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I am submitting herewith a thesis written by Teresa C. Perry entitled "A Quantitative Uncertainty Analysis for the Assessment of Risk Associated with Radionuclide Releases from the K-1435 Incinerator at Oak Ridge, Tennessee - Human Inhalation Pathway Analysis." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Environmental Engineering.

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A QUANTITATIVE UNCERTAINTY ANALYSIS FOR THE ASSESSMENT OF RISK ASSOCIATED WITH RADIONUCLIDE RELEASES FROM THE K-1435 INCINERATOR AT OAK RIDGE, TENNESSEE - HUMAN INHALATION PATHWAY ANALYSIS

A Thesis

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Master of Science

Degree

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DEDICATION

This thesis is dedicated to my husband, Rick, my daughter, Barbara, my son, Richard, my mom, Stella Cook, and my dad, Ray Cook, who are my continuing source of support and inspiration.

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ABSTRACT

The objective of this study is to perform a quantitative uncertainty and sensitivity analysis of the dose and risk to the maximally exposed individual from the inhalation of radionuclides emitted from the K-1435 TSCA incinerator located at the DOE K-25 facility in Oak Ridge, TN. Dose and risk estimates are computed from monthly stack emissions data beginning in 1990 when the incinerator went into operation and continuing through August, 1994. A gaussian plume dispersion model is used to obtain radionuclide concentrations from the emissions data, and an inhalation pathway analysis is performed. Probability density functions are assigned for each of the risk model parameters. Monte Carlo methods are applied to propagate the parameter distributions, and a confidence interval is determined for the computed dose and risk estimates.

The results of the uncertainty analysis indicate that the estimated cancer risk varies about one and one-half orders of magnitude for the 90 percent confidence interval. More specifically, the chance of cancer incidence due to inhalation of radionuclides ranges from 2 in ten million at the 5 percent confidence level to 9 in a million at the 95 percent confidence level. The EPA deterministic method yielded an estimated risk in the lower quartile of the uncertainty analysis range, and the ICRP deterministic methods yielded an estimated risk in the upper quartile of the uncertainty range. The deterministic computations indicate that the revised EPA

slope factors estimate more than a factor of 5 lower cancer risk due to inhalation of radionuclides as compared to the ICRP methodology which uses dose and risk factors.

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LIST OF ACRONYMS

AMAD	Activity Mean Aerodynamic Diameter
Cs-137	Cesium-137
DOE	United States Department of Energy
E	East
ENE	East Northeast
ESE	East Southeast
EPA	Unites States Environmental Protection Agency
ICRP	International Commission on Radiological Protection
K-40	Potassium-40
Max	Maximum
MEI	Maximally Exposed Individual
Min	Minimum
N	North
NCRP	National Commission on Radiological Protection
NE	Northeast
NESHAPS	National Emissions Standards for Hazardous Air Pollutants
NNE	North Northeast
NNW	North Northwest
Np-237	Neptunium-237
NPDES	National Pollutant Discharge Elimination Standard
Nuclide	Radionuclide
NW	Northwest
ORNL	Oak Ridge National Laboratory

Pa-234m	Protactinium-234M
PCB	Polychlorinatedbiphenyl
Pu-238	Plutonium-238
Pu-239	Plutonium-239
Ru-106	Ruthenium-106
S	South
SE	Southeast
SSE	South Southeast
SW	Southwest
SSW	South Southwest
STAR	Stability Array (wind file format)
Tc-99	Technetium-99
Th-228	Thorium-228
Th-230	Thorium-230
Th-232	Thorium-232
Th-234	Thorium-234
TSCA	Toxic Substances Control Act
U-234	Uranium-234
U-235	Uranium-235
U-238	Uranium-238
WSW	West Southwest

LIST OF SYMBOLS AND UNITS

C	Concentration
cc	Cubic Centimeter
cm^3	Cubic Centimeter
d	Day
DF	Dose Factor
EDE	Effective Dose Equivalent
EF	Exposure Frequency
exp	exponential
GSD	Geometric Standard Deviation (σ_g)
hr	Hour
I	Intake in pCi
IR	Inhalation Rate
LR	Lifetime Risk of Excess Cancers
m^3	Cubic Meter
mth	Month
mrem	Millirem
n	Number of Months
pCi	PicoCurie
R	Risk per pCi
RF	Risk Factor
s	Second
Sv	Sievert
yr	Year

$X_{.50}$	Geometric Mean or Median
$X_{84.1}$	The concentration such that 84.1 percent of the concentrations are smaller.
μ	Mean
μ_g	Geometric Mean
σ	Standard Deviation
σ_g	Geometric Standard Deviation (GSD)

1.0 INTRODUCTION

1.1 Problem Statement

Increased attention from regulators, the public, and environmental professionals is being focused on the methods for conducting risk assessment, the assumptions used in the assessment, and the degree of uncertainty that is associated with the calculated risk estimate. The calculated risk may be a basis for decision making regarding human health and ecological impacts as well as the need or priority for performing costly environmental cleanup or upgrading of pollution controls. A single value or deterministic estimate of the risk gives decision makers very little insight into the variability that may be associated with the estimated number. In some instances, a variation of one or more orders of magnitude could affect the outcome of the decision process for allocation of limited environmental funds. It thus becomes increasingly important to have a more realistic picture of the magnitude of uncertainty associated with the computed dose and risk values.

The objectives of this study are to:

- demonstrate an approach for performing a quantitative uncertainty analysis of the estimated human health risk from the inhalation of radionuclide particulates emitted from the K-1435 TSCA (Toxic Substances Control Act) incinerator located at the United States Department of Energy (DOE) K-25 facility in Oak Ridge, TN,

- perform independent dose and risk calculations for comparison to deterministic methods currently used,
- show how going beyond a single value estimate in the analysis process can provide valuable information to stakeholders and decision makers for use in facility risk management activities, and
- perform uncertainty and sensitivity analyses for the dose and risk calculations to identify parameters contributing most to uncertainty.

Figure 1 shows the location of the K-1435 facility on the K-25 site. Radionuclide emissions data from 1990 through August 1994 are used to compute the annual dose and risk to the offsite MEI (maximally exposed individual). In this case, the assessment endpoint is a hypothetical reference man (ICRP75).

The approach undertaken in this study is to provide a reasonable estimated range of uncertainty. It is not intended to demonstrate compliance with environmental standards which has been previously shown through existing permit reporting mechanisms (DOE94a).

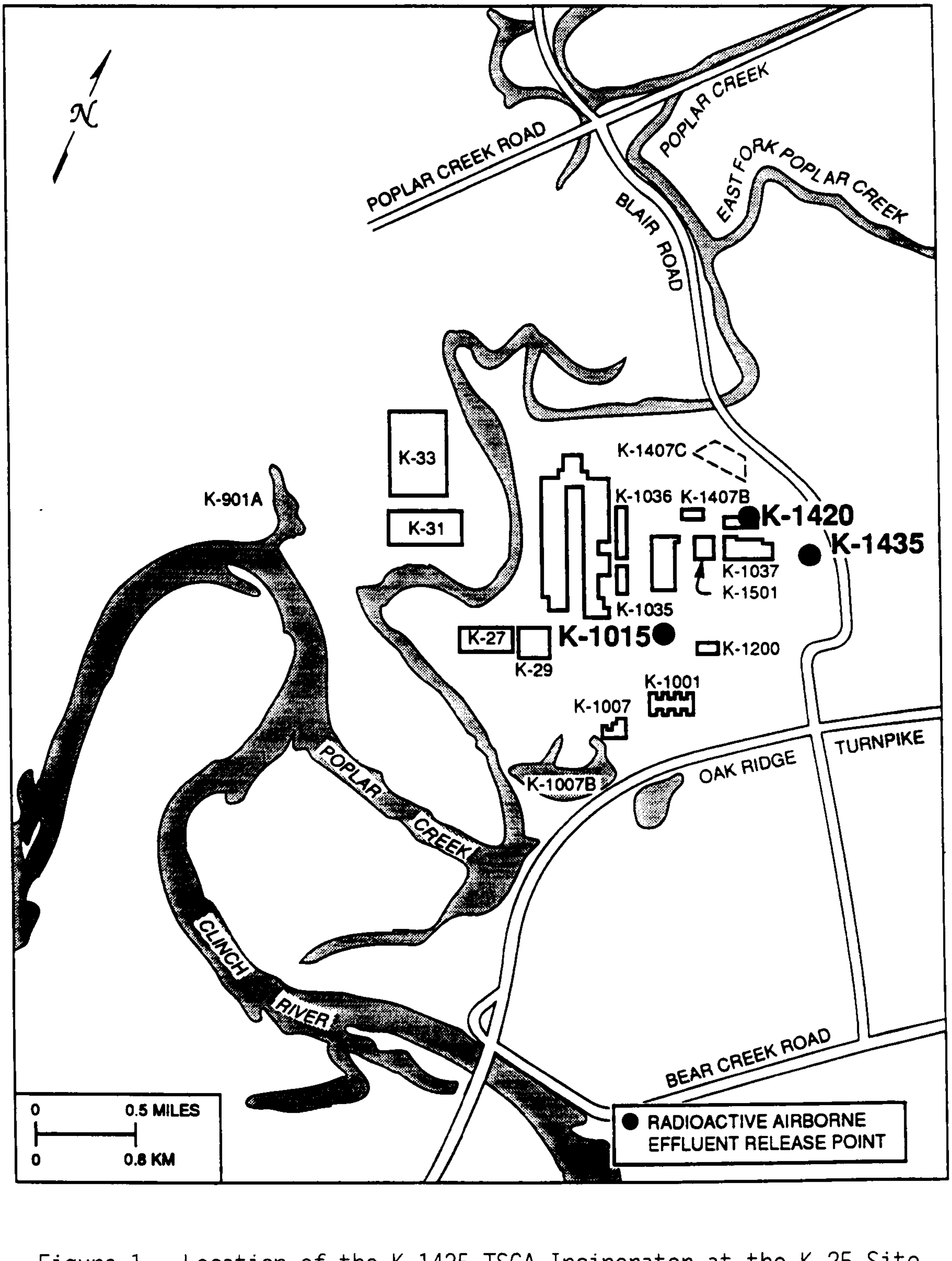

Figure 1. Location of the K-1435 TSCA Incinerator at the K-25 Site

1.2 Background Information

The K-25 TSCA (Toxic Substances Control Act) Incinerator is a DOE facility licensed to dispose of PCB's (Polychlorinatedbiphenyls) and other waste contaminated with radioactive materials. The incinerator is also permitted in accordance with RCRA (Resource Conservation and Recovery Act), NESHAPS (National Emissions Standards for Hazardous Air Pollutants, NPDES (National Pollutant Discharge Elimination Standard) and Tennessee air regulations. The facility initially began incinerating waste in 1990 and was authorized for full-scale operation effective April 1, 1991. The incinerator is capable of destroying 99.9999 percent of PCB's and 99.99 percent of other hazardous organic materials fed into the system. This destruction efficiency is achieved by operating at temperatures in excess of 2000 degrees Fahrenheit. Waste fed into the incinerator passes through a rotary kiln combustion chamber, a secondary combustion chamber, and a quench chamber. Air pollution control equipment includes a venturi scrubber, a packed bed scrubber, and two ionizing wet scrubbers. Radionuclide emissions from the 30-meter stack are continuously monitored and sent for analysis on a weekly basis. Analysis results are composited into monthly and annual emissions' reports. These data are then used to compute the annual dose to the MEI which is published in annual reports available to the public (Ko91, Ko92, Ko93, Ko94).

2.0 REVIEW OF LITERATURE

A literature review of current risk assessment uncertainty analysis methods indicates that a combination of computational and subjective techniques are employed to perform the analysis. Uncertainty analysis of the risk equation parameters has been described as a parameter uncertainty analysis or a parameter error propagation analysis (Ti83). The basic steps to follow in performing an uncertainty analysis have been outlined by several authors in the environmental risk business (Ti83, EPA89b, EPA89c, EPA91, NRC90, Ho82, Ho92, H093, Ho95, Ki94, Sh93, DOE93a, DOE94c). The steps to follow in performing an uncertainty analysis are (Ho95):

- Determine the risk assessment endpoint
- Identify the sources of uncertainty in the model (eg., exposure frequency, concentrations, intake rates)
- Quantify confidence intervals or "credibility intervals" and select probability distributions to represent the true value of each parameter for estimating the assessment endpoint
- Propagate parameter uncertainty to obtain a statement of confidence about the risk estimate
- Compare confidence statements to the decision criteria
- Review the parameters that dominate the uncertainty, obtain more information on those parameters, and repeat the analysis.

Although much guidance on performing risk parameter uncertainty analysis has been published in recent years, none of the sources of literature on the subject of quantifying parameter uncertainties has published guidelines on the best and definitive set of parameter distribution, mean, and standard deviation values to use. Site-specific data is preferred if appropriate for the assessment endpoint. In lieu of site-specific information, national statistics are available on many parameters for estimates of the arithmetic mean, median, 95th and 99th percentiles. Site-specific data from other sites with similar situations is also a source of information.

The associated distribution function to use to characterize the parameter is more difficult to establish. Selection of the distribution function is often based on subjective confidence or "credibility intervals" established by expert opinion or committee consensus (Ti83, H082). EPA guidance is based on deterministic risk estimation; however, EPA recommends consideration of uncertainty in risk analysis.

Selection of the probability distribution for each parameter should be based on an understanding of the parameter data set. Literature reviews can provide valuable information; however, the reviewer should determine if the data referred to in the literature are relevant to the assessment endpoint. If the data are partially but not totally relevant to the site being assessed, the selected distribution range should be set wide enough to encompass the additional uncertainty. There are some general guidelines to follow for selecting a distribution shape (Ho82, Ho95, Ti83):

- Use uniform for maximum uncertainty

- Use normal or lognormal when extrapolating from similar data sets or when the range is several orders of magnitude
- Use triangular when a most likely value and extreme values are known, and the variation is not several orders of magnitude
- Use a custom distribution when specific information about the data is known and the other distributions do not represent the data as well

The parameters of interest in this study are the following risk model parameters: radionuclide concentration, inhalation rate, exposure frequency, exposure duration, dose factor, and risk factor. Substantial research has been performed in support of advancing the understanding and quantification of these parameters. For detailed discussion of the basis for estimating the range and distribution characteristics, the reader is referred to later sections in this study covering each parameter.

3.0 METHODOLOGY

The study presented herein uses monthly radionuclide emissions, facility data, and meteorological data as input to an air dispersion modeling program in order to determine radionuclide concentrations at the MEI location. The monthly concentrations are used to determine an appropriate distribution, an expected mean annual concentration, and an expected variance for each radionuclide. These values are input into a simulation analysis program to predict an expected range for the annual dose and risk for comparison to the values obtained from deterministic calculations similar to the calculations performed for the annual report previously cited. The analysis of radionuclide emissions is performed for the inhalation pathway which is the predominant contributor to the total internal and external dose.

The risk model used is multiplicative for computing risk for each radionuclide and is an additive model for estimation of risk from all radionuclides across all pathways. The risk can be represented by the following equations (ICRP90, EPA89b):

$$LR = \sum_{i=1}^{n} (EDE_i \times ED \times RF \times K2)$$

where:

- LR = lifetime risk of excess cancers
- EDE_i = effective dose equivalent in mrem/yr per radionuclide, i
- ED = exposure duration in yr
- RF = risk factor or probability coefficient for converting dose to risk in Sv^{-1}. For total cancers, both fatal and nonfatal, the RF is 0.06/Sv.
- K2 = units conversion factor = 1E-5 Sv/mrem

and $EDE_i = C_i \times IR \times EF \times DF_i \times K1$

where: C_i = concentration of radionuclide, i, in ambient air in pCi/m^3
IR = inhalation rate in cm^3/hr
EF = exposure frequency in d/yr
DF_i = dose factor for radionuclide, i, for converting exposure to dose in mrem/pCi
K1 = units conversion factor = 24 hr/d x 1E-6 m^3/cm^3

Monthly emissions data are used to evaluate an expected mean annual concentration and expected variance for each radionuclide. Due to the relatively short time that the incinerator has been operating, approximately 3-1/2 years, monthly data rather than the annual average data provide a better basis for determining a probability density function for use in a quantitative analysis.

An alternative methodology used by EPA for computing total cancer risk is:

$$R = \sum (I \times SF)$$

where SF is the slope factor given in units of risk per pCi for each radionuclide (EPA 89b, ORNL95). Intake, I, in pCi via inhalation for each radionuclide is computed from the following equation:

$$I = C \times IR \times EF \times ED$$

where C is the radionuclide concentration in pCi/m^3 at the receptor location, IR is the inhalation rate in m^3/d, EF is the exposure frequency in days per year, and ED is the exposure duration in years.

Until 1994, the ICRP and EPA methodologies yielded somewhat different estimated risks with the ICRP methodology giving higher estimates of risk than the EPA methodology. In 1994, EPA revised many of the slope factors to give risk values more comparable to the ICRP values (NRC90, EPA94, ORNL95). The EPA slope factors were revised to be more conservative for many radionuclides based on current epidemiological data and on recommendations from the National Academy of Science (EPA95). For comparative purposes in this study, the EPA methodology will be used along with the ICRP methodology to provide deterministic estimations of the risk.

The uncertainty analysis performed for the ICRP methodology uses Monte Carlo analysis of the risk model equation parameters. A probability density function, mean, and standard deviation are defined for each parameter. For certain parameters, minimum and maximum values are also defined. Short term averaging times are used for some parameters and will be discussed in the sections addressing the parameter assumptions. For the Monte Carlo analysis, a computer simulation is run in which sample values are randomly selected from each parameter's distribution. The risk is computed by substituting the selected values into the equation. For this study, the simulation uses a Latin Hypercube sampling methodology rather than simple random sampling due to the increased efficiency and reduced run time required. The sampling is repeated for 1000 trials. The simulation yields a probability density function and confidence limits for the predicted cancer risk. A sensitivity analysis is also performed which gives the correlation coefficient for each equation parameter.

4.0 AIR DISPERSION MODELING

CAP88PC is an EPA-approved, Gaussian plume, flat terrain computer model that is used to perform the dispersion and deposition calculations and to estimate the radionuclide concentrations at a point 5180 meters West Southwest (location of the MEI) of the incinerator stack. Table 1 lists the MEI locations for each of the sixteen wind directions from the incinerator stack (Od94). The computed annual dose at the location 5180 meters WSW yields the greatest dose of the sixteen locations.

CAP88PC is a desktop computer adaptation of the AIRDOS, DARTAB, and PREPAR codes originally compiled in FORTRAN to run on a mainframe computer. The AIRDOS program contains a database of dose and risk factors for radionuclides. The program, in combination with the DARTAB code, selects the appropriate dose and risk factors to use and computes the health effects. The selection of which factors to use is based on the particular isotope, the particle size or the activity mean aerodynamic diameter (AMAD), and the lung retention class. Table 2 gives the particle size and lung retention class for each radionuclide. The particle size is based partly on measurements and partly on agreements reached between the USDOE and regulators (Po94).

Table 1. Distances to the Nearest Receptors in All Directions Around the K-25 TSCA Incinerator

House	Direction	Distance (meters)
1	ENE	6150
13	E	11450
14	ESE	10600
19	SE	7050
23	SSE	4340
24	S	4460
25	SSW	3650
26	SW	5180
28	WSW	5180
30	W	4460
32	WNW	3250
34	NW	3000
35	NNW	3150
36	N	3380
37	NNE	5420
38	NE	5780

Table 2. Radionuclide Particle Size and Lung Retention Class

Nuclide	AMAD (microns)	Lung Retention Class
Cs-137	1.0	Day
K-40	1.0	Day
Np-237	1.0	Week
Pa-234m	1.0	Year
Pu-238	1.0	Week
Pu-239	1.0	Week
Ru-106	1.0	Year
Tc-99	1.0	Week
Th-228	0.3	Year
Th-230	0.3	Year
Th-232	0.3	Year
Th-234	0.3	Year
U-234	0.3	Year
U-235	1.0	Year
U-238	0.3	Year

The PREPAR code was written as a preprocessor to simplify user input to the AIRDOS and DARTAB codes. The CAP88PC program combines the three codes into one program that executes on a desktop computer. CAP88PC Version 1.0 is the currently available version that is used for the analysis presented in this study. The CAP88PC program requires input data to be loaded into an input file with restrictions on the units that can be input for each parameter. Preparation of a Windows-based PC version that offers more flexibility for inputting parameters is currently underway but is not yet available.

Total incinerator emissions in Curies per month and the associated measurement uncertainties are depicted in bar charts shown in Appendix A (Gr94). These uncertainties were determined by the radiological analysis laboratory based on the analytical methods used and the counting statistics. The average emission provided by the laboratory is used for the uncertainty analysis in this study. Reported negative emissions are treated as zero emissions. The charts shown were computed based on the total sum of the absolute values of the emissions and measurement error. As shown in the charts, uncertainty is high for some of the radionuclides but comparatively low for the uranium isotopes which result in having the greatest influence on the magnitude of the estimated dose and risk.

The CAP88PC software requires emissions to be input in units of Ci/year. The monthly emissions were adjusted to annual units for input to the program. Concentrations computed by the program are output in units of pCi/m^3. Additional input data for the program such as stack velocity, ambient temperature, and precipitation are also provided in Appendix A. The desktop version of the program uses certain default values and units. Some of the key program defaults and K-25 specific input constants are summarized in Table 3.

Table 3. CAP88PC Program Defaults and K-25 Input Constants

Parameter	Value	Units
Human Inhalation Rate	9.17E+05	cc/hr
Particle Diameter	0.3 or 1	micrometer
Stack Height	30	meters
Stack Diameter	1.37	meters
Mixing Height of Lid	1000	meters

Meteorological data must be input into a specific wind file format required by the CAP88PC program. A conversion program supplied with the CAP88PC program will convert an EPA STAR (STability ARray) file format to the required wind file format. An example of the EPA STAR file format is given in Appendix B. For each month of emissions data, the wind roses and the corresponding wind data were obtained in the EPA STAR file format (Sha94). The monthly data have been composited from hourly wind speed, stability category, and direction data taken at 60 meters on the K-25 meteorological tower located closest to the incinerator as shown in Figure 1. The percentages in each month's wind file add to one or 100 percent. Appendix B also contains the monthly wind roses.

In a deterministic risk assessment, the computed concentration from the CAP88PC program is used to perform the analysis. If uncertainty is considered in the analysis, EPA recommends consideration of the model uncertainty. Earlier studies sponsored by Oak Ridge National Lab indicate an uncertainty factor of 0.5 to 2.0 is appropriate to account for model uncertainty for a flat terrain environment with distances less than 10 km from the source (Li79). The uncertainty factor is intended to account for overall uncertainty in the model for estimating the annual average concentrations or concentrations at other averaging times. Instead of using an estimated model factor of 2.0, actual field measurements or stack data were available and were used to validate the model results (Li79). The authors recommend that as much site-specific information as possible be used for meteorological conditions and release height information. In this study, site-specific meteorological and emissions data are used to determine the concentrations at different averaging times. Thus, an analysis of the concentrations is used to quantify uncertainty in lieu of a single factor.

5.0 RISK MODEL PARAMETERS

In a given analysis of dose and risk due to inhalation of radionuclides, the uncertainties can be grouped into the following categories:

- Emissions uncertainties
- Model uncertainties
- Transport, deposition, and uptake
- Conversion of exposure to dose
- Conversion of dose to risk
- Representativeness of reference man

The measurement error shown in Appendix A and previously discussed is one source of uncertainty associated with the emissions data. In the case of the uranium emissions, the measurement error is about one third of the measured value. The particle size distribution presents an additional area of uncertainty for the emissions data.

As mentioned earlier, the simplified Gaussian plume, flat terrain model is a source of uncertainty. Considerable uncertainty exists in the ability of the model to be representative of the real-life transport and deposition characteristics of the emitted radionuclide particles, but these uncertainties can be reduced by using site-specific data where available.

Estimation of the uptake of radionuclides and the conversion to dose and risk are key areas of uncertainty that exist in a risk analysis. The uncertainty lies primarily in the biokinetic modeling such as estimation of the absorption to blood from the small intestine. Very little uncertainty exists in the physics or energy deposition of the radionuclides.

Reference man is not truly representative of the general population but is an agreed upon standard (ICRP75). Reference man is designed to represent a Western European or North American in habitat and custom, a caucasian adult male who weights 70 kilograms and is 170 cm tall, and inhales 20 cubic meters of air daily. The International Committee on Radiation Protection is developing additional standards that consider differences in the human anatomy and physiology due to age, gender, race and geographic region. The study presented herein uses the reference man standard which was developed to provide a means of consistency between risk assessments. The following sections provide a more in-depth discussion of the uncertainties for each parameter in the risk equation.

