (10) neither underestimates nor overestimates F_d consistently. The SD of E_3, which represents the measurement error of F_d, was assumed to be 0.01, the same value as was used for E_1. The SD of E_3 could not be estimated from data because no replicate measurements of F_d (i.e., no repeat measurements of F_d made by the same laboratory at the same time) have been found in historical reports. Assuming a uniform distribution for E_3 with a mean of 0 and a SD of 0.01, the minimum and maximum values of E_3 are -0.01732 and 0.01732, respectively.

The SD assumed to apply to E_4 was 0.0055, which was obtained by computing the SD of the differences between the measured and modeled [Equation (10)] values of F_d for shelf distances equal to 0.485 and 2.07 cm and for DIAM values of 2.54, 3.81, and 5.08 cm. Assuming a uniform distribution for E_4 with a mean of 0 and a SD of 0.0055, the minimum and maximum values of E_4 are -0.00953 and 0.00953, respectively.

A.8 IODINE-131 BETA-ABSORPTION COEFFICIENT, m (mg/cm^3)

The parameter m was reported by Baltakmens (1977) to be 0.0365 ±0.007 mg/cm^3. Baltakmens did not define the ±0.007 uncertainty term, but he states that m "...can be determined with a typical accuracy of ±2% if the counting geometry is kept constant." Since 0.007 is 2% of 0.0365, we assume that 0.0365 ±0.007 approximates the minimum and maximum values for m, 0.0295 and 0.0435, respectively (Table A.1). The parameter m is assumed to have a uniform pdf because no information was available to justify using a distribution shape.

A.9 MASS THICKNESS OF THE MICA WINDOW, M_w (mg/cm^2)

Healy, Schwendiman, and Thorburn (1950) reported mica-window mass thicknesses for 13 beta counters in use at Hanford in 1950. The mean and SD of these 13 values were 3.68 and 0.780, respectively, and these 1950 values are assumed to apply to the period from 1945 to 1947. We have assumed that M_w has a uniform pdf because only minimal information was available. A uniform pdf with a mean equal to 3.68 and a SD equal to 0.780 implies the minimum and maximum values of M_w are 2.33 and 5.03 mg/cm^2, respectively, as obtained using the formulas for maximum and minimum given in Section A.6. No information has been found to indicate whether the skill in manufacturing mica windows improved between 1945 and 1950.

A.10 BACKSCATTER PARAMETER, F_{bs}

As discussed in the Mart et al. (1993) report, no measurements of F_{bs} for vegetation pellets have been found in historical Hanford documents. However, one measurement of F_{bs} was reported for iodine-131 on cardboard (Burtt 1949) and six values were reported for iodine-131 on filter paper (Schwendiman 1954; Thomas, Polinsky, and Schwendiman 1956; Mart et al. 1993). Although backscattering within a thick radioactive substance is much more complex than that measured for a radioactive substance placed on an inert backing, these data were used in this report because of the lack of more definitive data [see Mart et al. (1993) for additional discussion]. The mean and SD of these seven values are 1.101 and 0.0219, respectively. We assume a uniform pdf for F_{bs} because the data are inadequate to justify a specific distribution shape. A uniform pdf with mean equal to 1.10 and SD equal to 0.0219 results in minimum and maximum values for F_{bs} of 1.06 and 1.14, as computed using the formulas for maximum and minimum given in Section A.6.

A.11 CELLOPHANE SCATTERING PARAMETER, F_{cel}

For bismuth-210 beta radiation from a radium (RaDEF) source placed on the second shelf of the GM detector, the shelf used historically at Hanford, Schwendiman (1954) estimated F_{cel} to be 1.07. However, more scattering of beta radiation is assumed to occur for bismuth-210 than for iodine-131 because of the higher beta energy of bismuth-210. We can infer from Nervik and Stevenson (1952) that F_{cel} is about 1.04 for iodine-131. Here (because of minimal information) we have assumed that F_{cel} has a uniform distribution with a mean of 1.04. The minimum and maximum of the uniform distribution were assumed, on the basis of professional judgment, to be 1.02 and 1.06, respectively. [See Mart et al. (1993) for additional discussion and rationale.] The maximum and minimum values were not computed using the formulas for maximum and minimum in Section A.6 because no information about the mean and SD of F_{cel} was available.

A.12 NUMBER OF DAYS (t) BETWEEN SAMPLE COLLECTION AND COUNTING

The parameter t was not constant during the period from 1945 to 1946. However, the dates on which sampling and beta-counting occurred were recorded for most vegetation samples in the original data sheets for both 1945 and 1946 (Bulow 1945; Healy 1945; Dickinson 1946). For this report, uncertainty analyses were conducted for only two samples: one that was both collected and counted on December 20, 1945 (Healy 1945), and another that was both collected and counted on July 15, 1946 (Dickinson 1946). The exact number of hours between sample collection and counting for these samples is unknown. We have assumed here that neither sample was collected before 8:30 a.m. or after 2:30 p.m. We have also assumed that neither sample was counted before 3:30 p.m. or after 11:30 p.m. Given these assumptions, the minimum number of hours between sample collection and counting is 1 (from 2:30 p.m. to 3:30 p.m.), or $t = 1/24 = 0.0417$ days. The maximum number of hours is 15 (from 8:30 a.m. to 11:30 p.m.), or $t = 15/24 = 0.625$ days. The mean number of hours is 8 (average of 1 and 15), or $t = 8/24 = 0.333$ days. The uniform pdf was assumed to be applicable for t in the absence of detailed information. Hence, t was assumed to have a uniform pdf with a mean of 0.333 days, a minimum of 0.0417 days, and a maximum of 0.625 days.

A.13 IODINE-131 CORRECTION FACTOR, I_{cf}

For the December 20, 1945, vegetation sample, the central value of I_{cf} is specified as 0.98 based on decay measurements of onsite samples collected in 1945 for the months of February (Parker and Gamertsfelder 1945), July (Bulow

1945), and November (Healy and Eisenacher 1946). The lower and upper limits for I_{cf} were subjectively selected to be 0.90 and 1.0, respectively, taking into account the fuel cooling times for November and December 1945. [See Mart et al. (1993)]. The triangular pdf [with lower limit = 0.90, central value (mode) = 0.98, and upper limit = 1.0] was selected for I_{cf} because minimal information was available. The uniform pdf was not selected because the mode (0.98) was not midway between the lower and upper limits.

For the July 15, 1946, vegetation pellet, the triangular distribution with a lower limit equal of 0.30, a central value (mode) of 0.90, and an upper limit of 0.95 was selected for I_{cf}. The central value of 0.90 was selected on the basis of historical values of I_{cf} reported by Healy (1948) and Parker (1948), as well as information obtained by the HEDR Project and discussed in Mart et al. (1993). The lower and upper limits were selected by E. I. Mart on the basis of professional judgment. Because there was considerable uncertainty about what value for the lower limit of I_{cf} was most appropriate, uncertainty and sensitivity results for iodine-131 were also obtained when I_{cf} was assigned lower limits of 0.50 and 0.70. These additional analyses allowed us to check the sensitivity of the distribution of potential (plausible) iodine-131 concentrations for the July 15, 1946, vegetation sample to changes in this important parameter.

It should be noted that the values used in this report for I_{cf} and its lower and upper limits apply only to vegetation samples for which the cpm measurement obtained by the GM counter is not negligibly small. A vegetation sample for which the cpm measurement was negligibly small would indicate that there had been no significant deposition of iodine-131 on that plant for several weeks before sampling. For such samples, the parameter I_{cf} could be essentially zero, which is less than the lower limits for I_{cf} used in this paper. [See Mart et al. (1993) for further discussion.] The two vegetation samples analyzed in this report were selected partly because they did not have negligibly small cpm.

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APPENDIX B

GLOSSARY OF STATISTICAL TERMS

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GLOSSARY OF STATISTICAL TERMS

B.1 DEFINITIONS

Central (Best Estimate) Value of a Model Parameter

The central (best estimate) value of a model parameter is the single value considered to be the most representative, which is usually considered to be the mean, median, or mode of the set of possible values.

Coefficient of Determination (R^2)

The quantity $R^2 \times 100$ is the percentage of the total variation of the dependent variable (parameter), V, that is explained by a multiple linear regression of V on the other variables in the regression model. In this report, the dependent variable V represents the computed vegetation iodine-131 concentration. The "other variables" are the parameters in the model used to calculate V.

Computer Simulation Study

A computer simulation study is one in which the value of a model output variable is computed many times, each time using a new vector (set) of input parameter values, which are generated using a computer. In this report, the iodine-131 concentration for a specific vegetation sample is computed 1000 times, each time using a new set of computer-generated values for the input parameters. The distribution of 1000 concentrations for a given vegetation sample reflects the uncertainties about the values of model parameters.