5.1 Radionuclide Concentration

In order to estimate the annual concentration for each radionuclide emitted from the incinerator, emissions based on a monthly averaging time were input to the CAP88PC program. Approximately 40 months of emissions data were available for the incinerator. The annual concentrations were computed from monthly emissions data by converting the Ci/mth data to Ci/yr for input to the CAP88PC air dispersion model which requires annual units. The program then converts the emissions data to Ci/s for performing the analysis. Appendix C contains a summary of the resulting concentrations obtained from running CAP88PC. The concentrations calculated in units of pCi/m^3 by the program were then adjusted by the factor 10.4/12 to account for the incinerator operating an average of 10.4 months per year. The remaining 1.6 months is the average outage time for the incinerator. Monthly rainfall measurements are also converted from cm/mth to cm/yr for input to CAP88PC. Monthly wind files are used as the meteorological data input to the program. As indicated by the wind roses shown in Appendix B and the supporting wind file data, the wind blows in the WSW direction approximately 10 percent of the time. As discussed previously, for the sixteen MEI locations, 5180 meters WSW is the location that receives the highest concentration of radionuclides.

Radionuclide concentrations were plotted on normal probability and lognormal probability curves using the Statgraphics software (Ma94). The program ranks the concentration values from high to low, then produces a scatterplot with the values on the x-axis and the plotting position on the y-axis computed using the following equation:

$$\phi(i - 3/8) / (n + 1/4)$$

where $\phi(p)$ is the value of the inverse cumulative normal distribution at probability p, i is the rank of the data point being plotted, and n is the total number of months of data. If the data approximate a normal curve, the plotted data should fall along the linear curve representing the theoretical cumulative normal distribution. If the data approximate a lognormal curve, the logarithm of the values should fall along the line representing the theoretical cumulative lognormal distribution.

As shown in the normal and lognormal probability plots given in Appendix D for the concentration data of each nuclide, the concentrations for the uranium, thorium, and other isotopes more nearly approximate a lognormal distribution than a normal distribution. Goodness of fit tests were also run using the Statgraphics software. Results of the chi-square and Kolmogorov-Smirnov tests indicated that the sample distribution and the lognormal distribution were not significantly different at a 90 percent confidence level for the uranium and thorium radionuclides which have the greatest influence on the dose and risk value due to the magnitude of their concentrations and toxicities. The results of the goodness of fit tests are consistent with a visual inspection of the probability plots. Thus, at a confidence level of 90 percent, the data indicate that the lognormal distribution is an acceptable probability density function. Several studies have also noted that the distribution of pollutant concentrations tends to be lognormally distributed due to the large number of low pollutant concentrations, a lesser frequency of medium level concentrations, and a small number of high concentrations (Co86, Gi87, No77, Ti83).

For a lognormal distribution, the geometric mean and geometric standard deviation are the parameters needed to describe the distribution. The geometric mean of a lognormal distribution is the exponential of the mean of the associated normal distribution. The geometric standard deviation (GSD) of a lognormal distribution is the exponential of the standard deviation of the associated normal distribution. The relationships between the geometric mean and the geometric standard deviation for a lognormal distribution are as follows:

$$\log(X_{84.1}) = \log(X_{.50}) + \log \sigma_g \qquad \text{or} \qquad \sigma_g = X_{84.1} / X_{.50}$$

where:
$X_{.50}$ = the geometric mean diameter
$X_{84.1}$ = the concentration such that 84.1 percent of the concentrations are smaller
σ_g = the geometric standard deviation

In order to determine a reasonable estimate of the geometric mean and geometric standard deviation, a methodology was used similar to the Larsen "arrowhead" diagram approach to quantify parameters for an averaging time of 9 years. EPA defines 9 years as the national median time that one would reside at a residence (EPA89b). Figure 2 shows an example of the Larsen technique where the line connecting the maximum and minimum concentrations for different averaging times resembles an arrowhead. Research and analysis has been performed in the area of estimating pollutant concentrations at a given location for different averaging times. Studies relating short term (hours) measurement variations to long term (years) concentration variations

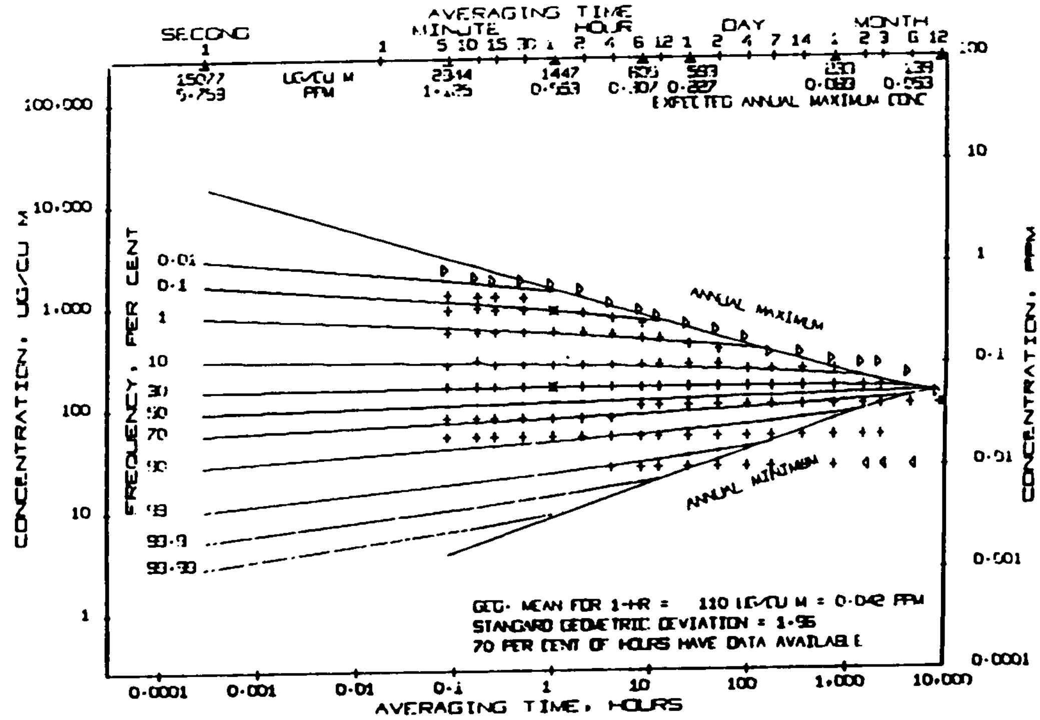

Figure 134. Computer plot of concentration versus averaging time and frequency for sulfur dioxide at site 256, Washington, D.C., December 1, 1961 to December 1, 1968.

Figure 2. Illustration of the Larsen "Arrowhead" Diagram
(Source: No77)

indicate that the uncertainty decreases as the averaging time increases (La71, No77).

The approach developed by Larsen (La71, No77) and illustrated in Figure 2 provides a means of estimating the maximum concentration of a pollutant for any given averaging time by plotting concentration frequencies versus averaging time on a log-log scale. Once a linear maximum concentration line has been fitted to the data, the maximum concentration, C_{max}, for the desired averaging time can be computed by the equation:

$$C_{max} \text{ desired} = (C_{max} \text{ for the reference averaging time}) \times t^q$$

where:
- t = the desired averaging time in the same units as the reference averaging time (eg. hours, days, months)
- q = the slope of the fitted C_{max} line

Concentrations at each percentile level should also plot as a straight line based on the assumptions for the methodology. The key assumptions for the "arrow" methodology can be summarized as follows (La71, No77):

- Concentrations at all averaging times have a lognormal distribution
- Median concentrations plot as a straight line on log paper
- All averaging times have the same mean concentration
- Maximum concentration can be estimated as being inversely proportional to averaging time raised to an exponent

For adaptation of this methodology to this study, the desired estimator is for the 50th and 84th percentiles for a 9 year averaging time. The following assumption will be employed in addition to the previously stated assumptions:

- The 84th percentile concentration is proportional to averaging time raised to an exponent and will plot as a straight line on log-log paper.

Concentration percentiles were computed for each radionuclide at three averaging times (monthly, quarterly, annually). The following percentiles were computed using the Statgraphics program: 99%, 95%, 90%, 84.1%, 50%, 15.9%, 10%, 5%, 1%. Following the assumptions defined for the "arrowhead" approach, the concentration percentiles were plotted against the three averaging times on log-log paper. Figure D.31 shows the plots for each radionuclide. The fitted lines bounding the 99th and 1st percentile concentrations were projected to determine an approximate averaging time when the lines converge to the mean concentration value. The 84.1, median, and 15.9 lines also plot as a straight line converging to the mean concentration. The slope of the line representing the 50th percentile is noted by the letter "r", and the slope of the line representing the 84th percentile is noted by the letter "q". Once the slope of each line was determined, the median and 84th percentile concentrations were computed for an averaging time of 9 years by multiplying the concentration of the reference averaging time by the desired averaging time, 9 years (or 36 quarters or 108 months depending on the reference averaging time) raised to the exponent "r" to determine the 50th percentile or "q" to determine the 84th percentile. The results of the graphical solution are summarized in Table 4.

Due to input constraints on the distribution parameters allowed by the Crystal Ball program, geometric mean, μ_g, and standard geometric mean, σ_g, cannot be input to the program to describe a lognormal distribution. The program requires the mean and standard deviation as descriptors of the lognormal distribution. The equations for the mean, μ, and standard deviation, σ, for a lognormal distribution are as follows (An75):

$$\mu = \exp [\ln \mu_g + 1/2 (\ln \sigma_g)^2]$$

$$\sigma = \{ \mu^2 [\exp (\ln \sigma_g)^2 - 1] \}^{0.5}$$

The mean and standard deviation for each radionulide as input to the Crystal Ball program are given in Table 5. The option of inputting geometric mean and geometric standard deviation into the program was discussed with the Crystal Ball developers who plan to add the option in the next version of the program due to the number of requests from the user community (De95). The maximum value shown is three geometric standard deviations from the median. Zero is used as the minimum value since the concentration can be as low as zero.

Table 4. Geometric Mean, μ_g, and Geometric Standard Deviation, σ_g, Values for Radionuclide Concentrations for a 9-Year Averaging Time

Nuclide	Slope Values r	Slope Values q	$\mu_g = (x_{.50})$ (pCi/m^3)	$x_{.84}$	$\sigma_g = (x_{.84}/x_{.50})$
Cs137	0.095	-0.001	9.760E-6	1.390E-5	1.42
K40	0.150	-0.002	1.600E-4	4.980E-4	3.11
Np237	0.050	-0.002	1.240E-6	6.100E-6	4.92
Pa234m	0.035	-0.036	3.840E-8*	*	*
Pu238	0.085	-0.008	6.450E-8	3.420E-7	5.30
Pu239	0.053	-0.018	8.140E-8	2.560E-7	3.14
Ru106	0.210	-0.050	8.370E-5*	*	*
Tc99	0.029	-0.002	4.150E-4	1.012E-3	2.44
Th228	0.159	0.193	1.420E-6	3.310E-6	2.33
Th230	0.046	-0.025	5.060E-7	1.600E-6	3.16
Th232	0.086	-0.020	4.095E-7	6.380E-7	1.56
Th234	0.035	-0.042	1.300E-5	2.410E-4	1.85
U234	0.021	-0.026	2.360E-5	5.480E-5	2.32
U235	0.021	-0.002	9.65E-7	2.060E-6	2.13
U238	0.020	-0.020	1.970E-5	6.360E-5	3.23

* Note: Values converged to arithmetic mean at an averaging time less than 9 years indicating minimal variability for a 9 year averaging time. The arithmetic mean concentration is used for the analysis as a point estimate.

Table 5. Mean, Standard Deviation, Minimum, and Maximum Values for Radionuclide Concentrations for Input to Crystal Ball

Nuclide	Mean (μ)	Standard Deviation (σ)	Minimum	Maximum
Cs137	1.028E-5	3.720E-6	0.000E+0	2.769E-5
K40	3.046E-4	4.933E-4	0.000E+0	4.813E-3
Np237	4.412E-6	1.507E-5	0.000E+0	1.477E-4
Pu238	2.591E-7	1.008E-6	0.000E+0	9.603E-6
Pu239	1.566E-7	2.576E-7	0.000E+0	2.520E-6
Tc99	6.178E-4	6.812E-4	0.000E+0	6.029E-3
Th228	2.031E-6	2.076E-6	0.000E+0	1.796E-5
Th230	9.809E-7	1.629E-6	0.000E+0	1.597E-5
Th232	4.521E-7	2.114E-7	0.000E+0	1.555E-6
Th234	1.571E-5	1.065E-5	0.000E+0	8.231E-5
U234	3.363E-5	3.414E-5	0.000E+0	2.947E-4
U235	1.284E-6	1.128E-6	0.000E+0	9.325E-6
U238	3.917E-5	6.733E-5	0.000E+0	6.639E-4

An additional consideration can be the effects of seasonality on the estimated concentration median and geometric standard deviation values. Concentrations for uranium, thorium, and neptunium were checked to see if seasonality trends were present. Monthly concentration values for select radionuclides were plotted over the full range of months of the incinerator operation. These time series plots are shown in Appendix E. Monthly values were then averaged to give an average concentration for each of the 12 months in the year. A regression analysis was also performed and the residuals plotted over time as shown in Appendix E for certain radionuclides. Visual inspection of the monthly average concentrations and residuals plotted over time indicates a cycling effect for different seasons of the year. This is consistent with the variation in the monthly meteorological data and wind roses (Appendix B), Additional statistical analysis of the seasonality effects on the monthly concentration variance was not undertaken as part of this study due to time and resource constraints; however, it is noted that seasonality effects would further add to the uncertainty of estimating the concentration variance. Quantification of this effect on the variance is left for future study. The reader is referred to reference Gi87 for further discussion of the effect of seasonality on the estimation of variance.

5.2 Inhalation Rate

The inhalation rate used in the risk model is based on a mean inhalation rate for reference man established by the International Commission for Radiation Protection (ICRP). Reference man is assumed to inhale an average of 8.333×10^5 cm^3 of air per hour or 20 m^3 per day (ICRP75, EPA89b, EPA89c). This average resting inhalation rate is typically the recommended value to use in a deterministic risk assessment. For use in a probabilistic assessment, the parameter can be characterized as having a lognormal distribution with a geometric mean of 8.506×10^5 cm^3/hr and a geometric standard deviation of 8.506×10^5 cm^3/hr (EPA89b, EPA89c, DOE93a). A minimum value of 4.533×10^5 cm^3/hr and a maximum of 1.532×10^6 cm^3/hr are set as upper and lower limits based on three geometric standard deviations from the median. The minimum and maximum values are very conservative limits based on 99th percentile extremes for adult resting and highly active rates (EPA89b, DOE93a). The 20 m^3/d was determined by ICRP to represent a daily inhalation rate for "reference man" engaged in 16 hours of light activity and 8 hours of rest. The determination of a median rate was based on short term inhalation rate measurements at different activity levels and reported in literature reviews by EPA and ICRP (EPA85, EPA89b, EPA91). EPA also performed time-use and activity level studies in order to determine ranges for the inhalation rate for adults (EPA91). Separate averages were developed for children and are not considered in this study. The time-use/activity level data were divided into occupational subgroups, hours spent at work versus hours spent at home, total hours per day spent at each activity level, and subgroups for men and women. A weekly averaging time was used to estimate the average daily inhalation rate for an adult for use in lifetime risk assessment.

The selection of a lognormal probability density function is consistent with earlier studies by Oak Ridge National Lab where measurements of children's inhalation rates were found to approximate a lognormal distribution (Ho79). Appendix F shows the probability density function for this parameter for use in the uncertainty calculations. Based on input requirements for the Crystal Ball program, the median and geometric standard deviation have been converted to the mean and standard deviation values.

5.3 Exposure Frequency

An exposure frequency of 350 days per year is considered to be a reasonable maximum exposure and accounts for two weeks away from home for a vacation or trip. An exposure frequency of 275 days per year is considered to represent an average exposure and the most likely value which accounts for a more realistic proportion of away time from home and the local area (DOE93a). An exposure frequency of 365 days per year is the maximum possible value. The exposure frequency is intended to be representative of the exposure time in days per year for every year of exposure to a particular pathway(EPAb, EPAc). In a deterministic risk assessment computation, 350 days is often used. For uncertainty analysis, EPA recommends that a triangular distribution be used with a midpoint value of 275 days, minimum value of 200 days, and maximum value of 365 days (EPA89c). EPA recommends using local population patterns when available. This information was not available for this study. A graphical depiction of the exposure frequency parameter is given in Appendix F.

5.4 Exposure Duration

Exposure duration is typically assumed to be 9 years as an average time someone would live in the same location, 30 years for a reasonable worst case duration and 70 years as an average lifetime maximum value for use in a deterministic assessment. Nine years is the national median time or 50th percentile at one residence. Thirty years is the national upper-bound time (90th percentile) at one residence (EPA89a). Seventy years is an accepted lifetime convention for carcinogenic effects (EPA89b). For a probabilistic representation of the parameter, scientists and environmental professionals have recommended using a lognormal distribution (DOE93a, DOE94c). For a lognormal distribution, the geometric mean used is 9 years, and the geometric standard deviation is 1.826 based on setting 30 years at two geometric standard deviations from the median. For an adult, a minimum value of 1.478 years and a maximum value of 54.8 years represent 99th percentile bounds based on national data (DOE93a, DOE94c). Appendix F gives a graphical representation of the exposure duration parameter. Based on input requirements for the Crystal Ball program, the median and geometric standard deviation have been converted to the mean and standard deviation values.

5.5 Dose Factor

Another key uncertainty lies in the dose conversion factor that is used to convert exposure by inhalation to organ and total body doses. A dose conversion factor is derived specifically for each radionuclide (EPA89c, Ec95). Table 6 gives the dose conversion factors used and the associated uncertainties. The uncertainty factor for each radionuclide is based on the classification of the radionuclide and uses a triangular distribution (EPA89c). The dose factor is used as the most likely value, and the uncertainty factor is multiplied and divided by the dose conversion factor to obtain estimates of the 95th percentile upper and lower confidence limits. The selection of uncertainty intervals is referred to as a "credibility interval" because they are based on the judgement of the "National Institutes of Health Ad Hoc Working Group to Develop Radioepidemiological Tables" (EPA89c, NRC90).

Table 6. Dose Conversion Factors (mrem/pCi) and Uncertainty Ranges

Nuclide	Uncertainty Factor	Lower Value	Mid Value	Upper Value
Cs-137	3	1.033E-5	3.099E-5	9.300E-5
K-40	3	4.260E-6	1.278E-5	3.834E-5
Np-237	5	9.418E-2	4.907E-1	2.454E+0
Pa234m	5	7.584E-10	3.792E-9	1.896E-8
Pu-238	5	9.452E-2	4.726E-1	2.363E+0
Pu-239	5	1.056E-1	5.278E-1	2.639E+0
Ru-106	5	9.554E-5	4.777E-4	1.433E-3
Tc-99	10	8.391E-7	8.391E-6	8.391E-5
Th-228	5	8.766E-2	4.383E-1	2.192E+0
Th-230	5	8.474E-2	4.237E-1	2.119E+0
Th-232	5	1.236E-1	6.178E-1	3.089E+0
Th-234	5	1.080E-5	5.400E-5	2.700E-4
U-234	5	4.584E-2	2.292E-1	1.146E+0
U-235	5	2.446E-2	1.223E-1	6.115E-1
U-238	5	4.078E-2	2.039E-1	1.020E+0

The primary uncertainty in the dose estimate is the behavior of the radionuclide in the human body rather than the physics of the isotope which are predictable. Essential elements such as potassium-40 or cesium-137 have been assigned an uncertainty factor of 3 because they behave in the human body like their stable elements, thus the time required for the body to eliminate the dose is approximately the same for both the stable and radioactive isotopes (EPA89c, NRC90). A factor of 5 is selected for radioactive toxic metals that have been well-studied in animals and in occupational and accident scenarios but have limited information on the biokinetic effects in humans (such as nuclide absorption into the blood from the intestines) (EPA89c). Examples of these nuclides are uranium, thorium, and plutonium. Rare earth elements such as technetium-99 are assigned an uncertainty factor of 10 since biokinetic information on these elements are extrapolated from results of animal studies and minimal information is available to provide a means to extrapolate to humans (EPA89c). Appendix F provides a graphical representation of the parameters.

An area of uncertainty affecting the dose estimation in which new information will be available in the future is the ICRP lung and gastrointestinal tract models which are simplified representations of the human body and its absorption characteristics. Much work has been done in recent years to improve the representativeness of the lung and gastrointestinal tract models, but new conversion factors are not yet published and incorporated into software programs like CAP88PC (Ec95).

5.6 Risk Factor

The risk conversion factor established by ICRP was developed to provide a means of estimating the risk of excess cancer incidence given an exposure to ionizing radiation and a given dose. NCRP estimates the uncertainty to be about a factor of 4 due to the uncertainty associated with a number of factors including the dosimetric model mis-specification, dosimetry, age and latency, gender, and the shape of the dose-response relationship (NCRP93). Data supporting the estimation of excess cancers is primarily based on ongoing studies of atomic bomb survivors for which more than 40 years of data exists, miners, medical applications, and animal and tissue sample studies (ICRP90).

There are two key components of the uncertainty factor. The first is the uncertainty in the risk per dose for exposures at high dose and high-dose rate which is estimated to be uncertain to about a factor of two. The second key uncertainty is in the extrapolation of risks from exposure at high dose and high dose rate to exposures at low dose and low dose rate. This uncertainty accounts for an additional factor of two (NCRP93, NRC90).

Although not considered in the uncertainty factor, there is uncertainty and ongoing debate on the linearity of the dose-response curve at exposure levels comparable to external background radiation. The BEIR committee acknowledges that the possibility exists that there may be no risk from exposures at low levels (NRC90). Another key uncertainty in risk estimation that is not accounted for in the uncertainty factor is the population difference. The Japanese population upon which much of the A-bomb data is based has several differences from the population of the United States. The two populations have different diets, ethnic composition, and lifestyles which affect the cancer mortality rate (NRC90).

A triangular distribution is used to characterize the parameter. The cancer incidence factor reported by NCRP is used as the most likely value, and the end points are set by multiplying and dividing by the uncertainty factor (NCRP93, NRC90). Input parameters used for the risk conversion factor are graphically shown in Appendix F.

6.0 UNCERTAINTY ANALYSIS

The uncertainty analysis was run using the Crystal Ball and Excel software programs. The Latin Hypercube random sampling technique is used due to the quick run time achieved. Comparable results are obtained in fewer trials of the Latin Hypercube technique compared to using simple random sampling in the Monte Carlo analysis. In simple random sampling, samples are randomly taken from any point in the distribution which requires a large number of samples to be taken before the full distribution has been sampled. For simple random sampling, 10,000 samples are typically taken (De93,Ho95). In Latin Hypercube sampling, more computer memory is required because the program keeps track of where the sample was pulled from for each sampling trial. Subsequent samples are then taken from unsampled intervals of the probability density function for each assumption parameter and new forecast dose and risk values are computed. This method takes less time to finish a more complete forecast distribution. For this study, 1000 trials of the Latin Hypercube sampling technique were used. A copy of the EXCEL spreadsheet used to set up the uncertainty analysis is shown in Appendix G. Percentile results of the uncertainty analysis are provided in Figure 3 for the dose estimate and Figure 4 for the risk estimate. The probability distributions obtained for the dose and risk forecasts are shown in Figures 5 and 6.

Percentiles:

Percentile	mrem/yr (approx.)
0%	2.169E-02
5%	5.528E-02
10%	7.006E-02
15%	8.257E-02
20%	9.346E-02
25%	1.033E-01
30%	1.154E-01
35%	1.288E-01
40%	1.422E-01
45%	1.533E-01
50%	1.669E-01
55%	1.840E-01
60%	2.039E-01
65%	2.199E-01
70%	2.448E-01
75%	2.743E-01
80%	3.128E-01
85%	3.665E-01
90%	4.437E-01
95%	5.775E-01
100%	1.911E+00

Figure 3. Results of the Uncertainty Analysis for Dose

Percentiles:

Percentile	Value (approx.)
0%	6.583E-08
5%	2.428E-07
10%	3.594E-07
15%	4.560E-07
20%	5.616E-07
25%	6.779E-07
30%	7.934E-07
35%	9.173E-07
40%	1.090E-06
45%	1.256E-06
50%	1.437E-06
55%	1.640E-06
60%	1.896E-06
65%	2.187E-06
70%	2.594E-06
75%	2.984E-06
80%	3.566E-06
85%	4.515E-06
90%	5.812E-06
95%	8.922E-06
100%	4.063E-05

Figure 4. Results of the Uncertainty Analysis for Risk

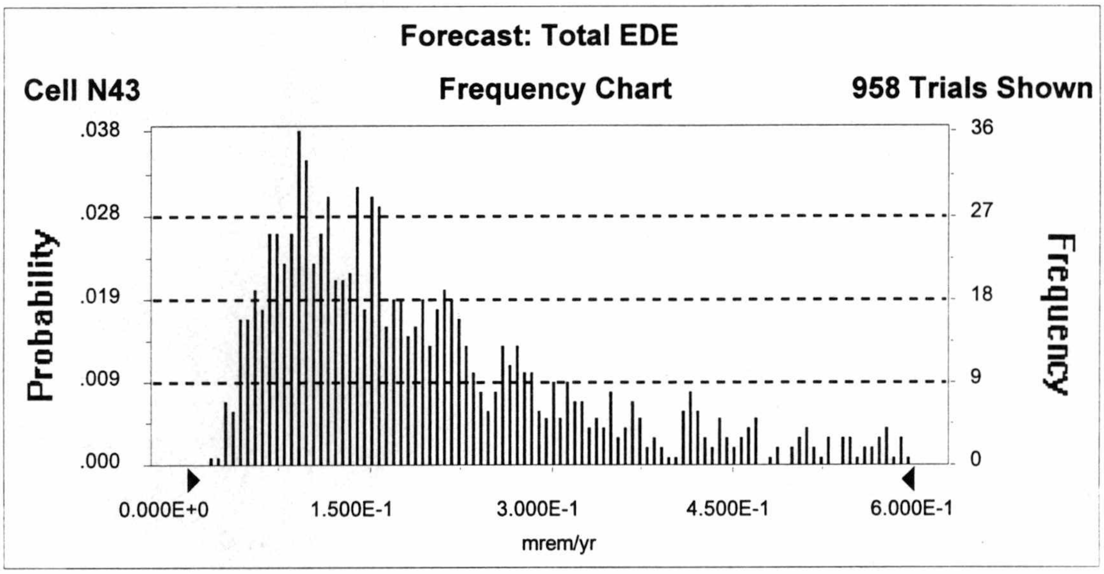

Figure 5. Distribution Function for the Estimation of Dose

(Units are in mrem/yr)

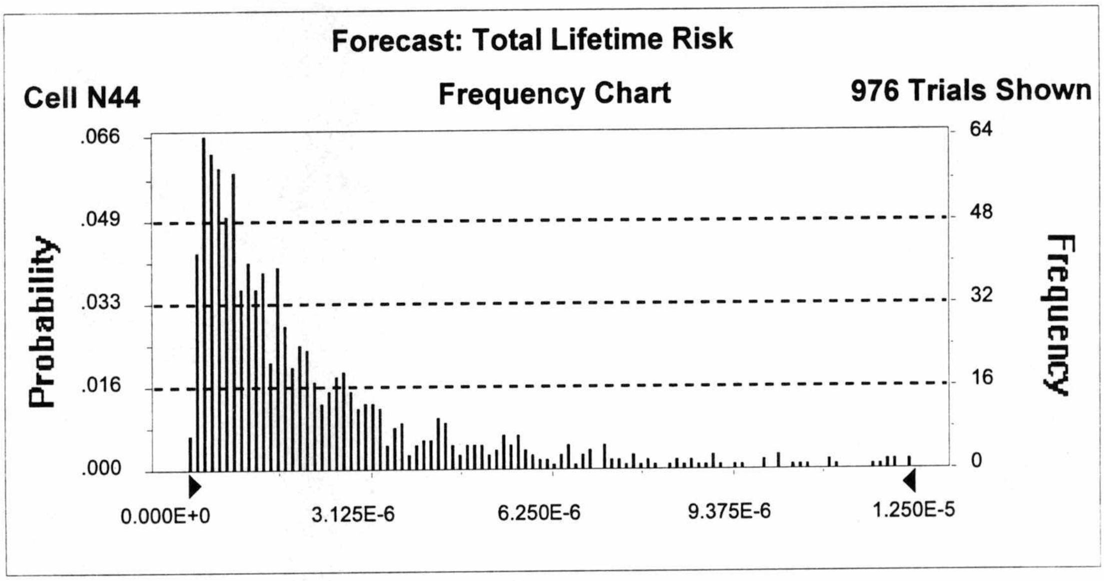

Figure 6. Distribution Function for the Estimation of Risk

(Lifetime Excess Cancer Incidence- Inhalation Pathway)

7.0 SENSITIVITY ANALYSIS

In addition to the uncertainty analysis, a sensitivity analysis was performed using the Crystal Ball software. The sensitivity calculation is based on a correlation computation measured by the contribution to the variance in the resulting dose and risk estimates. Results of the sensitivity analysis are given in Figure 7 for dose and Figure 8 for risk. As indicated by the correlation coefficients in the figures, the uranium-234 and uranium-238 concentrations and dose factors have a much stronger influence on the variance of the forecasted dose and risk than the other radionuclides. The inhalation rate accounted for nine percent of the variance in the dose estimate, and the exposure duration and risk factor were each approximately thirty percent of the variance in the computed risk probability distribution.

In consideration of ways to reduce the uncertainty, development of exposure duration values based on local or regional data would reduce a key source of uncertainty. Little reduction of uncertainty for the risk factor and dose factors is possible at this time. An attempt to validate the nuclide concentrations at residential locations would provide a basis for comparison with the dispersion model results, but it is highly unlikely that any meaningful data could be obtained for reducing the uncertainty of the computations. Concentrations are so low that it would be hard to detect, and even if detected, it would be difficult to distinguish what portion of the

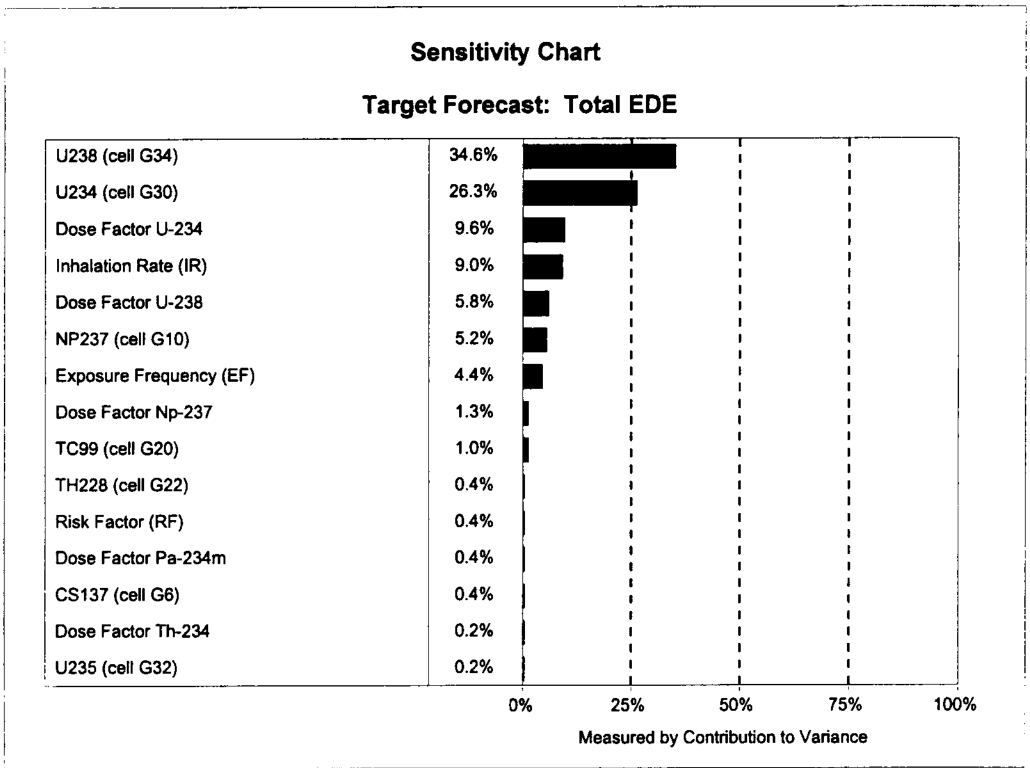

Figure 7. Results of the Sensitivity Analysis for Dose

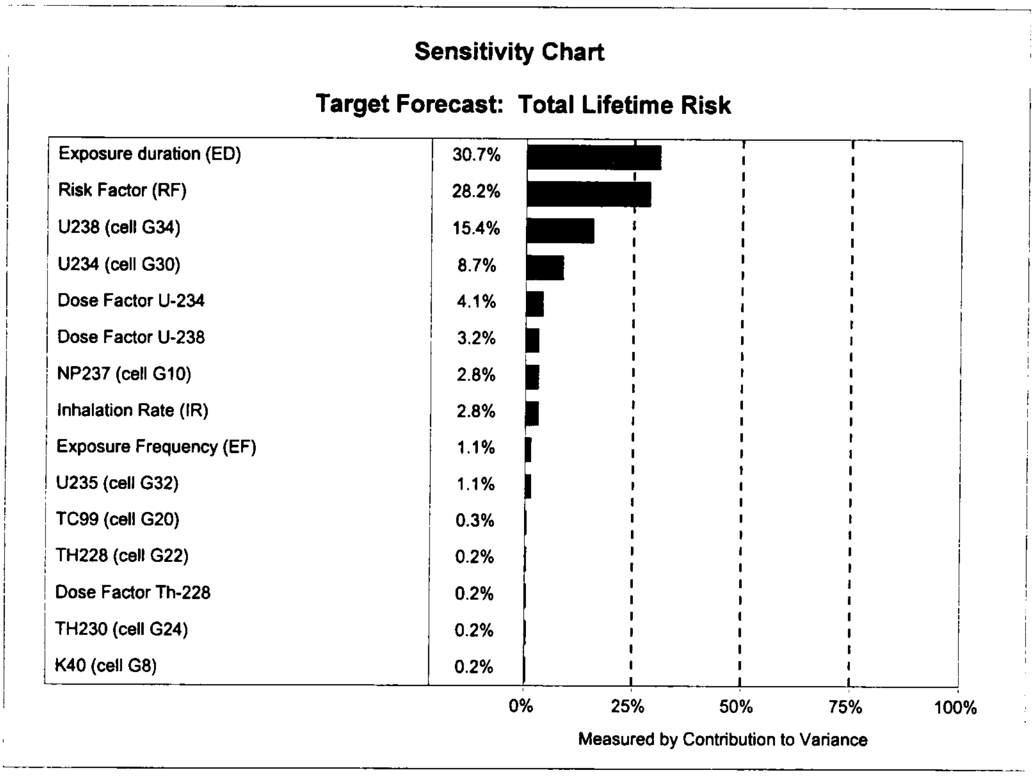

Figure 8. Results of the Sensitivity Analysis for Risk

measured amount could be attributed to the incinerator since there are other facilities that have uranium emissions located in the surrounding areas. There are also background levels.

8.0 RESULTS AND CONCLUSIONS

The compounding effects of parameter error propagation are evident in the results of the uncertainty and sensitivity analysis. Table 7 summarizes the uncertainty assumptions for each model parameter. The overall compounded error that is attributed to the lognormal parameters can be estimated by taking the square root of the sum of the squares of the geometric standard deviations (Ti83, NRC90). Consistent with the sensitivity analysis, the parameters contributing most to the variance in the estimation of risk are the ones with the greatest standard deviation. These are the inhalation rate, exposure duration, and the risk factor. At the current time, an improved estimate of the risk factor and dose factor uncertainties has not been developed although ICRP and NCRP are continuing to pursue better quantification as more information on cancer incidence and biokinetics becomes available. The inhalation rate and exposure duration information are based on national statistics or studies. The uncertainty in the number could be greatly reduced if site-specific surveys were taken.

The results of the uncertainty analysis were compared to the results of deterministic calculations for lifetime cancer incidence. A deterministic calculation of dose using the ICRP methodology is given in detail in the spreadsheet shown in Appendix H, and the EPA slope factor methodology calculations are also shown in Appendix H. Figure 4 shows a comparison of the results of the different

Table 7. Summary of Risk Model Parameter Error

Parameter	Distribution	Uncertainty[a] Factor or GSD	Basis[b]	Ref
Concentration	Lognormal	1.02-5.3	1	Gr94, Sha94, La71
Inhalation	Lognormal	1.225	2,5	EPA89b, DOE94c, Ho79
Exposure Freq.	Triangular	1.27	4,5	EPA89b
Exposure Dur.	Lognormal	1.826	4,5	EPA89b, DOE94c
Dose Factor	Triangular	3-10	3,5	EPA89c, NRC90, NCRP93
Risk Factor	Triangular	4	2,3,5	NCRP93

[a]For lognormal distributions, the geometric standard deviation (GSD) is given. For triangular distributions, the uncertainty factor is the value shown. Ranges of values are given for concentration and dose factor because the GSD and uncertainty factor vary for each radionuclide.

[b]1 =Based on site-specific measurements and calculations. Averaging times are typically short term.
2 =Based on a combination of data and studies from accidents, medical applications, occupational exposures, research or surveys involving humans, and may be extrapolated from high to low doses. Averaging times vary from short term (eg. measurement of inhalation rates over several minutes for different levels of activity for different individuals) to long term (eg. 40 years for Japanese A-bomb survivors).
3 =Based on research involving animals and tissue samples which is extrapolated to humans. Most averaging times are short term due to the short life span of most research animals.
4 =Data and/or statistical analysis from national surveys or studies (eg. The Census Bureau).
5 =Based partially or fully on credibility intervals established by expert panels or committees, involves subjectivity, and may have some mathematical basis and statistical analysis.

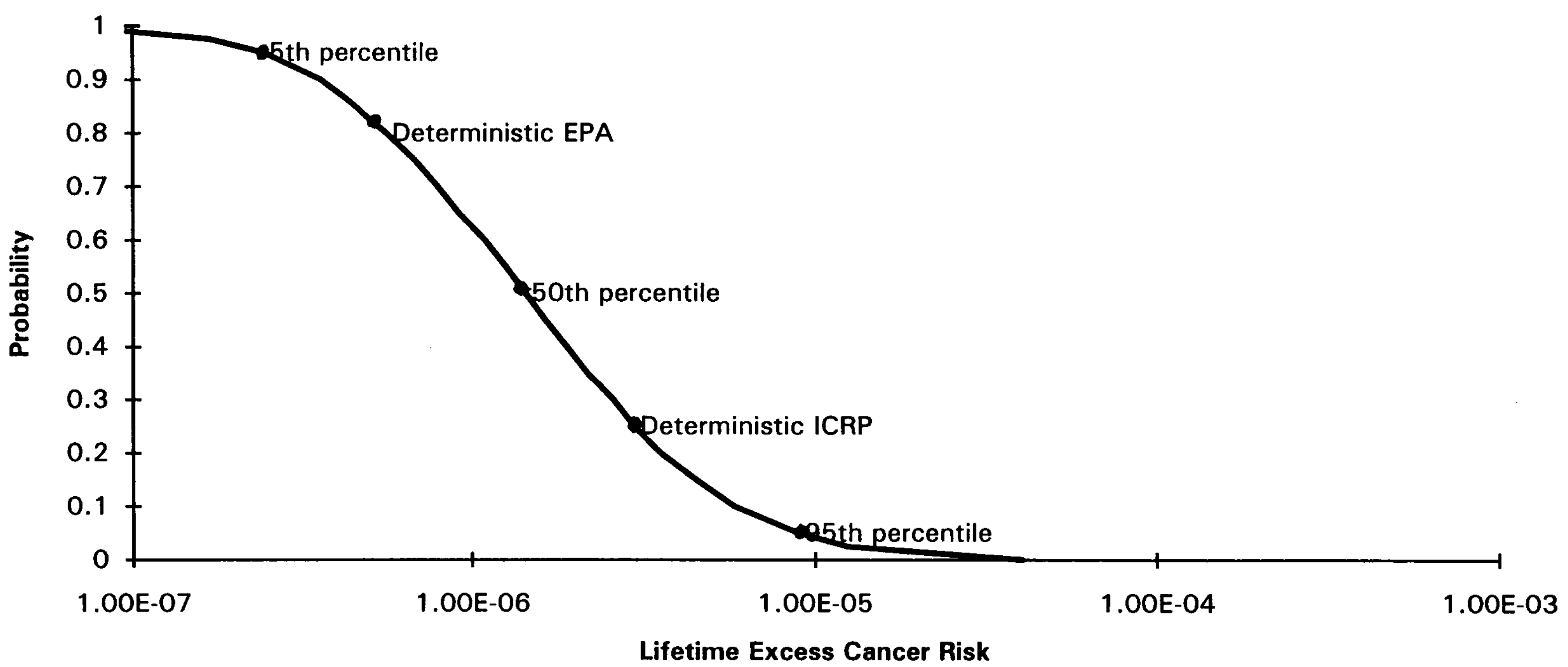

Figure 9. Reverse Cumulative Distribution for Cancer Risk Based on 1000 Trials of Latin Hypercube Sampling

calculational methods. The results of the uncertainty analysis and the deterministic values are plotted on a reverse cumulative curve. The 5th-, 50th-, and 95th-percentiles for the estimated cancer risk are also indicated on the curve. The following conclusions resulted from the analysis:

- The deterministic ICRP risk was 2.8 E-6 which was more than 5 times greater than the risk computed using the EPA slope factors. The slope factor values used were the revised, more conservative factors which still yielded a much lower risk value than the ICRP factors.

- The ICRP methodology yielded results in the upper quartile of the uncertainty analysis probability distribution, whereas the EPA methodology yielded risks in the lower quartile of the uncertainty analysis results. Both deterministic methods fell within the overall range of the uncertainty analysis. The additional information the uncertainty analysis provides is a 90 percent confidence range from 2.428 E-7 to 8.922 E-6. This provides a base of comparison for keeping deterministic estimates in perspective. The uncertainty analysis is based on median values whereas the deterministic analysis is based on mean values for the radionuclide concentrations and 95th percentiles for the other parameters. The uncertainty analysis results further confirm the low level of risk to the public. Even at the 95th percentile of the uncertainty analysis range, the risk of cancer is less than one in 100,000.

- The 50th percentile or median risk for the inhalation pathway less than two cancer incidences in 1,000,000 which is well below regulatory concern. The radionuclide concentrations would be expected to be essentially indistinguishable from background radiation. The uranium isotopes U234 and U238 are the primary contributors to the dose and risk. Unless indicated by a waste contents analysis, cost savings could be incurred by reducing the frequency of analysis for nuclides other than uranium.

- The Larsen "arrowhead" methodology (La71) provides a logical approach to estimating long term radionuclide concentrations and variability from short term measurements. By use of the log-log scale slope equation, values for the maximum, median, and geometric standard deviation of the concentration can be estimated for long averaging times. As would be expected, the method worked best for nuclides having the most data points. Concentrations based on a weekly averaging time would improve the slope estimates.

9.0 RECOMMENDATIONS

For reduction of the dose and risk uncertainty, the greatest impact would be achieved by finding out more information about the exposure duration and inhalation rate. The same analysis could be rerun for a reevaluation of the factors contributing the most to uncertainty in the dose and risk estimation.

In the area of emissions and concentration estimation, a calculation of the partial contribution of radionuclides from all area sources could be performed to give a better idea of the relative contribution from each source. In addition, better quantification of the variability of radionuclide emissions from the incinerator would improve the assessment of offsite concentrations. Since 1994, the incinerator has continued to operate, and several months of additional emissions data has been obtained. Consideration of this additional information would be useful in better understanding the nature of the emissions and concentration variability. An averaging time of months was the shortest averaging time used. Hourly and weekly averaging times would provide a better estimation of the slopes to use in determining long term median and geometric standard deviation values. The analysis could be limited to uranium isotopes.

In consideration of the continuing ICRP and NCRP research and data evaluation, a comparative risk analysis could be run when the new lung model values become available for use in computer programs. Results of studies currently being performed in the area of applying population difference factors to the estimation of dose should be considered when the data become available. This could further reduce the uncertainty in risk estimation.

In addition to the inhalation pathway, it would be useful to perform a parameter uncertainty analysis on the other pathways and hazardous pollutants in order to have an analysis based on median values as a basis for comparison. This would be useful for risk communication.

REFERENCES

An75 Ang, A.H-S., and Tang, W.H., Probability Concepts in Engineering Planning and Design, 1975. New York, NY: John Wiley & Sons, Inc.

Be81 Begovich, C.L., et al., DARTAB: A Program to Combine Airborne Radionuclide Environmental Exposure Data with Dosimetric and Health Effects Data to Generate Tabulations of Predicted Health Impacts, ORNL-5692, 1981. Oak Ridge, TN: Oak Ridge National Laboratory.

Co86 Cooper, C.D., and Alley, F.C., Air Pollution Control: A Design Approach, 1986. Prospect Heights, Il: Waveland Press.

De93 Decisioneering, Inc., Crystal Ball Version 3.0 User Manual, 1993. Denver, CO.

De95 Telephone conversation with the Crystal Ball development staff on November 13, 1995 concerning input parameters for the lognormal distribution.

DOE93a DOE (United States Department of Energy) Hanford Site Baseline Risk Assessment Methodology, DOE/RL-91-45, Revision 2, 1993. Richland, WA.

DOE93b Minutes from the DOE Probabilistic Baseline Risk Assessment Workshop, 1993. Richland, WA.

DOE94a DOE Air Emissions Annual Report (ES/ESH-46) (under Subpart H, 40 CFR 61.94) for Calendar Year 1993, June, 1994. Oak Ridge, TN.

DOE94b DOE RCRA Corrective Action Human Health Assessment Information Brief, EH-231-045/0594, 1994.

DOE94c DOE Probabilistic Baseline Risk Assessment Demonstration Report for the Hanford Site 1100-EM-1 Operable Unit, 1994. Richland, WA.

Ec95 Eckermann, Keith, Presentation on Dosimetric Models, Tennessee Industry Week, University of Tennessee, Knoxville, TN, August 1995.

EPA85 EPA Development of Statistical Distributions of Ranges of Standard Factors Used in Exposure Assessments, OHEA-E-

161, March 1985.

EPA89a EPA Exposure Factors Handbook, EPA 600/8-89/043, 1989.

EPA89b EPA Risk Assessment Guidance for Superfund, Human Health Evaluation Manual Part A Interim Final, 9285.701A, 1989.

EPA89c EPA Risk Assessments Methodology, Environmental Impact Statement for NESHAPS Radionuclides, Background Information Document - Volume 1, EPA 520/1-89-005, 1989.

EPA91 EPA Risk Assessment Guidance for Superfund (RAGS) Volume I: Human Health Evaluation Manual Supplemental Guidance "Standard Default Exposure Factors" Interim Final, 9285.6-03, 1991.

EPA92 EPA User's Guide for CAP88PC, Version 1.0, 402-B-92-001, 1992.

EPA93 EPA Report on the Technical Workshop on WTI Incinerator Risk Issues, EPA/630/R-94/001, 1993.

EPA94 EPA Health Effects Assessment Summary Tables (HEAST) FY94, Supplement No. 2, EPA/540/R-94/114, 1994.

EPA95 EPA Radiation Exposure and Risk Assessment Manual (RERAM) Development of Radionuclide Slope Factors Review Draft, April 1995.

Gi87 Gilbert, R.O., Statistical Methods for Environmental Pollution Monitoring, 1987. New York, NY: Van Nostrand Reinhold.

Gr94 Facimile received from Laura Graves, K25 TSCA Incinerator, September-December 1994.

Ho77a Hoffman, F.O., et al., A Compilation of Documented Computer Codes Applicable to Environmental Assessment of Radioactivity Releases, ORNL/TM-5830, 1977. Oak Ridge, TN: Oak Ridge National Laboratory.

Ho77b Hoffman, F.O., et al., Computer Codes for the Assessment of Radionuclides Released to the Environment, NUCLEAR SAFETY, Vol. 18, No. 3, May-June 1977.

Ho79 Hoffman, F.O., et al., A Statistical Analysis of Selected Parameters for Predicting Food Chain Transport and Internal Dose of Radionuclides, NUREG/CR-1004, ORNL/NUREG/TM-282, 1979. Oak Ridge, TN: Oak Ridge

National Laboratory.

Ho82 Hoffman, F.O., et al., Variability in Dose Estimates Associated with the Food Chain Transport and Ingestion of Selected Radionuclides, NUREG/CR-2612, ORNL/TM-8099, 1982. Oak Ridge, TN: Oak Ridge National Laboratory.