Correlation Coefficient

A correlation coefficient measures the degree of linear association between two variables. A positive correlation coefficient (i.e., one between 0 and 1) indicates that there is a tendency for the value of one variable to be relatively large when the value of the other variable is relatively large. A negative correlation (i.e., one between 0 and -1) indicates a tendency for the value of one variable to be relatively large when the value of the other variable is relatively small. Uncorrelated variables have a correlation of 0. In this report, the parameters in the model to compute iodine-131 concentrations are random variables that have either a zero or positive correlation with other variables.

Cumulative Distribution Function (cdf) of a Variable

The cumulative distribution function (cdf) gives the probability that the variable takes on values less than or equal to various specified values. A graph of the cdf is useful for quickly determining these probabilities. Figures 6 and 7 in this report are estimated cdfs for the variable "iodine-131 concentrations."

Deterministic Predicted (DP) Value of a Model

The deterministic predicted (DP) value of a model is the value that is obtained when the central (best estimate) value of each parameter is used in the model. In this report, the DP value for the model [Equation (5)] used to compute iodine-131 concentrations, V, for two vegetation samples is computed.

Latin Hypercube Sampling

Latin Hypercube Sampling is a method of selecting multiple sets of model parameter values for use in a computer simulation study to compute multiple values of the model output. In this report, the method involved dividing the specified pdf of each model parameter into 1000 intervals of equal probability, randomly selecting a value from each interval for each parameter, and appropriately pairing these values to obtain 1000 sets of random parameter values.

Mean

The mean refers to the arithmetic average of a set of values.

Median

The median of a probability density function is that number $X_{.5}$ which has the property that a randomly obtained observation will be less than $X_{.5}$ with probability no greater than 0.5, and will exceed $X_{.5}$ with probability no greater than 0.5. The median of a data set is the middle value when the sample is ordered from smallest to largest. If the number of values is even, the median is the average of the two middle values in the ordered array of values.

Mode

The mode of a probability density function is the highest point on the graph of the function. Probability density functions can have secondary modes. A secondary mode is a local maximum (high) point on the graph of the density function. The mode of a data set is the data value that occurs most frequently. Secondary modes of a data set can also occur.

Model Validation

Model validation is a process of comparing model predictions with field observations and experimental measurements that are independent of the measurements used to develop the model. A model may be considered validated when sufficient testing has been performed to ensure an acceptable level of predictive accuracy (agreement between predictions and measurements) for the range of conditions over which the model may be applied. The acceptable level of accuracy is a judgmental issue and will vary depending on the specific problem or question to be addressed.

Monotonic Relationship Between Two Variables

Two variables, say X and Y, have a monotonic relationship if X increases, decreases, nonincreases, or nondecreases as Y increases in value.

Normal (Gaussian) Probability Density Function (pdf)

A normal pdf is symmetric and has the general shape of a bell (hence it is often called the bell curve). The mathematical definition of a normal pdf is given by Iman and Shortencarier (1984, p. 16), IAEA (1989,

p. 73), and most statistics text books. In this report, several parameters (variables) of the model to compute iodine-131 concentrations are assumed to have a normal pdf.

Parameter Uncertainty Analysis

Parameter uncertainty analysis is a quantitative analysis whereby the uncertainty of each parameter in a model is carried through the model to estimate the uncertainty in the model output that arises from the uncertainties or variabilities of the model parameters. In this report, the uncertainty of parameters in the model given by Equation (5) is carried through to estimate the uncertainty in the iodine-131 concentration.

Partial Rank Correlation Coefficient (PRCC)

The partial rank correlation coefficient (PRCC) measures the correlation between the ranks of the measurements of two variables when the effect of some other ranked variable on which they both depend is removed. The definition of the expression "ranks of measurements" is given in this glossary. The PRCC indicates, on the basis of a multiple linear regression analysis, which variables in the regression model are most correlated with computed output of the model. The multiple linear regression is performed on the ranks (integers 1, 2, 3,...) of the values of the variables rather than on their numerical values. In this report, the variables in the regression model are the parameters in Equation (5) that are used to compute iodine-131 concentrations.

Percentile of the Distribution of a Variable

The pth percentile of the distribution of a variable is X_p, such that at most p percent of the values of the variable are less than or equal to X_p, and at most (100 - p) percent of the values are greater than X_p.

Probability Density Function (pdf) of a Variable

The probability density function (pdf) is a real-valued function for assigning probabilities to ranges of values of a random variable. In this report, the parameters of the model [Equation (5)] used to compute iodine-131 concentrations are variables. This report uses normal (Gaussian), uniform, and triangular pdfs.

Random Variable

A random variable is a function that assigns real numbers to the set of possible outcomes of an experiment.