Ho92 Hoffman, F.O., and Hammonds, J.S., An Introductory Guide to Uncertainty Analysis in Environmental and Health Risk Assessment, ES/ER/TM-35, 1992. Oak Ridge, TN: Oak Ridge National Laboratory.

Ho93 Hoffman, F.O., and Hammonds, J.S., Propagation of Uncertainty in Risk Assessments: The Need to Distinguish between Uncertainty Due to Lack of Knowledge and Uncertainty Due to Variability, 1993. Oak Ridge, TN: Center for Risk Analysis, SENES Oak Ridge, Inc.

Ho95 Hoffman, F.O., Presentation on Uncertainty Analaysis, Tennessee Industry Week, University of Tennessee, Knoxville, TN, August 1995.

ICRP75 ICRP Publication No. 23, Report of the Task Group on Reference Man, 1975.

ICRP90 ICRP Publication No. 60, 1990 Recommendations of the International Commission on Radiological Protection, 1990.

Ki94 Kirchner, T.B., Uncertainty Analysis, 1994. Fort Collins, CO: Natural Resource Ecology Laboratory, Colorado State University.

Ka80 Kanak, K.A., and Miller, C.W., The Evaluation of Models Used for the Assessment of Radionuclide Releases to the Environment - A Summary of Documentation for the Period April 1976 through June 1979, ORNL-5573, 1980. Oak Ridge, TN: Oak Ridge National Laboratory.

Ko91 Kornegay, F.C., et al., Oak Ridge Reservation Environmental Report for 1990 - Volumes 1 and 2, ES/ESH-18/V1 and ES/ESH-18/V2, 1991. Oak Ridge, TN: Martin Marietta Energy Systems, Inc. (MMES) for United States Department of Energy (DOE).

Ko92 Kornegay, F.C., et al., Oak Ridge Reservation Environmental Report for 1991 - Volumes 1 and 2, ES/ESH-22/V1 and ES/ESH-22/V2, 1992. Oak Ridge, TN: MMES for USDOE.

Ko93 Kornegay, F.C., et al., Oak Ridge Reservation Environmental Report for 1992 - Volumes 1 and 2, ES/ESH-31/V1 and ES/ESH-31/V2, 1993. Oak Ridge, TN: MMES for USDOE.

Ko94 Kornegay, F.C., et al., Oak Ridge Reservation Annual Site Environmental Report for 1993 - 8/12/94 Draft, ES/ESH-47, 1993. Oak Ridge, TN: MMES for USDOE.

La71 Larsen, R.I., A Mathematical Model for Relating Air Quality Measurements to Air Quality Standards, EPA-450/4-74-012, September 1974.

Li79 Little, C.A., and Miller, C.W., The Uncertainty Associated with Selected Environmental Transport Models, ORNL-5528, 1979. Oak Ridge, TN: Oak Ridge National Laboratory.

Ma94 Manugistics STATGRAPHICS Windows Version 1.0 User's Guide, 1994. Rockville, ML.

Mic92 Microsoft EXCEL Version 4.0 User's Guide, 1992. Redmon, WA.

Mil87 Miller, C.W., and Hively, L.M., A Review of Validation Studies for the Gaussian Plume Atmospheric Dispersion Model, NUCLEAR SAFETY, Vol. 28, No. 4, Oct-Dec 1987.

Mo79 Moore, R.E., et al., AIRDOS-EPA: A Computerized Methodology for Estimating Environmental Concentrations and Dose to Man from Airborne Releases of Radionuclides, ORNL-5532, 1979. Oak Ridge, TN: Oak Ridge National Laboratory.

NCRP89 NCRP Commentary No. 3, Screening Techniques for Determining Compliance with Environmental Standards, 1989.

NCRP93 NCRP Report No. 116, Limitation of Exposure to Ionizing Radiation, 1993.

No77 Noll, K.E., and Miller, T.L., Air Monitoring Survey Design, 1977. Ann Arbor, MI: Ann Arbor Science.

NRC90 Health Effects of Exposure to Low Levels of Ionizing Radiation, BEIR V Committee on the Biological Effects of Ionizing Radiation, National Research Council, 1990. Washington D.C.

Od94 Facimile received from Frank O'Donnell, Oak Ridge National Laboratory, September 1994.

ORNL94 Environmental Restoration Toxicity Values for Use in Hazardous Waste Risk Assessment and Remediation, ES/ER/TM-76, 1994. Oak Ridge, TN: Oak Ridge National Laboratory.

ORNL95 Environmental Restoration Toxicity Values for Use in Hazardous Waste Risk Assessment and Remediation, May 1995 Update, 1995. Oak Ridge, TN: Oak Ridge National Laboratory.

Po94 Phone discussion with Tony Poole regarding determination of particle size distribution for radionuclides, K25 TSCA Incinerator, August 1994.

Sh93 Shevenell, L., and Hoffman, F.O., Necessity of Uncertainty Analysis in Risk Assessment, Journal of Hazardous Materials, Vol. 35, 1993. Amsterdam: Elsevier Science Publishers B.V.

Sha94 Wind roses and electronic meteorological data received from Ron Sharp, Oak Ridge National Laboratory, May-December 1994.

Sj84 Sjoreen, A.L., and Miller, C.W., PREPAR - A User-Friendly Preprocessor to Create AIRDOS-EPA Input Data Sets, ORNL-5952, 1984. Oak Ridge, TN: Oak Ridge National Laboratory.

Ti83 Till, John E., and Meyer, H. Robert, eds., Radiological Assessment - A Textbook on Environmental Dose Analysis, NUREG/CR-3332, 1983. Washington, DC: U.S. Government Printing Office.

APPENDICES

APPENDIX A

Emissions Data and Uncertainty Charts

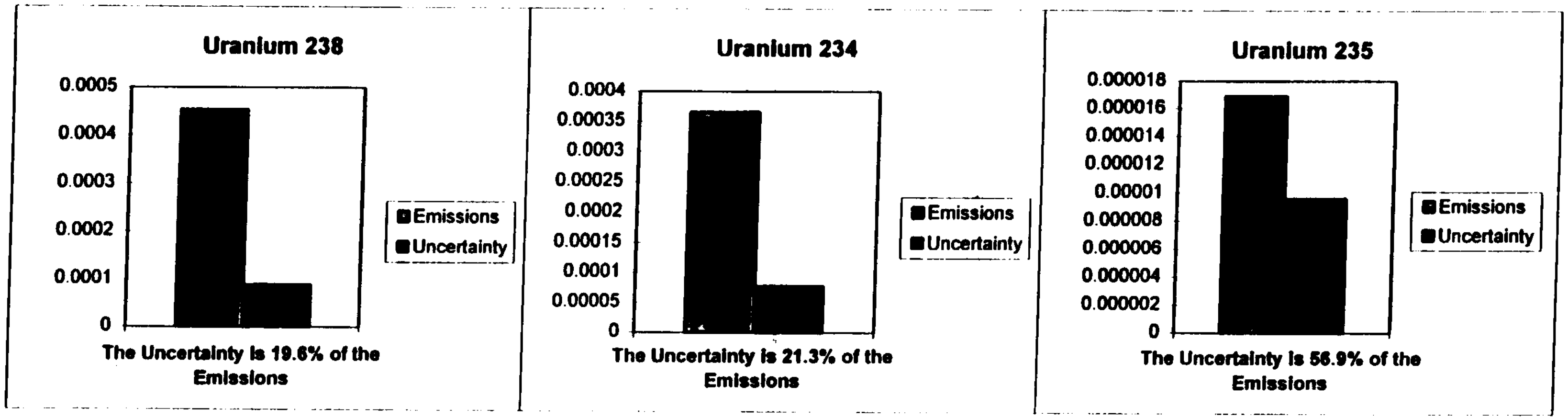

Figure A.1. Uranium Emissions and Measurement Uncertainty

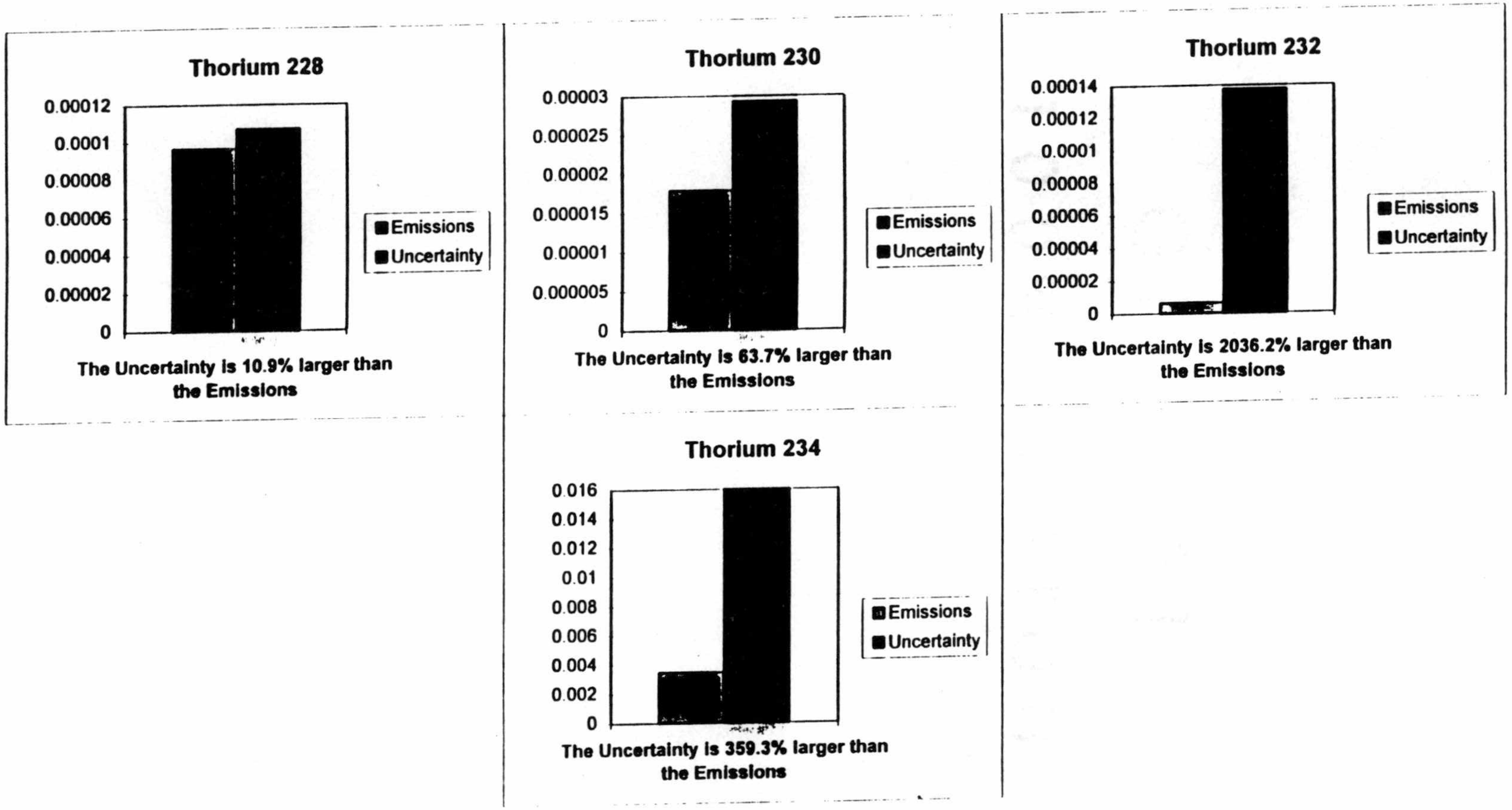

Figure A.2. Thorium Emissions and Measurement Uncertainty

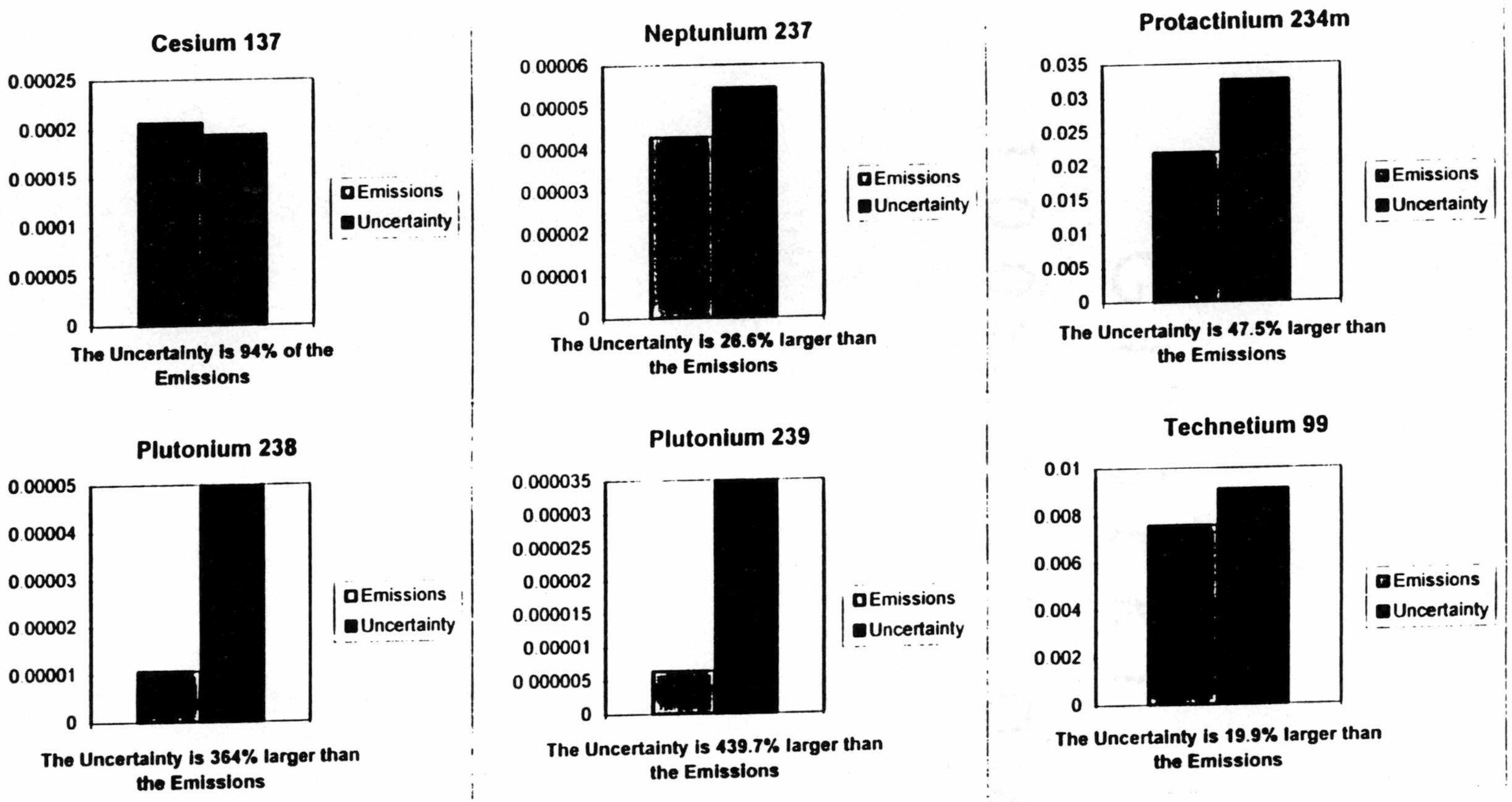

Figure A.3. Other Nuclide Emissions and Measurement Uncertainty

Table A.1. Monthly Emissions in Curies and Other Data

Month	Jan	Feb	Mar	Apr	May	Jun
Average Stack Velocity (m/s)	Did Not Operate		4.10	4.80	4.50	4.90
Average Ambient Temp (oC)			11.60	13.80	19.80	22.60
Precipitation (cm)			12.90	6.50	16.70	3.90
Emissions in Curies:						
CE141						
CE144						
CS137					7.580E-05	4.309E-05
CO57						
CO60						
NP237						
NB95						
PU238						
PU239						
K40						
PA234M						
RU106						
TC99			-1.540E-05	-5.790E-04	-1.226E-04	-8.120E-04
TH228						
TH230						
TH232						
TH234						
U234			3.510E-08	5.270E-06	4.280E-06	5.655E-05
U235			1.750E-09	2.630E-07	2.132E-07	3.115E-06
U238			3.470E-08	5.210E-06	4.225E-06	8.663E-05

1990

Table A.1. Continued

Month	Jul	Aug	Sep	Oct	Nov	Dec
Average Stack Velocity (m/s)	5.10	5.10	6.10	Did Not	4.30	5.30
Average Ambient Temp (oC)	21.90	23.10	21.00	Operate	10.90	6.40
Precipitation (cm)	12.90	12.90	3.70		6.10	32.10
Emissions in Curies:						
CE141						
CE144						
CS137	2.529E-05	3.723E-05	3.590E-05		5.451E-04	5.250E-05
CO57						
CO60						
NP237	1.690E-06				6.573E-06	9.220E-07
NB95						
PU238					1.659E-06	1.606E-07
PU239					4.720E-08	1.326E-07
K40						
PA234M		4.670E-04	5.090E-03			
RU106						
TC99	-1.024E-03	6.212E-04	-3.430E-05		-3.560E-04	3.386E-02
TH228	1.810E-05				5.420E-07	1.658E-06
TH230					1.003E-06	
TH232					-2.481E-07	4.320E-08
TH234	1.350E-05	5.381E-04	1.025E-04			3.650E-05
U234	2.992E-05	6.427E-05	1.250E-04		3.560E-05	4.220E-05
U235	1.853E-06	3.974E-06	6.220E-06		1.775E-06	2.301E-06
U238	6.677E-05	1.433E-04	1.236E-04		3.520E-05	6.335E-05

1990

Table A.1. Continued

Month	Jan	Feb	Mar	Apr	May	Jun
Average Stack Velocity (m/s)	5.80	5.30	4.50	5.70	5.70	6.00
Average Ambient Temp (oC)	4.30	6.00	10.90	16.40	21.30	22.20
Precipitation (cm)	7.50	20.20	18.90	9.80	6.50	17.90
Emissions in Curies:						
CA 109				-2.798E-06		
CE141						
CE144						
CS137	2.441E-04	1.137E-06	7.143E-05	8.181E-05	1.083E-04	1.004E-05
CO57					4.147E-07	
CO60			1.618E-06	-8.820E-06		
NP237	3.435E-05	1.053E-06	8.602E-06	2.747E-04	8.858E-05	1.605E-07
NB95			1.456E-06			
PU238	2.475E-07	7.297E-07	1.581E-08	-3.651E-05	-1.770E-07	1.298E-08
PU239	-1.767E-07	2.946E-06	3.909E-07	5.911E-05	7.423E-07	
K40						
PA234M	3.612E-03	3.631E-02	2.713E-02	1.519E-02	8.878E-03	2.180E-03
RU106						
TC99	4.101E-03	-6.622E-03	-1.157E-02	8.561E-03	9.992E-02	9.926E-04
TH228	3.412E-06	1.043E-06	-1.532E-06	-1.568E-05	5.433E-07	2.419E-07
TH230	1.674E-06	1.043E-06	6.130E-06	5.336E-05	8.557E-07	1.078E-06
TH232	1.884E-06	1.260E-06	2.261E-06	9.200E-06	5.868E-07	8.007E-08
TH234	1.543E-03	1.434E-03	2.504E-03	1.184E-02	3.110E-03	1.049E-04
U234	4.990E-04	5.580E-04	1.756E-03	4.999E-03	1.698E-03	1.502E-04
U235	2.273E-05	3.514E-05	8.402E-05	2.327E-04	7.845E-05	6.791E-06
U238	4.957E-04	1.551E-03	2.156E-03	5.478E-03	1.799E-03	1.439E-04

1991

Table A.1. Continued

Month	Jul	Aug	Sep	Oct	Nov	Dec
Average Stack Velocity (m/s)	5.60	5.70	5.40	5.80	5.70	5.50
Average Ambient Temp (oC)	24.60	23.30	20.10	15.70	8.10	6.30
Precipitation (cm)	10.30	11.70	7.30	4.50	10.50	27.70
Emissions in Curies:						
CA109						
CE141						
CE144						
CS137	6.416E-05	3.483E-06	1.174E-05	-2.226E-05	-1.941E-05	-3.017E-06
CO57						
CO60						
NP237	2.353E-05	2.219E-04	1.100E-04	1.998E-06	3.069E-05	1.763E-05
NB95						
PU238	-1.138E-07	-1.793E-07	3.729E-07	-1.451E-07	5.108E-07	1.867E-07
PU239	1.478E-07	-1.255E-05	2.150E-06	-8.084E-09	1.639E-07	8.741E-07
K40						
PA234M	3.564E-02	1.053E-02	1.887E-02	-5.833E-04	9.510E-03	5.488E-03
RU106						
TC99	2.292E-02	4.175E-04	-1.093E-03	5.037E-04	5.464E-03	5.851E-03
TH228	3.034E-07	2.669E-03	1.095E-07	-5.870E-07	3.666E-08	1.004E-06
TH230	1.582E-06	-9.719E-06	1.030E-05	4.248E-07	3.454E-06	4.782E-06
TH232	7.768E-07	-9.026E-06	3.843E-06	2.016E-07	1.346E-06	2.753E-06
TH234	4.806E-03	5.290E-03	5.758E-03	5.688E-05	4.490E-03	6.342E-03
U234	3.646E-04	9.059E-05	8.620E-04	8.677E-05	5.317E-04	1.618E-04
U235	1.739E-05	5.064E-06	3.528E-05	3.940E-06	3.136E-05	8.555E-06
U238	4.421E-04	1.861E-04	1.371E-03	8.488E-05	1.261E-03	2.821E-04

1991

Table A.1. Continued

Month	Jan	Feb	Mar	Apr	May	Jun
Average Stack Velocity (m/s)	5.80	5.80	5.80	5.80	5.80	5.80
Average Ambient Temp (oC)	4.30	7.60	9.06	17.40	17.01	22.06
Precipitation (cm)	8.56	8.26	9.63	4.17	5.77	10.16
Emissions in Curies:						
CE141						
CE144						
CS137	-3.387E-04	-5.852E-06	6.647E-05	-1.264E-06	-1.838E-05	-1.062E-05
CO57						
CO60						
NP237	1.022E-06	2.179E-06	-3.748E-07	2.184E-05	-1.441E-05	2.263E-05
NB95						
PU238	5.424E-07	1.949E-06	-3.731E-07	-1.440E-06	1.749E-05	2.868E-06
PU239	1.900E-07	1.363E-06	1.161E-06	4.982E-07	2.336E-07	4.077E-06
K40						
PA234M	1.918E-01	2.798E-02	2.225E-02	2.330E-02	2.262E-03	3.435E-02
RU106						
TC99	2.605E-03	7.040E-03	4.337E-03	9.770E-05	1.482E-04	1.718E-03
TH228	2.114E-06	-1.817E-07	2.056E-05	1.257E-06	1.509E-03	-4.238E-07
TH230	7.776E-07	6.600E-06	1.319E-05	2.274E-06	1.022E-06	1.820E-06
TH232	7.931E-07	1.016E-05	1.789E-05	1.936E-06	2.009E-07	-1.448E-05
TH234	-4.692E-02	-3.846E-04	1.190E-04	1.517E-03	-1.440E-03	-4.591E-03
U234	6.304E-04	4.027E-04	4.082E-04	1.632E-04	3.015E-04	1.633E-05
U235	2.349E-05	1.500E-05	1.692E-05	7.284E-06	1.344E-05	7.070E-07
U238	1.051E-03	6.723E-04	6.218E-04	1.721E-04	3.192E-04	1.903E-05

1992

Table A.1. Continued

Month	Jul	Aug	Sep	Oct	Nov	Dec
Average Stack Velocity (m/s)	5.80	5.80	5.80	5.80	Did Not	5.80
Average Ambient Temp (oC)	21.40	21.80	20.30	13.60	Operate	4.17
Precipitation (cm)	13.00	8.60	7.65	6.65		14.71
Emissions in Curies:						
CE141						
CE144			1.231E-06			
CS137	8.203E-05	3.686E-05	-2.198E-05	4.365E-06		4.797E-06
CO57						
CO60						
NP237	3.798E-05	2.387E-05	2.912E-06	6.187E-07		4.824E-07
NB95						
PU238	6.102E-07	-7.609E-06	-1.538E-06	-2.450E-06		-7.113E-07
PU239	-1.099E-06	2.607E-07	2.127E-07	-3.861E-07		6.696E-08
K40			1.013E-03			
PA234M	2.629E-02	1.092E-02	1.436E-02	3.104E-03		1.064E-02
RU106				4.359E-04		
TC99	-2.916E-03	-1.362E-03	-2.748E-02	9.329E-04		8.168E-03
TH228	2.806E-06	-6.004E-07	-2.063E-07	4.704E-08		5.752E-07
TH230	1.067E-05	1.852E-05	9.970E-07	5.947E-06		-1.299E-06
TH232	3.631E-06	7.005E-06	7.627E-07	4.544E-08		
TH234	-4.560E-03	-1.896E-05	-2.204E-03	1.844E-03		-1.477E-03
U234	1.879E-04	4.009E-04	-1.841E-05	-8.532E-06		-1.859E-06
U235	8.357E-06	1.782E-05	-5.663E-07	-3.662E-07		
U238	2.004E-04	4.289E-04	-4.031E-05	-1.024E-05		-8.763E-06

1992

Table A.1. Continued

Month	Jan	Feb	Mar	Apr	May	Jun
Average Stack Velocity (m/s)	5.60	5.60	5.60	6.00	6.00	5.60
Average Ambient Temp (oC)	5.90	1.00	7.10	13.20	18.80	23.10
Precipitation (cm)	7.80	7.50	17.40	11.90	7.50	4.90
Emissions in Curies:						
CE141	1.67E-04	8.34E-06				
CE144						
CS137	1.110E-05	4.270E-05	4.440E-03	-2.734E-05	6.774E-05	1.718E-04
CO57			1.180E-04			
CO60			4.380E-03			
NP237	8.880E-07	1.070E-05	7.110E-06	4.969E-06	7.438E-05	4.218E-06
PU238	6.050E-07	-1.620E-06	-6.190E-06	2.483E-04	2.119E-06	3.023E-06
PU239	-1.750E-06	-2.260E-06	-1.360E-06	-6.301E-05	-1.371E-06	2.899E-08
K40	2.590E-03		3.530E-02			2.242E-03
PA234M	1.510E-02	2.610E-02	6.940E-03	2.120E-02	2.038E-02	-7.140E-03
RU106			4.390E-03	4.934E-05	2.111E-05	-7.279E-03
TC99	7.160E-03	9.410E-03	3.510E-02	1.009E-03	1.744E-02	5.093E-03
TH228	1.100E-06	1.820E-06	4.370E-05	1.283E-05	-1.019E-06	-8.329E-07
TH230	5.780E-07	9.870E-07	1.390E-05	-1.107E-05	4.932E-06	3.241E-06
TH232	7.540E-05	-4.570E-08	-5.230E-07	7.143E-07	1.224E-05	4.061E-06
TH234	-7.660E-05	8.580E-04	5.740E-03	4.229E-03	8.623E-04	3.574E-03
U234	-6.680E-05	3.380E-04	4.070E-04	-2.058E-05	9.647E-04	2.122E-04
U235	-2.730E-06	1.460E-05	1.780E-05	-8.942E-07	3.913E-05	1.003E-05
U238	-9.130E-05	3.930E-04	4.540E-04	-2.376E-05	1.345E-03	1.765E-04

1993

Table A.1. Continued

Month	Jul	Aug	Sep	Oct	Nov	Dec
Average Stack Velocity (m/s)	5.40	5.00	5.10	Did Not	5.00	5.30
Average Ambient Temp (oC)	26.70	24.60	20.40	Operate	8.40	1.00
Precipitation (cm)	7.80	8.20	11.80		9.40	23.90
Emissions in Curies:						
CE141	5.979E-06					
CE144						
CS137	8.574E-06	-2.613E-05	6.529E-05		2.428E-04	5.437E-05
CO57						
CO60						
NP237	8.383E-06	-1.229E-06	-6.234E-07		1.404E-05	4.409E-04
PU238	-1.165E-06	1.107E-07	2.620E-06		-3.436E-06	6.736E-06
PU239	6.507E-07	2.205E-08	-4.313E-08		1.763E-07	1.005E-05
K40			7.395E-05			
PA234M	2.589E-02	6.592E-02	2.703E-02		9.842E-03	1.518E-02
RU106					1.028E-05	
TC99	1.220E-02	4.033E-02	-1.512E-03		4.333E-03	-2.212E-02
TH228	2.308E-06	-1.670E-06	1.563E-07		3.007E-04	1.996E-05
TH230	8.024E-06	1.326E-06	2.101E-08		-1.516E-06	2.924E-05
TH232	7.567E-06	1.596E-06	-3.132E-06			7.491E-06
TH234	2.209E-04	3.834E-03	5.498E-03		4.835E-04	9.774E-05
U234	3.559E-04	5.021E-05	1.718E-04		1.048E-03	3.292E-04
U235	1.636E-05	2.373E-06	8.035E-06		4.657E-05	1.537E-05
U238	3.348E-04	4.167E-05	1.502E-04		1.120E-03	2.598E-04

1993

Table A.1. Continued

Month	Jan	Feb	Mar	Apr	May	Jun
Average Stack Velocity (m/s)	5.30	5.76	5.80	5.64	5.70	5.80
Average Temp (oC)	0.00	6.00	9.40	16.30	17.10	23.20
Precipitation (cm)	15.50	29.70	26.80	13.50	6.50	17.20
Emissions in Curies:						
CE141						
CE144						
CS137	1.565E-04	-2.192E-05	2.269E-04	-1.019E-04	9.852E-05	-1.937E-04
CO57						
CO60						1.460E-04
H3				4.268E-02	8.010E-02	
NP237	8.985E-06	3.668E-04	1.420E-06	6.907E-05	3.727E-05	-4.068E-05
NB95						
PU238	-4.346E-05	-4.458E-06	1.076E-06		3.864E-05	-4.000E-05
PU239	-5.826E-05	-4.692E-05				-2.157E-06
K40				2.405E-05	2.202E-05	
PA234M	-2.760E-03	9.030E-03	1.807E-02	1.427E-02	6.235E-02	-1.428E-02
RU106						
TC99	-2.529E-03	-8.440E-03	1.124E-03	4.961E-02	3.635E-02	7.035E-04
TH228	5.715E-06	-1.175E-08			-1.800E-06	3.581E-05
TH230	8.340E-07	-5.613E-06	2.152E-06	2.219E-04	-6.137E-05	5.618E-05
TH232	-9.406E-07	7.674E-07		6.445E-05		-1.483E-05
TH234	4.958E-03	4.535E-04	-1.394E-04	1.990E-04	5.338E-04	1.313E-02
U234	1.610E-04	2.695E-04	2.093E-04	5.432E-05	5.078E-05	1.463E-04
U235	7.329E-06	1.164E-05	9.739E-06	2.263E-06	2.424E-06	7.027E-06
U238	1.578E-04	3.171E-04	1.870E-04	7.082E-05	4.012E-05	1.119E-04

1994

Table A.1. Continued

Month	Jul	Aug	Sep	Oct	Nov	Dec
Average Stack Velocity (m/s)	5.80	5.80		Data Not Available		
Average Temp (oC)	23.50	22.90				
Precipitation (cm)	12.50	12.27				
Emissions in Curies:						
CE141						
CE144						
CS137	-4.815E-04	-9.150E-05				
CO57						
CO60						
H3						
NP237	4.504E-05	2.310E-05				
NB95						
PU238	2.014E-06	-1.000E-05				
PU239	-2.098E-06	9.550E-06				
K40	2.296E-05					
PA234M	2.538E-02	6.760E-02				
RU106						
TC99	1.509E-02	5.290E-03				
TH228	-2.314E-05	3.270E-07				
TH230	7.363E-05	1.730E-04				
TH232	-2.427E-05	-3.610E-07				
TH234	2.784E-03	2.400E-03				
U234	2.270E-05	1.340E-04				
U235	1.072E-06	6.750E-06				
U238	1.894E-05	7.640E-05				

1994

APPENDIX B

Wind Roses and Sample EPA STAR Format

Table B.1. Sample EPA STAR File Format

```
  N A 0.000080.000660.000000.000000.000000.00000
NNE A 0.000160.000330.000000.000000.000000.00000
 NE A 0.000160.000160.000000.000000.000000.00000
ENE A 0.000080.000000.000000.000000.000000.00000
  E A 0.000000.000000.000000.000000.000000.00000
ESE A 0.000000.000000.000000.000000.000000.00000
 SE A 0.000160.000160.000000.000000.000000.00000
SSE A 0.000410.000490.000000.000000.000000.00000
  S A 0.000160.000330.000000.000000.000000.00000
SSW A 0.000330.000410.000000.000000.000000.00000
 SW A 0.000740.000410.000000.000000.000000.00000
WSW A 0.000570.000410.000000.000000.000000.00000
  W A 0.000570.001070.000000.000000.000000.00000
WNW A 0.000330.000330.000000.000000.000000.00000
 NW A 0.000330.000570.000000.000000.000000.00000
NNW A 0.000160.000490.000000.000000.000000.00000
  N B 0.001860.001390.000250.000000.000000.00000
NNE B 0.001800.000820.000000.000000.000000.00000
 NE B 0.002130.000660.000000.000000.000000.00000
ENE B 0.000410.000160.000000.000000.000000.00000
  E B 0.000410.000160.000000.000000.000000.00000
ESE B 0.000330.000820.000080.000000.000000.00000
 SE B 0.000740.001880.000000.000000.000000.00000
SSE B 0.001480.002620.000250.000000.000000.00000
  S B 0.001560.002460.000080.000000.000000.00000
SSW B 0.001230.001720.000160.000000.000000.00000
 SW B 0.001390.001800.000330.000000.000000.00000
WSW B 0.002130.002130.000740.000000.000000.00000
  W B 0.003120.002300.000160.000000.000000.00000
WNW B 0.001880.002460.000330.000000.000000.00000
 NW B 0.001310.003610.000250.000000.000000.00000
NNW B 0.002050.003440.000080.000000.000000.00000
  N C 0.003440.003280.000900.000080.000000.00000
NNE C 0.002620.001480.000080.000000.000000.00000
 NE C 0.003120.000820.000080.000000.000000.00000
ENE C 0.001390.001070.000160.000000.000000.00000
  E C 0.001070.001310.000250.000000.000000.00000
ESE C 0.000570.000820.000900.000000.000000.00000
 SE C 0.001390.002460.002790.000410.000000.00000
SSE C 0.001970.005900.004260.000330.000000.00000
  S C 0.001390.005740.001880.000330.000000.00000
SSW C 0.001390.002790.001310.000080.000000.00000
 SW C 0.001800.004430.003770.000490.000000.00000
WSW C 0.002210.004020.004260.000820.000000.00000
  W C 0.003940.006310.003360.000330.000000.00000
WNW C 0.002700.004840.002380.000080.000000.00000
 NW C 0.003030.005900.003120.000080.000000.00000
```

Table B.1. Continued

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NE	D	0.004590.003200.000570.000160.000000.00000
ENE	D	0.002870.003770.001070.000160.000000.00000
E	D	0.002210.004430.002460.000660.000000.00000
ESE	D	0.002790.003280.006560.002950.000570.00008
SE	D	0.002620.007460.025170.015490.001230.00000
SSE	D	0.002300.013030.026310.010660.000490.00008
S	D	0.002300.010580.011310.005490.000490.00016
SSW	D	0.004100.007130.005820.005250.001070.00016
SW	D	0.005410.016070.016560.009840.000980.00016
WSW	D	0.003030.010250.018850.011390.000660.00000
W	D	0.003850.011230.021310.014020.002210.00016
WNW	D	0.004100.008940.015830.011230.000740.00016
NW	D	0.007460.013200.019590.011480.000330.00000
NNW	D	0.011070.013200.014510.003610.000080.00008
N	E	0.007460.014180.001150.000000.000000.00000
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NE	E	0.003770.008120.000250.000000.000000.00000
ENE	E	0.003940.007210.000250.000000.000000.00000
E	E	0.004670.012460.000330.000000.000000.00000
ESE	E	0.003770.007050.001880.000000.000000.00000
SE	E	0.002380.011970.008120.000000.000000.00000
SSE	E	0.002620.009590.004510.000000.000000.00000
S	E	0.002380.007130.002460.000000.000000.00000
SSW	E	0.002460.004260.000980.000000.000000.00000
SW	E	0.002620.003940.002300.000000.000000.00000
WSW	E	0.001390.002790.001800.000000.000000.00000
W	E	0.002790.009020.003610.000000.000000.00000
WNW	E	0.003770.010410.002130.000000.000000.00000
NW	E	0.006480.012620.003440.000000.000000.00000
NNW	E	0.010250.018120.003520.000000.000000.00000
N	F	0.000410.001070.000000.000000.000000.00000
NNE	F	0.000570.001970.000000.000000.000000.00000
NE	F	0.000980.000900.000000.000000.000000.00000
ENE	F	0.000330.002210.000000.000000.000000.00000
E	F	0.001230.001800.000000.000000.000000.00000
ESE	F	0.000660.001480.000000.000000.000000.00000
SE	F	0.000330.000820.000000.000000.000000.00000
SSE	F	0.000080.000490.000000.000000.000000.00000
S	F	0.000160.000250.000000.000000.000000.00000
SSW	F	0.000160.000000.000000.000000.000000.00000
SW	F	0.000000.000080.000000.000000.000000.00000
WSW	F	0.000160.000080.000000.000000.000000.00000
W	F	0.000080.000490.000000.000000.000000.00000
WNW	F	0.000740.001230.000000.000000.000000.00000
NW	F	0.000410.001070.000000.000000.000000.00000
NNW	F	0.000250.001720.000000.000000.000000.00000