Ranks of Measurements

The ranks of measurements are the integers 1, 2, 3, ... assigned to measurements that have been put in order from smallest to largest, with the smallest measurement assigned rank of 1, the next smallest measurement assigned the rank of 2, and so on.

Sensitivity Analysis

A sensitivity analysis, as performed in this report, consists of using the results of the uncertainty analyses in a multiple linear regression analysis to determine which model parameters contribute the most uncertainty to the model prediction. A sensitivity analysis is conducted to determine the effect on a model output (i.e., a prediction) of changes or perturbations in the values of one or more model parameters (Liebetrau and Scott 1991). As stated by IAEA (1989, p. 18), "A sensitivity analysis is used to identify the components of a model that are potentially important contributors to predictive uncertainty." If the model output is sensitive to a particular parameter, then a change in the value of that parameter will cause an important change in the model output. In this report, the "model output" is the computed vegetation iodine-131 concentration, V, obtained using Equation (5).

Standard Deviation (SD)

The standard deviation (SD) is a measure of the variability or spread of a set of measurements or values. A data set that has a large standard deviation has more spread than a data set that has a small standard deviation. In this report, the SD of the values of some model parameters is specified or estimated (see Appendix A). Also, the SD of 1000 values of iodine-131 vegetation concentrations [computed using Equation (5)] is presented in Tables 1, 3, and 5.

Triangular pdf

The mathematical definition of a triangular pdf is given by Iman and Shortencarier (1984, pp. 20-23), IAEA (1989, p. 72), and PNL (1991, p. B.9). A triangular pdf has the shape of a triangle. In this report, several parameters (variables) of the model to compute iodine-131 concentrations are assumed to have triangular distributions.

Uniform (Rectangular) Probability Density Function (pdf)

If a random variable has a uniform pdf, all values of the random variable between the specified minimum and maximum values are equally likely to occur. The uniform pdf has the shape of a rectangle. The mathematical definition of a uniform pdf is given by Iman and Shortencarier (1984, pp. 18), IAEA (1989, p. 71), and PNL (1991, p. B-8). In this report, several parameters (variables) of the model to compute iodine-131 concentrations are assumed to have uniform distributions.

B.2 REFERENCES

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APPENDIX C

SUMMARY OF TECHNICAL STEERING PANEL COMMENTS AND BATTELLE, PACIFIC NORTHWEST LABORATORIES RESPONSES

APPENDIX C

SUMMARY OF TECHNICAL STEERING PANEL COMMENTS AND BATTELLE PACIFIC NORTHWEST LABORATORIES RESPONSES

Document Number: **PNWD-1978 HEDR**

Document Title: **"Uncertainty and Sensitivity Analysis of Historical Vegetation Iodine-131 Measurements in 1945-1947"**

Comment Number	Commenter	Page, Paragraph	Comment Summary	Resolution
1.	A. Murphy S. Davis M.L. Blazek	General Comment	No specific comments	NA
2.	D. Walker	General Comment	I support B. Shleien's review comments in which he raises appropriate issues.	NA
3.	M. Robkin	General Comment	All of the parameterizations described in this report seem to be ad hoc. Their utility depends entirely on how well they work. Since there is no current experimental base, we have no way of evaluating how good the methodology is, and must use uncertainty measures to bound the predictions. I have previously discussed with some BNW personnel the desirability of running a Monte Carlo photon-electron transport problem to provide some measure of comparison between the ad hoc methodology and some reference calculations. I realize that doing this is not in the present scope of work. *The photon-electron Monte Carlo* method is well established. Are there no people at PNL who are experienced in this particular calculation and who could run it off quickly and with only modest expense without compromising the current budget?	BNW staff are familiar with the photon-electron Monte Carlo method, but the TSP did not ask BNW to make these calculations. Such calculations are not within current scope and budget.