WIND ROSE Tower K (@60m) for Mar., 1990

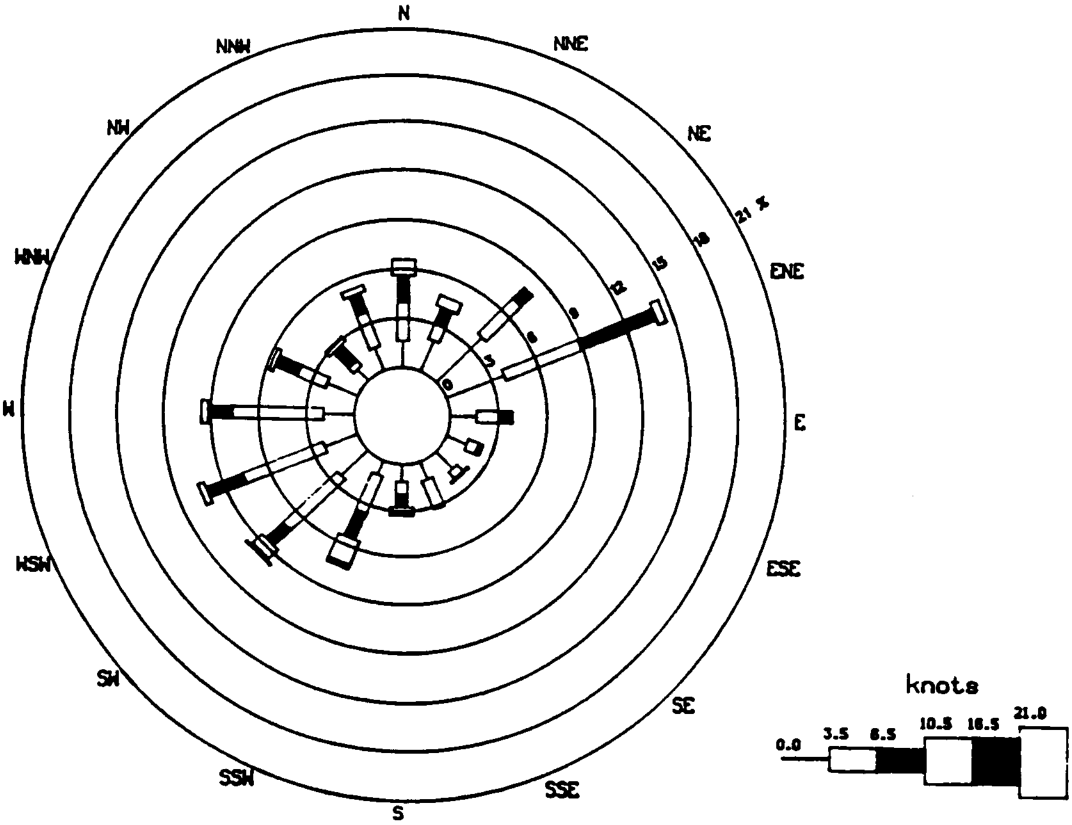


Figure B.1. Wind Roses for Each Month

WIND ROSE Tower K (@60m) for Apr., 1990

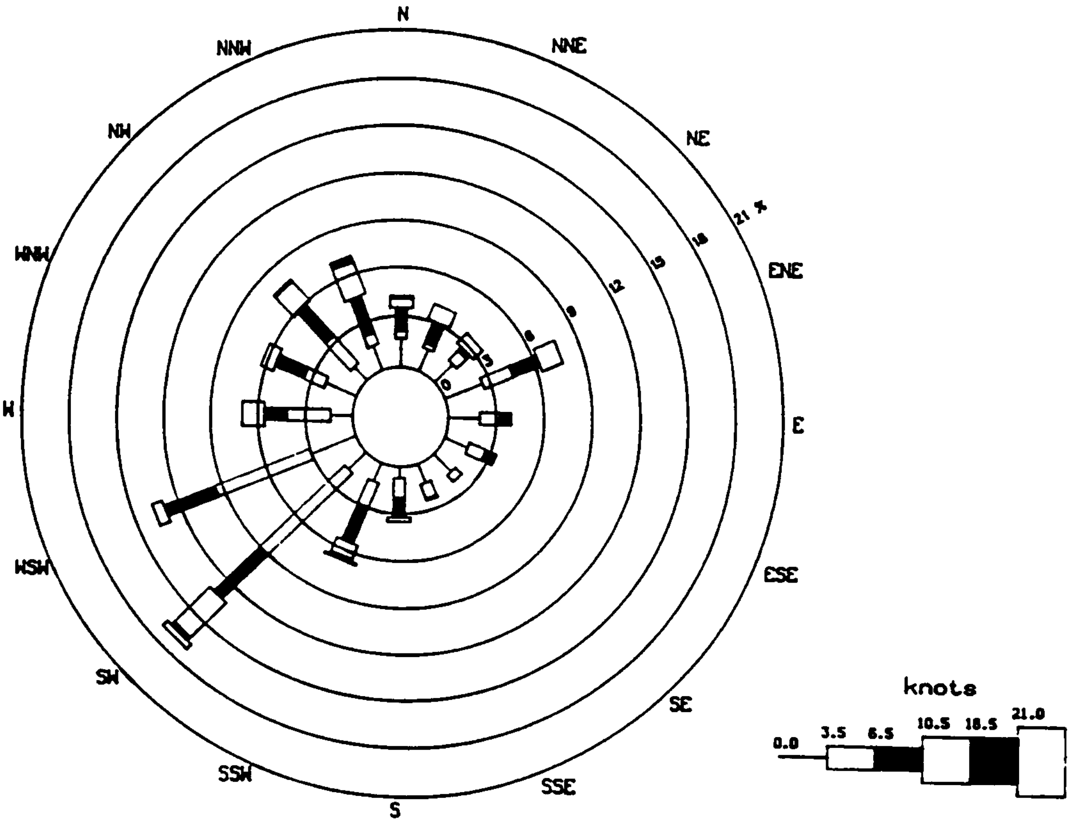


Figure B.1. Continued

WIND ROSE Tower K (@60m) for May, 1990

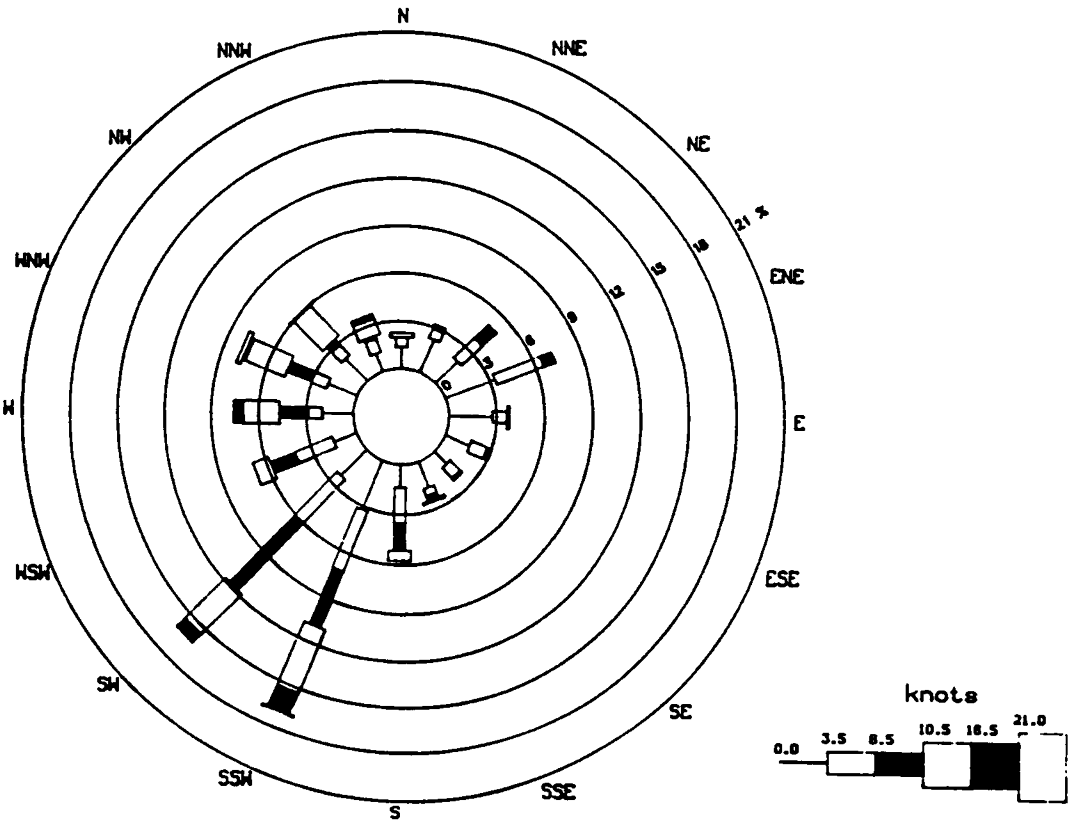


Figure B.1. Continued

WIND ROSE Tower K (@60m) for June, 1990

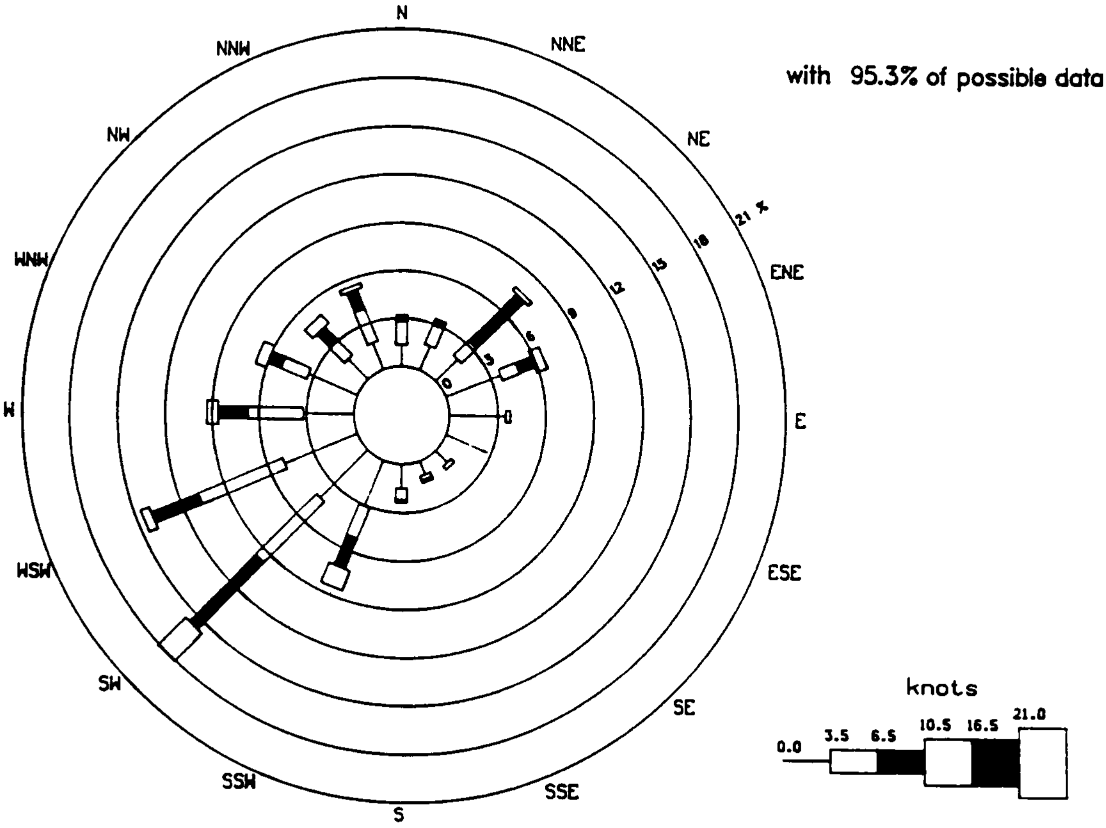


Figure B.1. Continued

WIND ROSE Tower K (@60m) for July, 1990

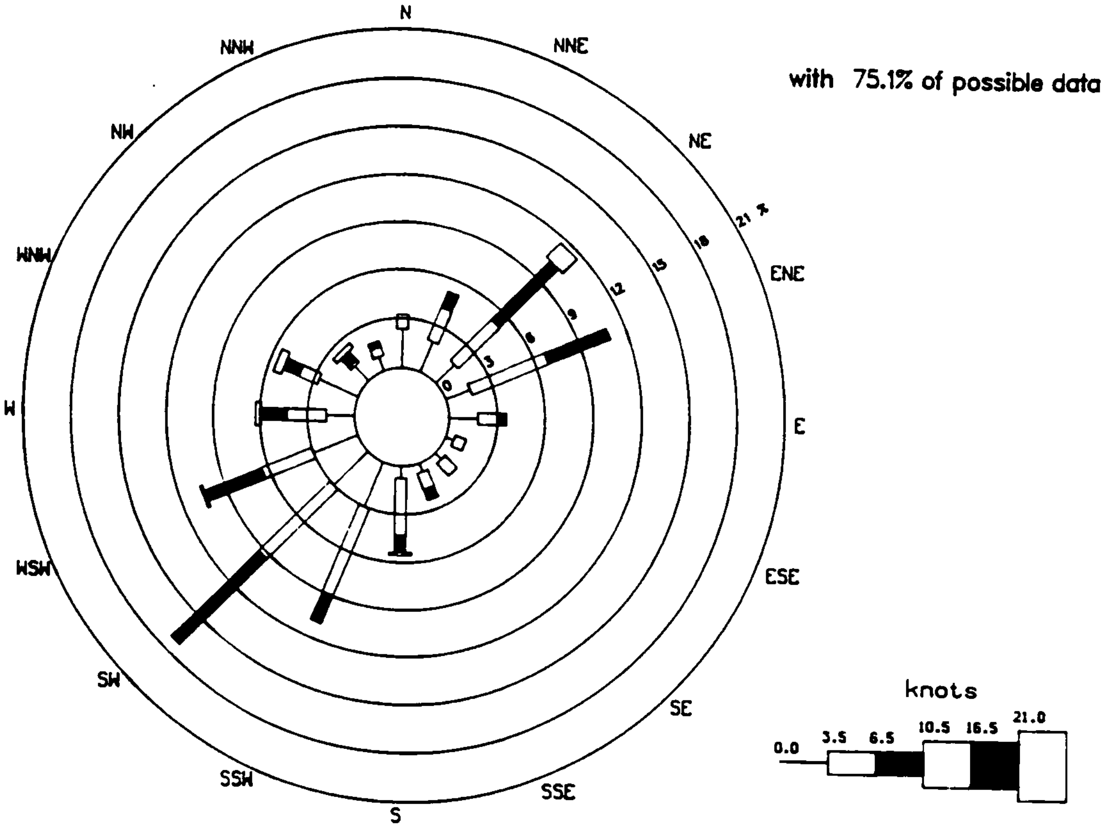


Figure B.1. Continued

WIND ROSE Tower K (@60m) for Aug., 1990

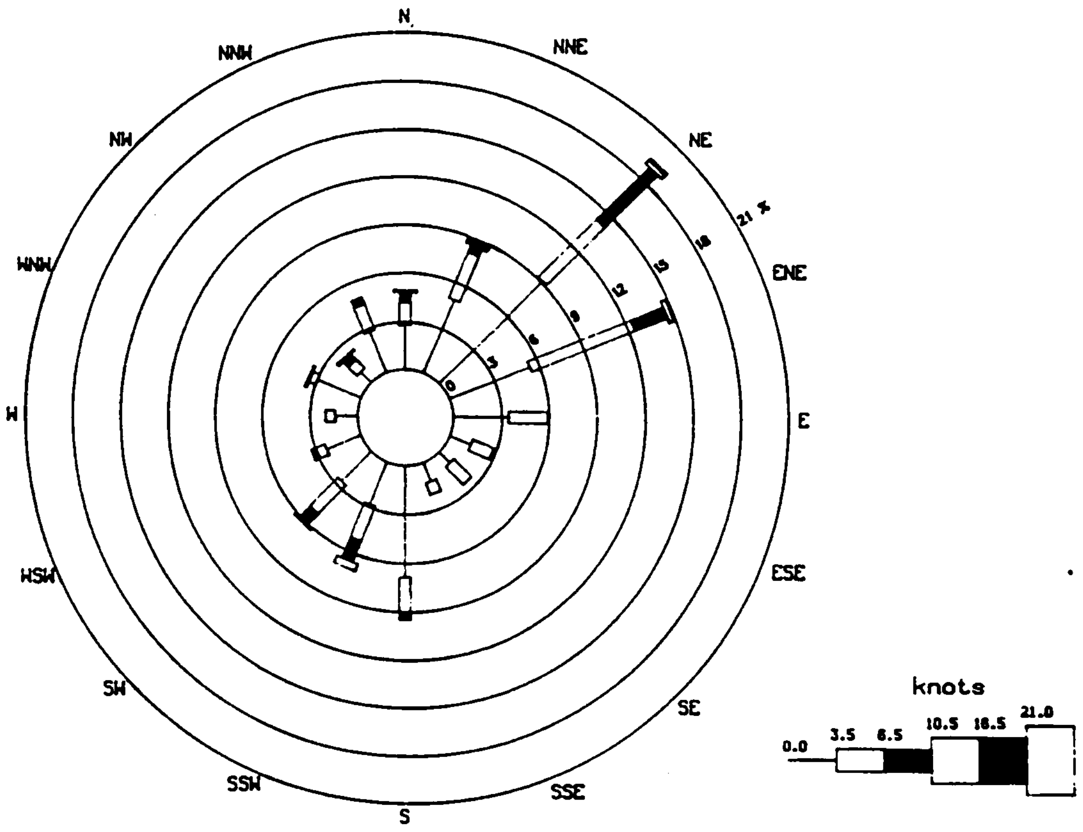


Figure B.1. Continued

WIND ROSE Tower K (@60m) for Sep., 1990

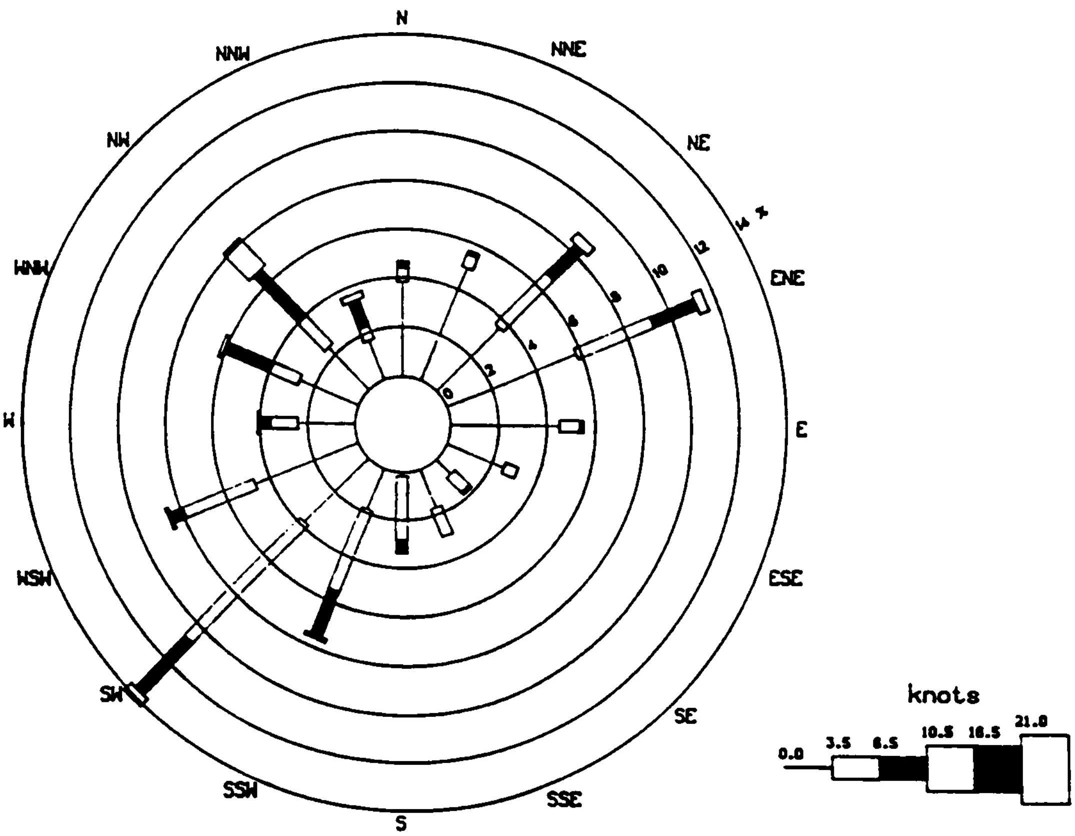


Figure B.1. Continued

WIND ROSE Tower K (@60m) for Nov., 1990

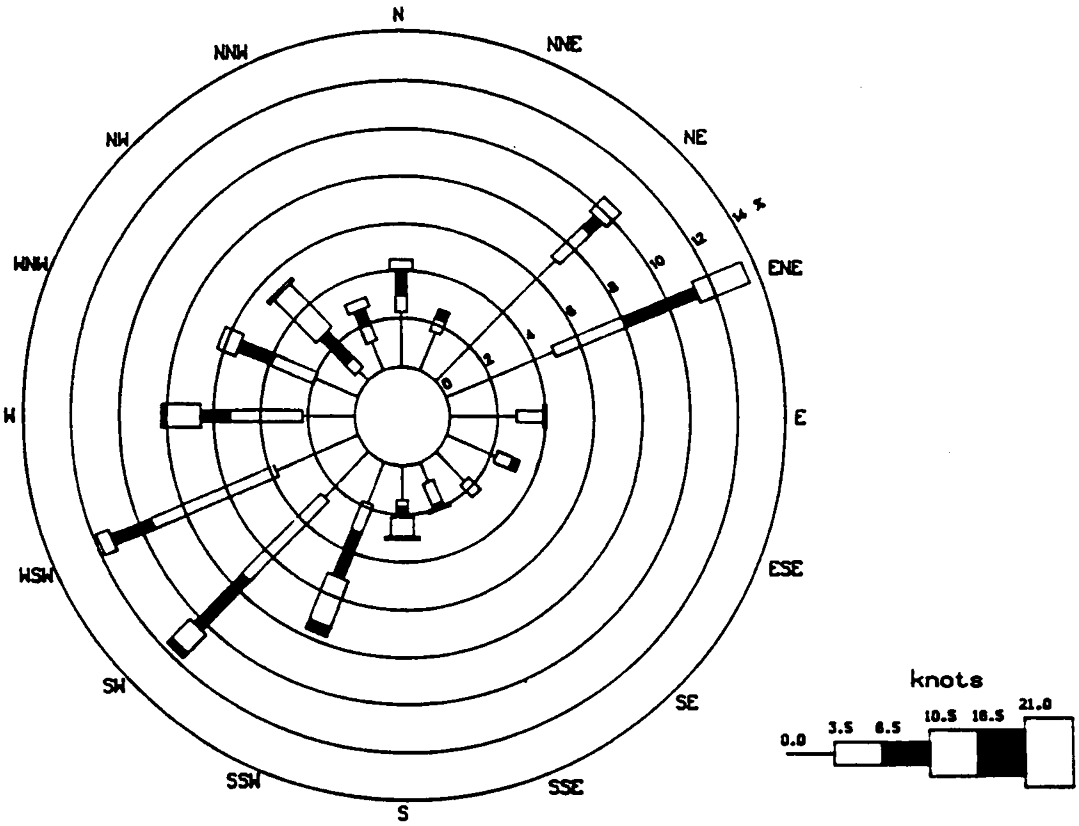


Figure B.1. Continued

WIND ROSE Tower K (@60m) for Dec., 1990

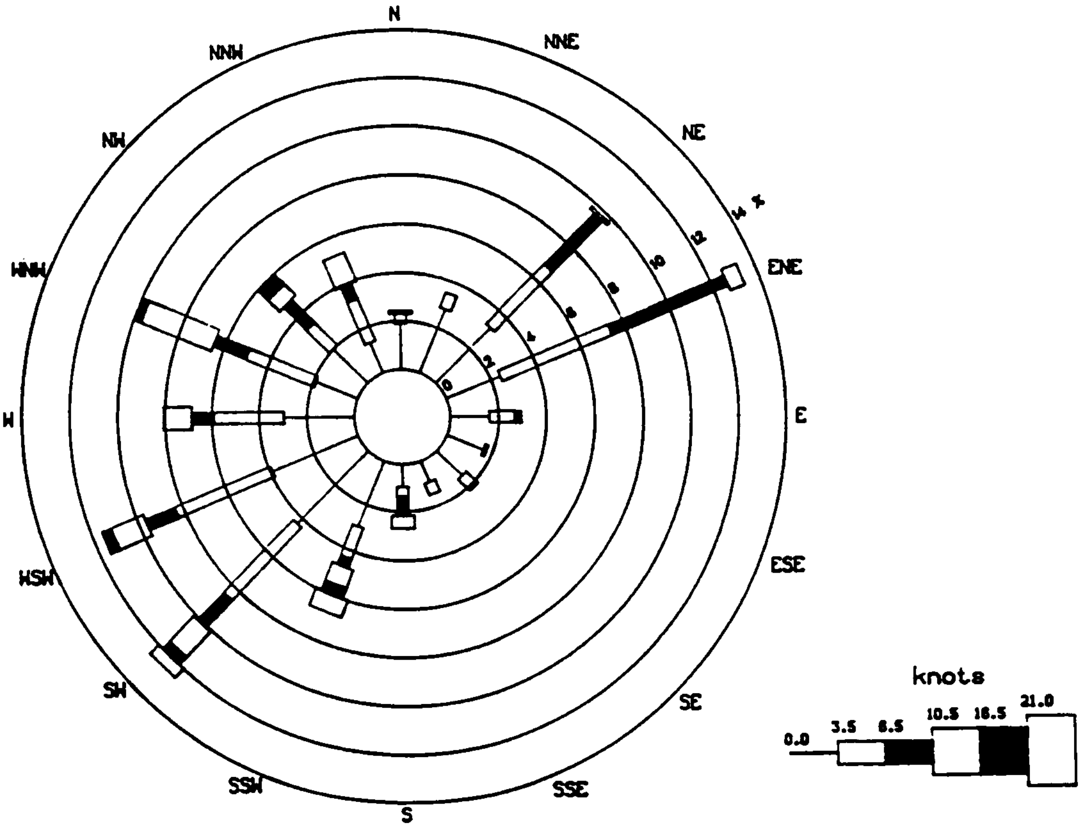


Figure B.1. Continued

WIND ROSE Tower K (@60m) for Jan., 1991

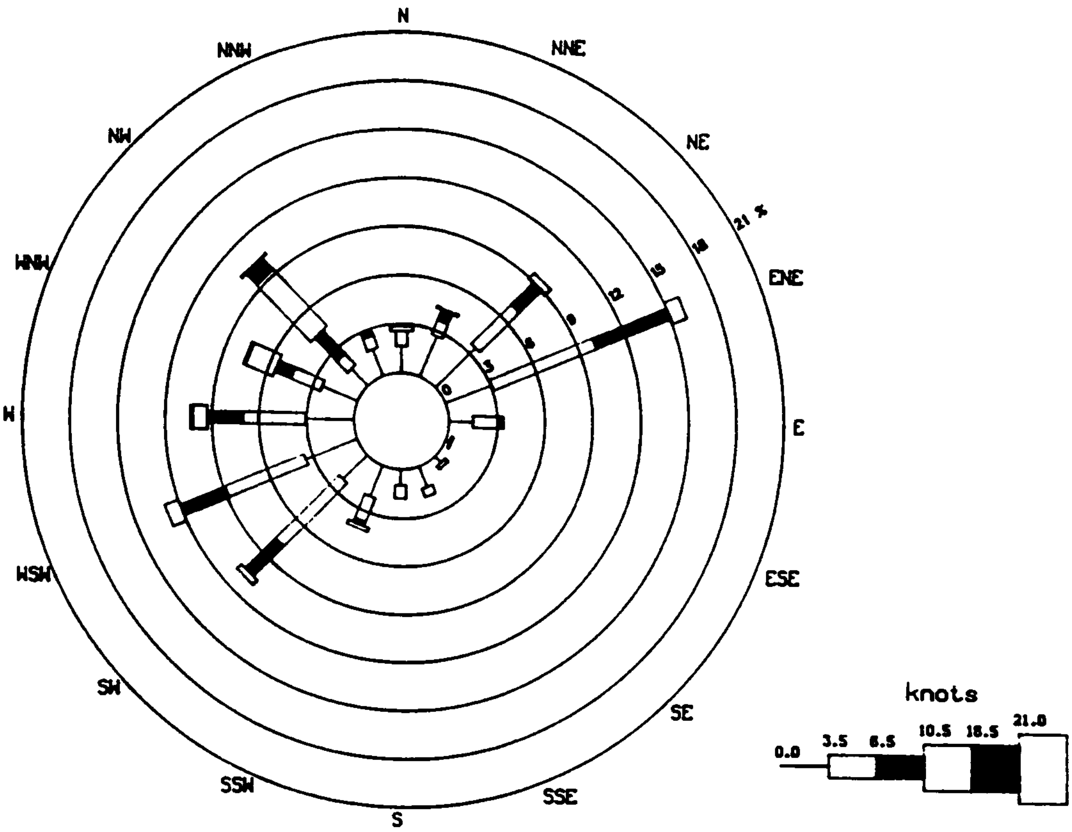


Figure B.1. Continued

WIND ROSE Tower K (@60m) for Feb., 1991

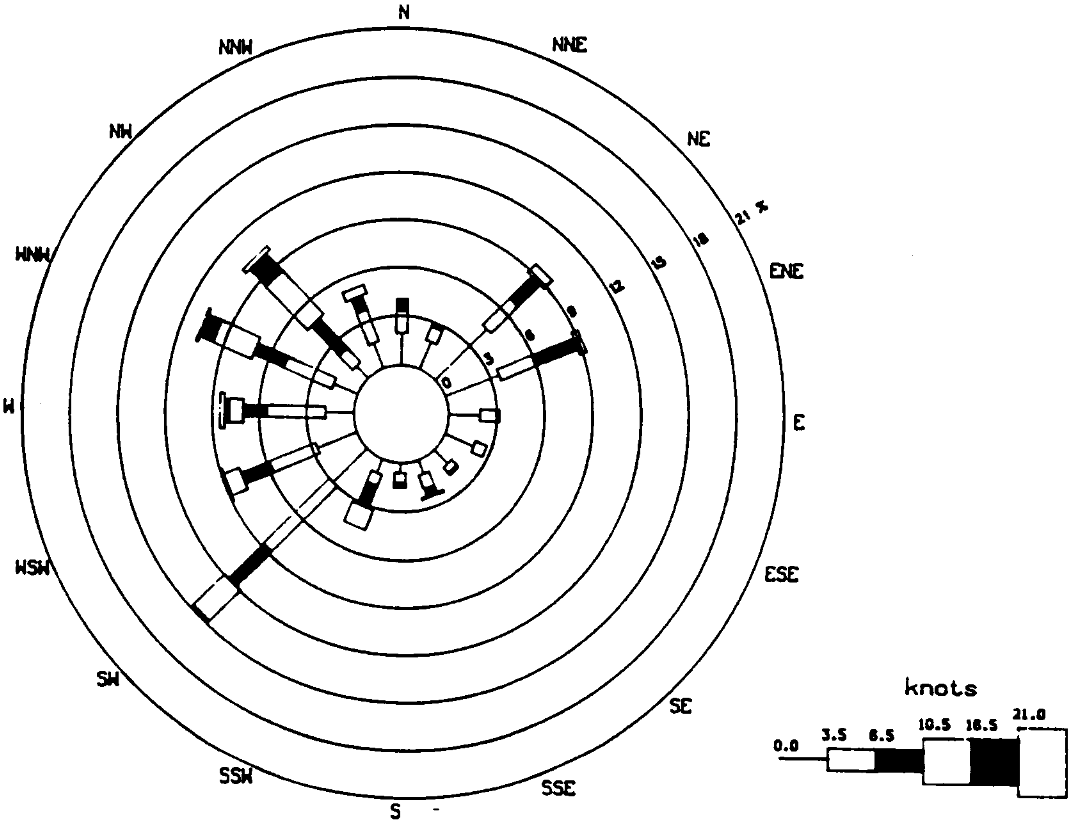


Figure B.1. Continued

WIND ROSE Tower K (@60m) for Mar., 1991

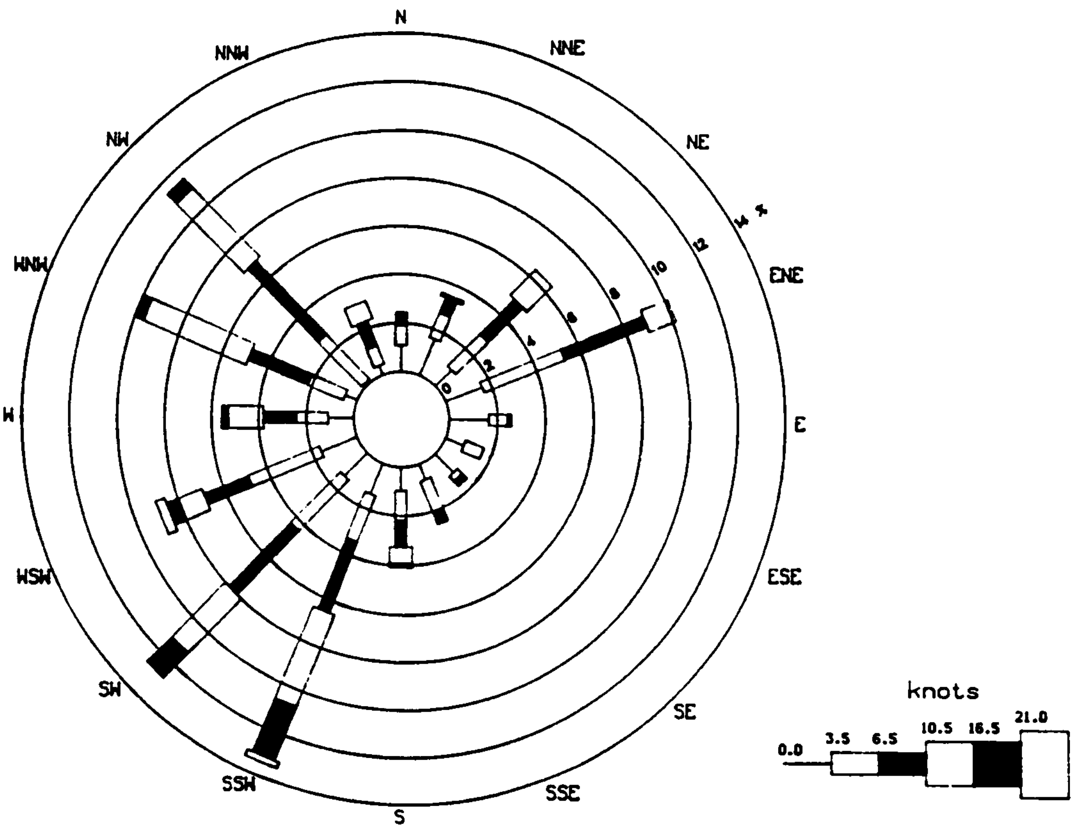


Figure B.1. Continued

WIND ROSE Tower K (@60m) for Apr., 1991

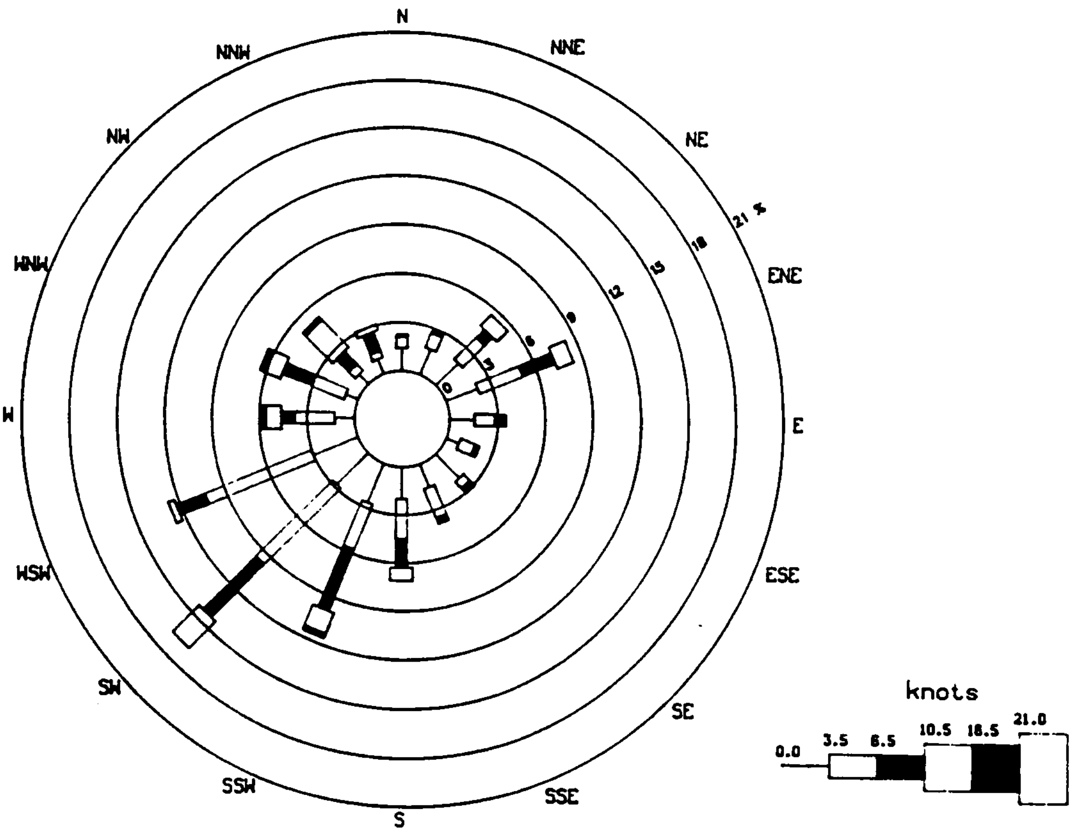


Figure B.1. Continued

WIND ROSE Tower K (@60m) for May, 1991

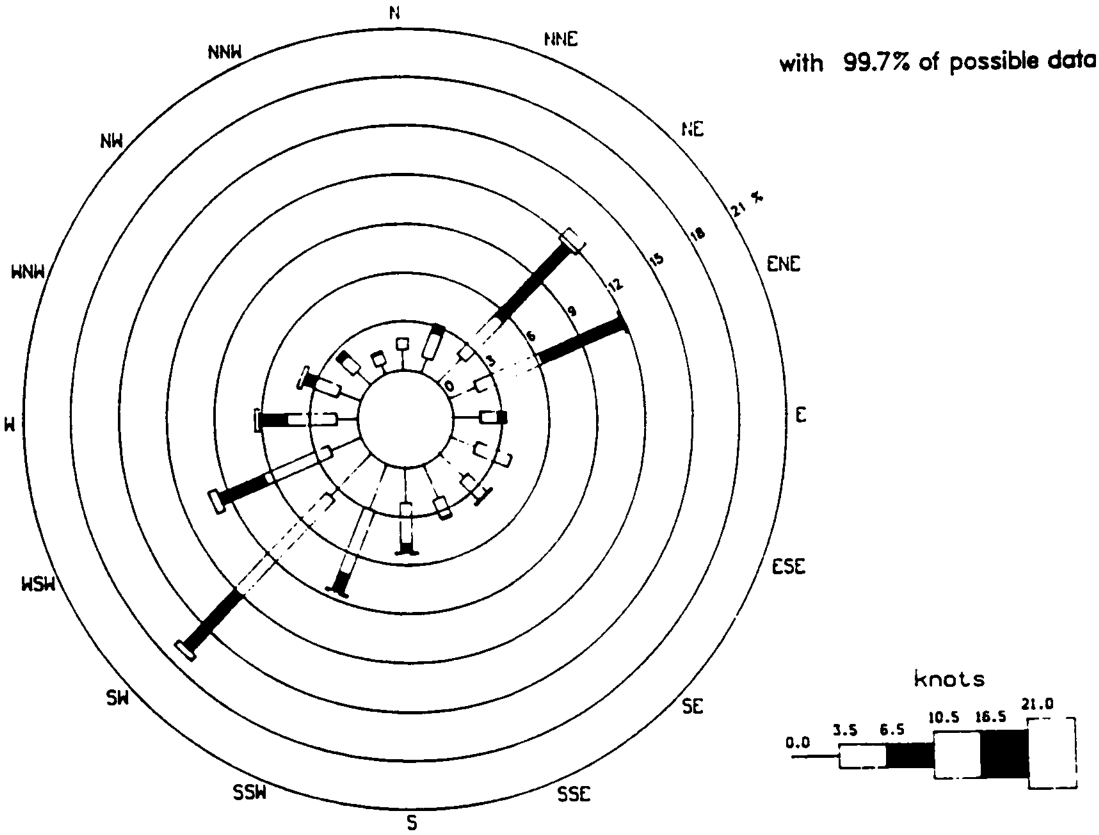


Figure B.1. Continued

WIND ROSE Tower K (@60m) for June, 1991

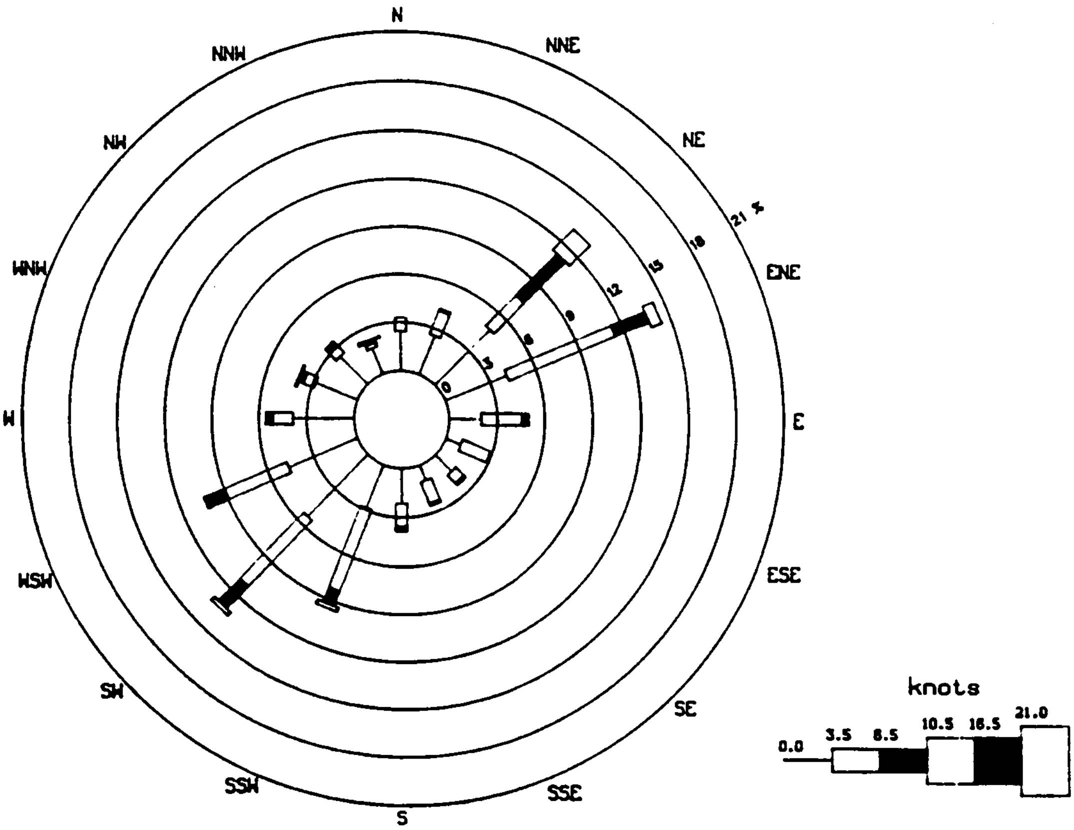


Figure B.1. Continued

WIND ROSE Tower K (@60m) for July, 1991

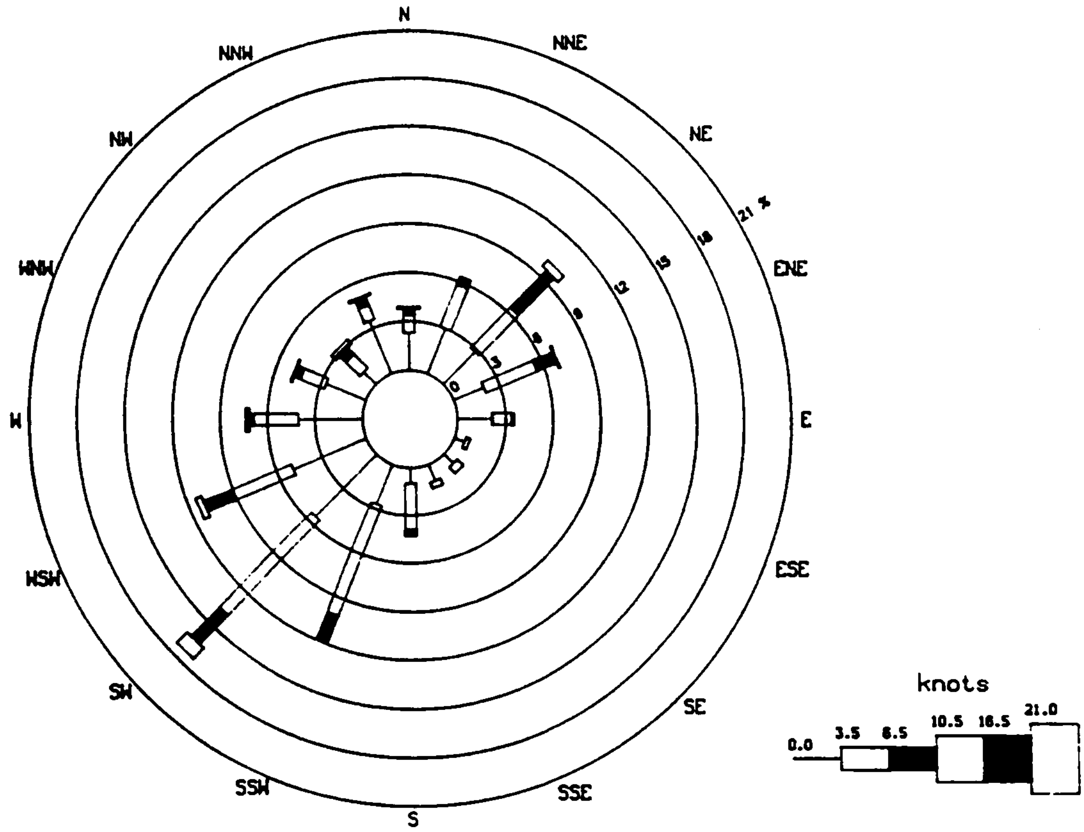


Figure B.1. Continued

WIND ROSE Tower K (@60m) for Aug., 1991

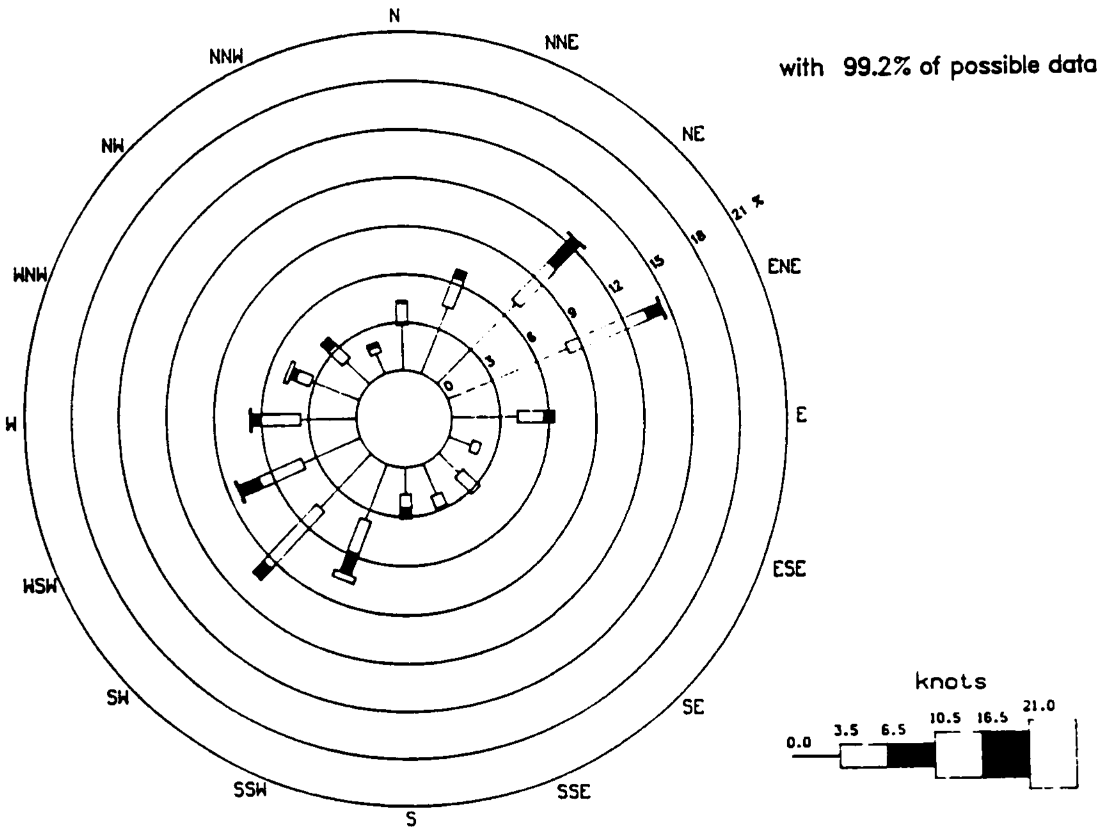


Figure B.1. Continued

WIND ROSE Tower K (@60m) for Sep., 1991

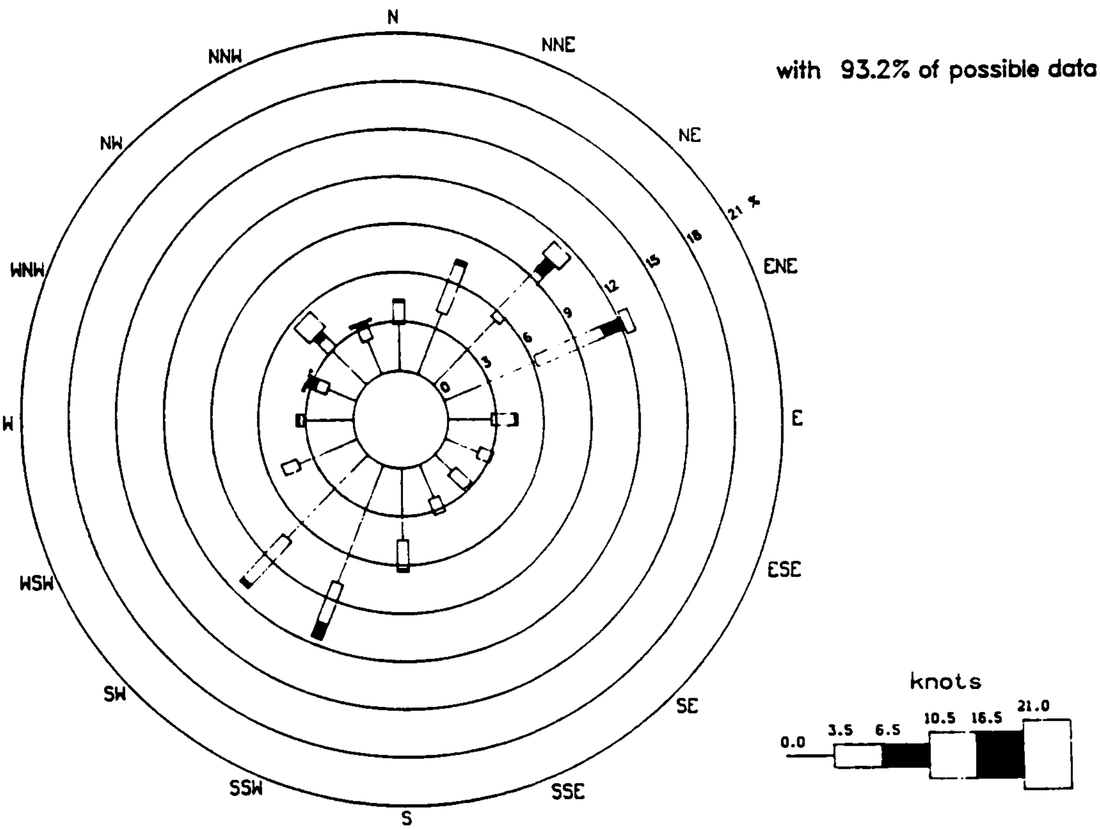


Figure B.1. Continued

WIND ROSE Tower K (@60m) for Oct., 1991