NA - No Action

Comment Number	Commenter	Page, Paragraph	Comment Summary	Resolution
4.	G. Roessler	General Comment	In Chapter 1, why are you concentrating on only 2 sample: -- why not more?	Conducting analyses on more than two pellets would have exceeded scope and budget and was not expected to provide significantly more information. Also, the data quality objective (DQO) for completeness for this study is to conduct uncertainty and sensitivity analyses for both hand-formed and press-formed vegetation pellets (see Section 5.1.3). This DQO was achieved by using the two vegetation samples.
5.	B. Shleien		The term "subjective confidence interval" not defined. The term "subjective" is very bothersome. It appears to be the statistic for the area between the 1st percentile and the 99th, or the 98% confidence level. I'm not familiar with its use. Why use it? 95% confidence interval usually employed in radioactivity counting.	The word "subjective" is used to remind the reader that subjective input (judgment) was required to obtain the confidence interval. This approach is recommended by IAEA (1989). A 95% confidence interval could have been used instead of a 98% interval. Confidence intervals of any desired percentage can be obtained graphically from Figures 6 and 7. Also, 90% and 50% subjective confidence intervals can be obtained from the percentiles given in Table 1.
6.	M. Robkin	Full Report	I assume that the methodology described will be depended on to convert reported count data to vegetation concentration and thus is an important part of the dose calculation.	The methodology for converting count data to vegetation concentrations is not part of the dose calculation procedure. However, the count conversion methodology is important when using measured values in the model validation effort.
7.	G. Roessler	Page iii, Para 2, Line 8	Should read "counts" per second	The correct term is "counts per minute."
8.	G. Caldwell	Page iii, Para 3, Line 4	Omit "further"	Removed "further."
9.	B. Shleien	Page 1.1, Line 4 from bottom	Indicate general aspects of "conversion factor" (geometry, self-absorption, and backscatter).	NA - These aspects are discussed in Section 3.0 of this report and in Mart et al. (1993).
10.	B. Shleien	Page 3.6	Sample uniformity probably influences self-absorption. Not indicated as factor.	Inserted sentence in Section 3.3: "Sample uniformity also influences self-absorption, but insufficient information about the uncertainty of this parameter was available to include it in the analyses."
11.	B. Shleien	Page 4.5	Could negative skewness be influenced by parameters for T chosen due to whether pellet was hand or machine pressed?	Yes. This possibility is mentioned in the last sentence of Section 4.1.2.
12.	B. Shleien	Page 4.12	If uncertainties in modeling available, or if their magnitude is known, it would be well to include in discussion present in last paragraph, pages 4.12 and 4.13.	NA - Quantitative information about model uncertainties is not available.

NA - No Action

Comment Number	Commenter	Page, Paragraph	Comment Summary	Resolution
13.	G. Caldwell	Page 2.5, Para 2	This paragraph is convoluted and unclear. The first part of the paragraph indicates a decision was made to not interview, the latter half (lines 10-12) seem to indicate they haven't decided.	Revised paragraph to eliminate confusion.
14.	B. Shleien	Page A.1	Explain why 0.1 percentile is mean -3.09 SD, and 99.90 percentile is mean +3.09 SD. What does 3.09 come from?	For a normal (Gaussian) distribution with some mean and standard deviation (SD), 0.1 percent of the distribution lies to the left of the value "mean - 3.09*SD," and 0.1 percent of the distribution lies to the right of the value "mean + 3.09*SD." The value 3.09 is obtained from a table of the Standard Normal Distribution found in most statistics methods books.
15.	B. Shleien	Page A.5 & A.6	If only 20 and 10% of DIAM variability explainable by T, what is remainder of variability attributable to?	The remainder of the variability may be due primarily to differences in density among pellets.
16.	B. Shleien	Pages A.6-A.8	Would not the uncertainty of the pellet weight be influenced by the accuracy of the balance? I think it would be. This factor not discussed. Was it considered? A balance accurate to 0.1 g would have a greater error for a 0.1 g sample than for a 0.9 g sample. Why is triangular distribution selected if normal and/or uniform ruled out? Is this a function of uncertainty analysis?	As discussed in Section A.4, the authors assumed that the actual pellet weight was 1 g with an uncertainty ranging from 0.9 to 1.1 g. This range of uncertainty was selected because the weighing balances used in the mid-1940s were notched in 0.1-g increments. Hence, the accuracy of the weighing balance was considered and discussed in the report. A uniform distribution is used when the only reliable information available is the minimum and maximum values of the parameter. If it is believed that the probability that the parameter's value is near the minimum or maximum is less than the probability that the parameter's value is near the center of the range, then the simplest distribution that can be used is the triangular distribution. The normal distribution should only be selected when one has enough information to justify the judgment that the distribution is symmetric and bell shaped.
17.	G. Caldwell	Page A.7, Para 2	It seems to me that weight must correlate with not only thickness and diameter, but density of the pellet material. Is density accounted for in A.3.2, page A.6?	Density is accounted for in Equations A.3 and A.4 in Sections A.3.1 and A.3.2, respectively, to the extent that density is correlated with pellet thickness, T.
18.	B. Shleien	Page A.13	*Is there a compilation of the ratio of I-131 to* long-lived radionuclides in various vegetation samples? If so, I would like to get it.	*No, there is no such compilation.*

NA - No Action

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