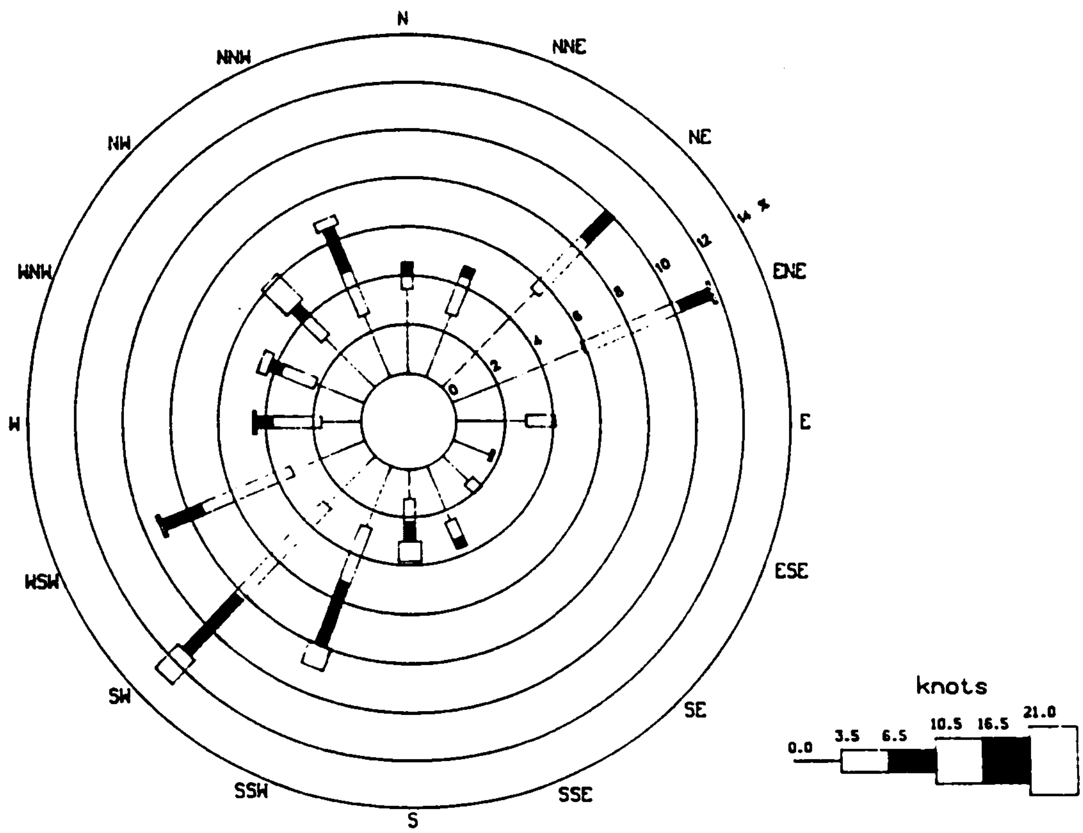


Figure B.1. Continued

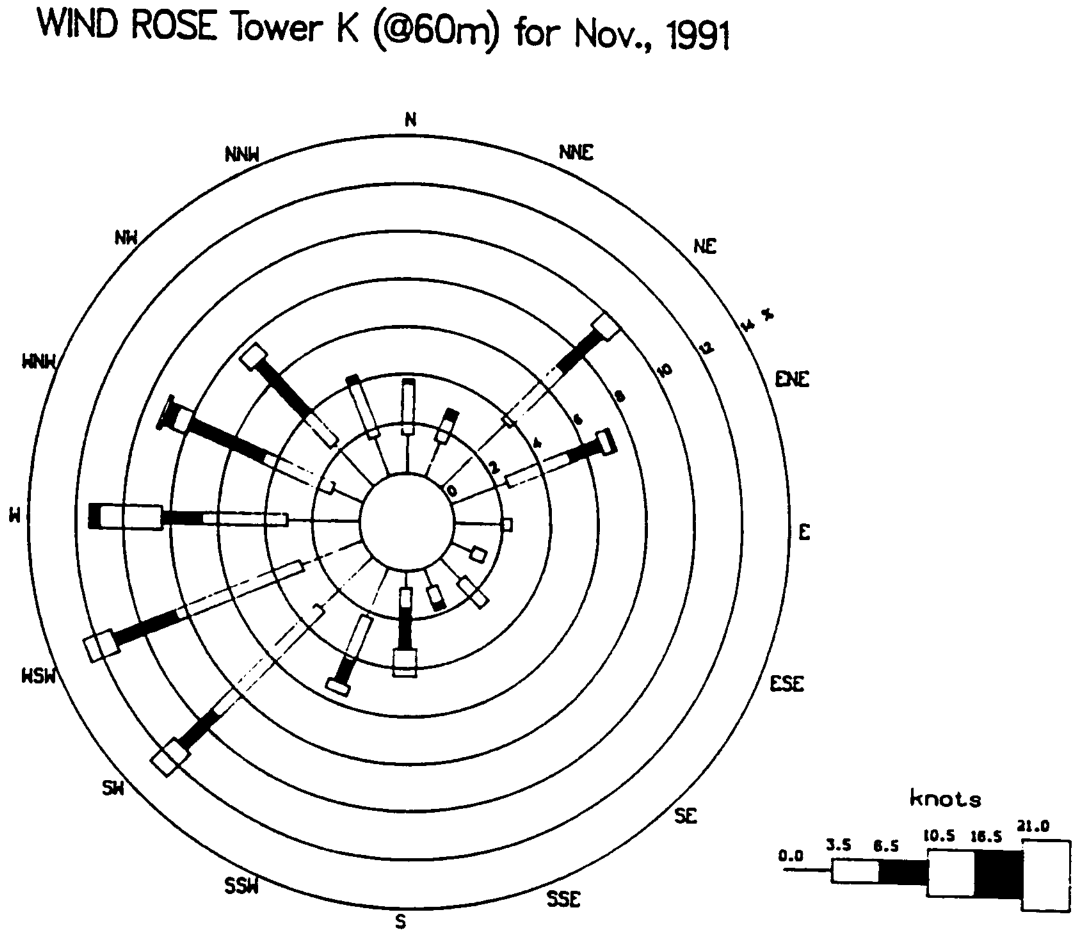


Figure B.1. Continued

WIND ROSE Tower K (@60m) for Dec., 1991

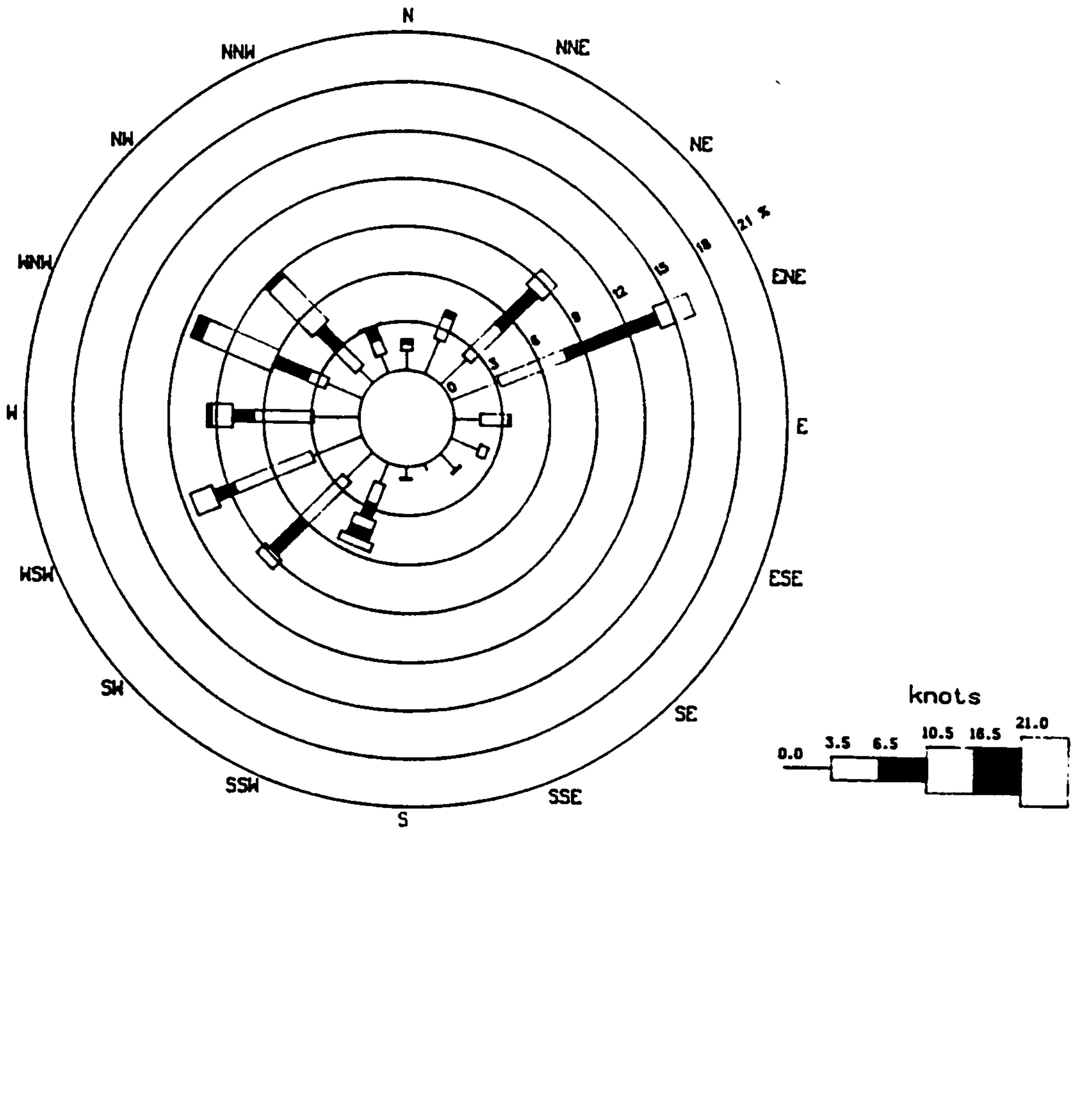


Figure B.1. Continued

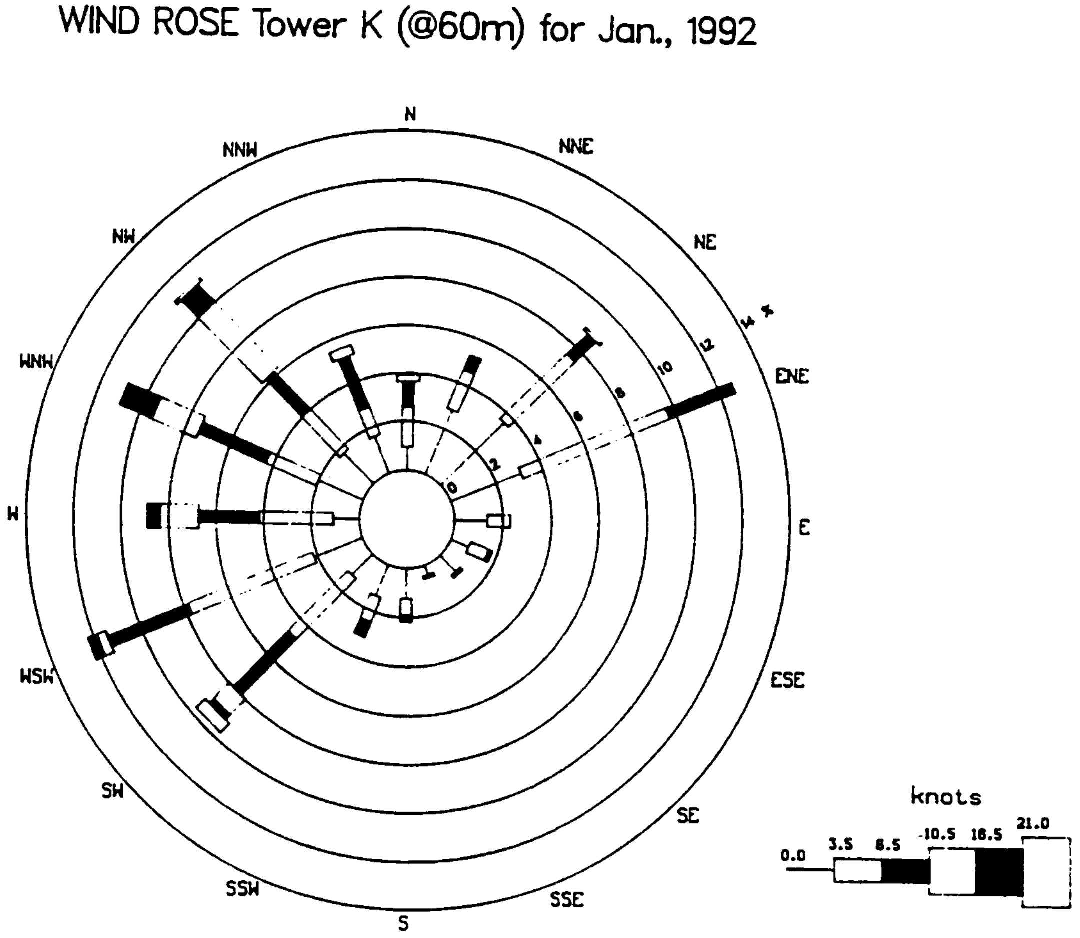


Figure B.1. Continued

WIND ROSE Tower K (@60m) for Feb., 1992

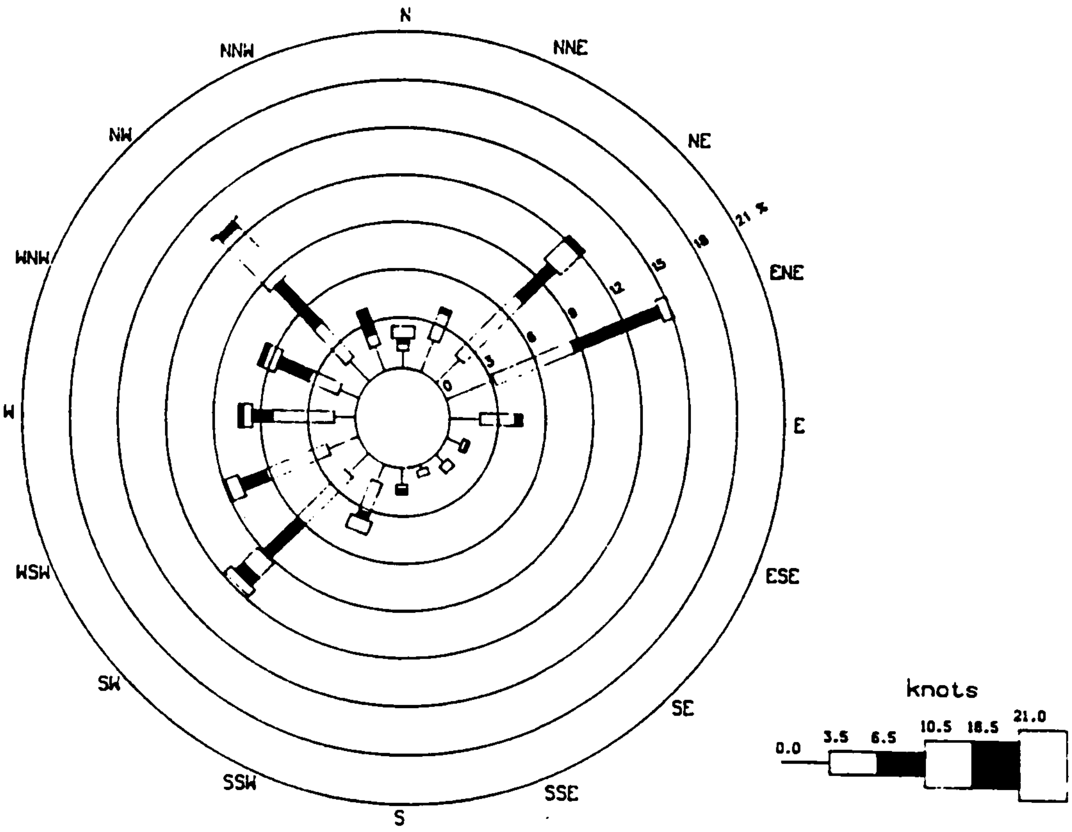


Figure B.1. Continued

WIND ROSE Tower K (@60m) for Mar., 1992

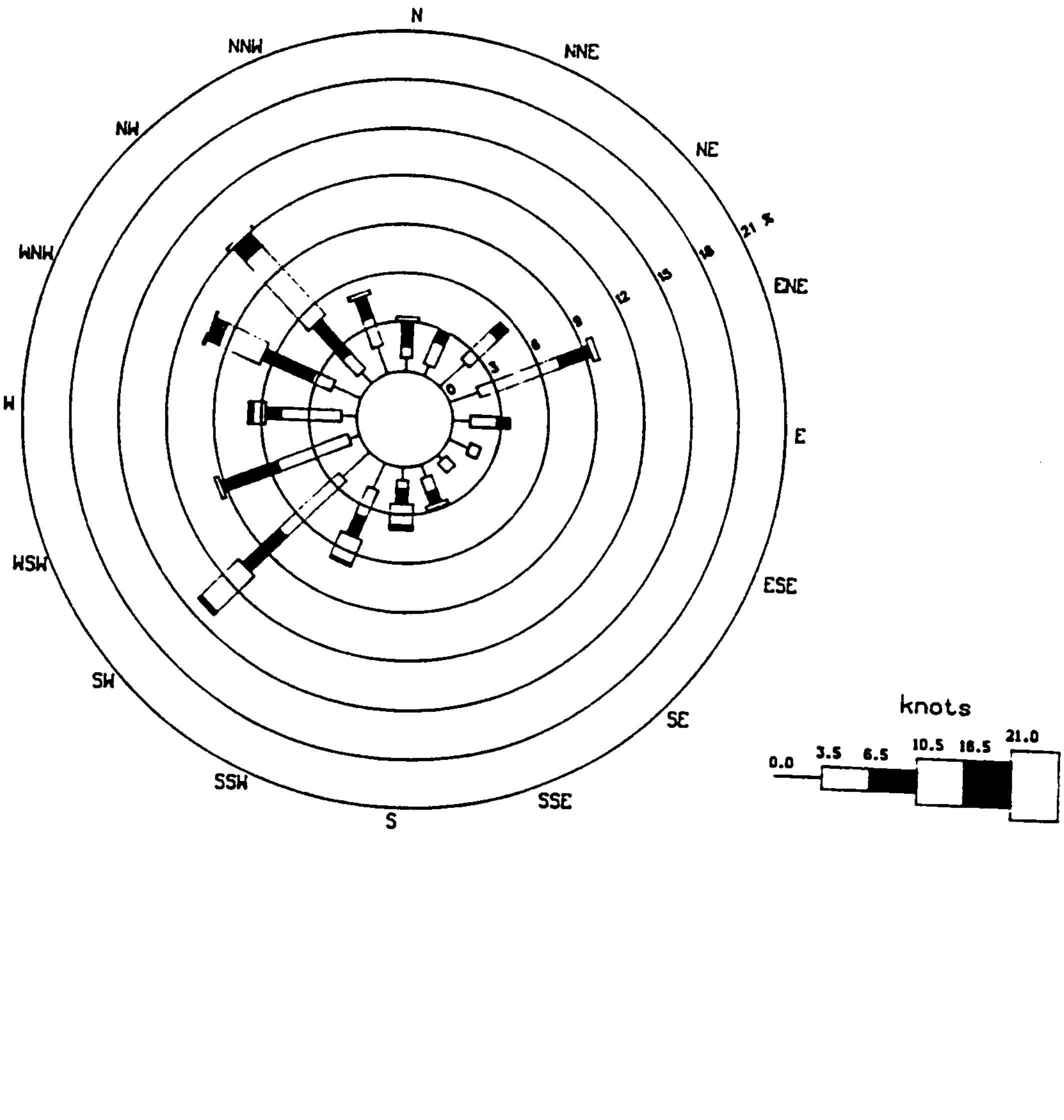


Figure B.1. Continued

WIND ROSE Tower K (@60m) for Apr., 1992

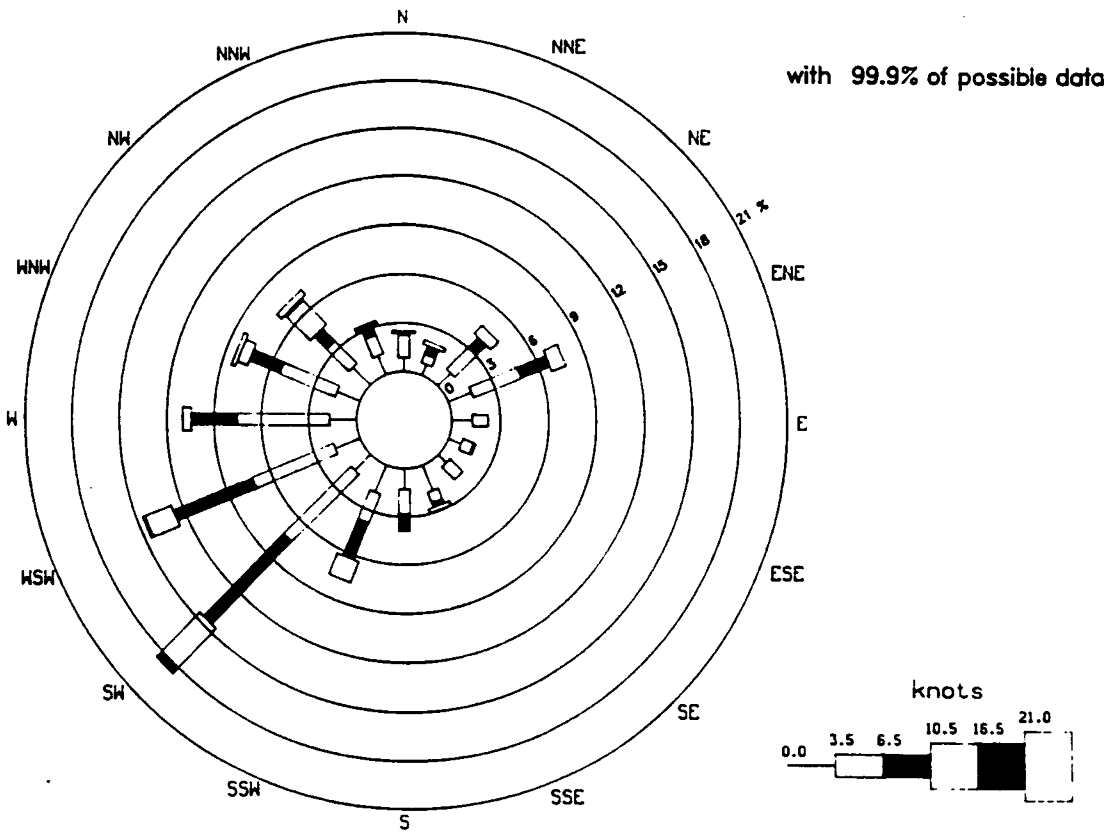


Figure B.1. Continued

WIND ROSE Tower K (@60m) for May, 1992

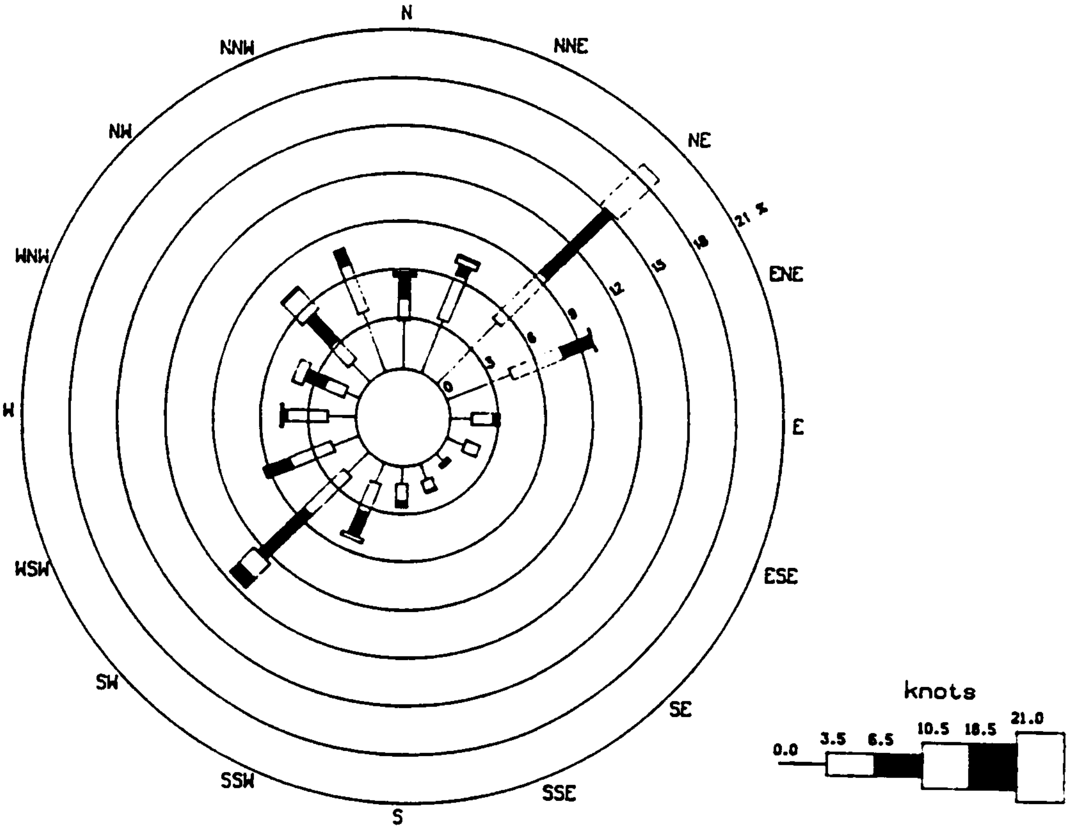


Figure B.1. Continued

WIND ROSE Tower K (@60m) for June, 1992

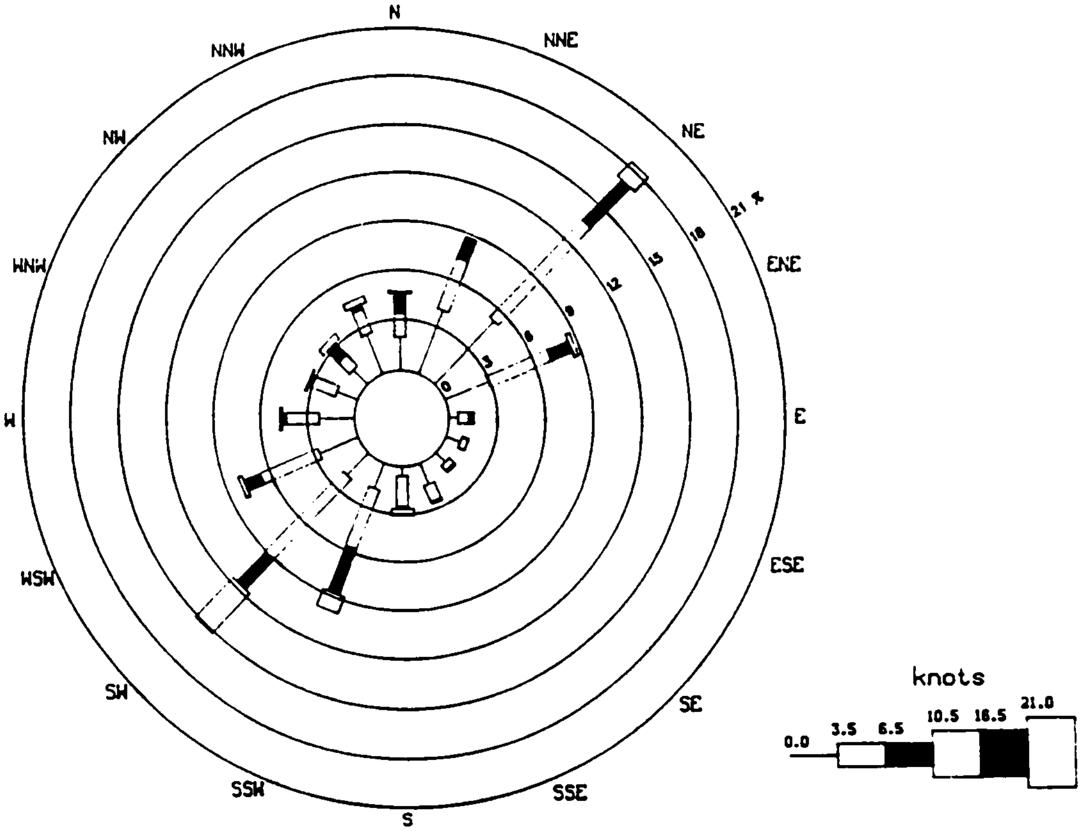


Figure B.1. Continued

WIND ROSE Tower K (@60m) for July, 1992

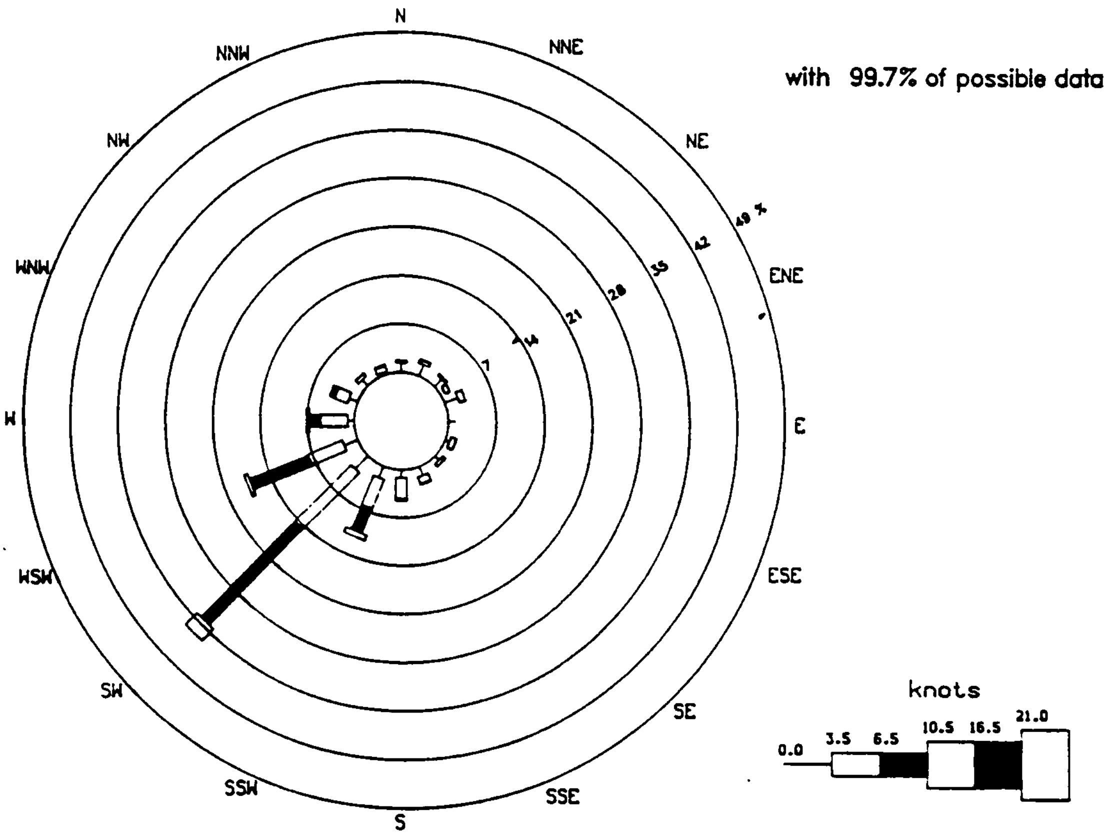


Figure B.1. Continued

WIND ROSE Tower K (@60m) for Aug., 1992

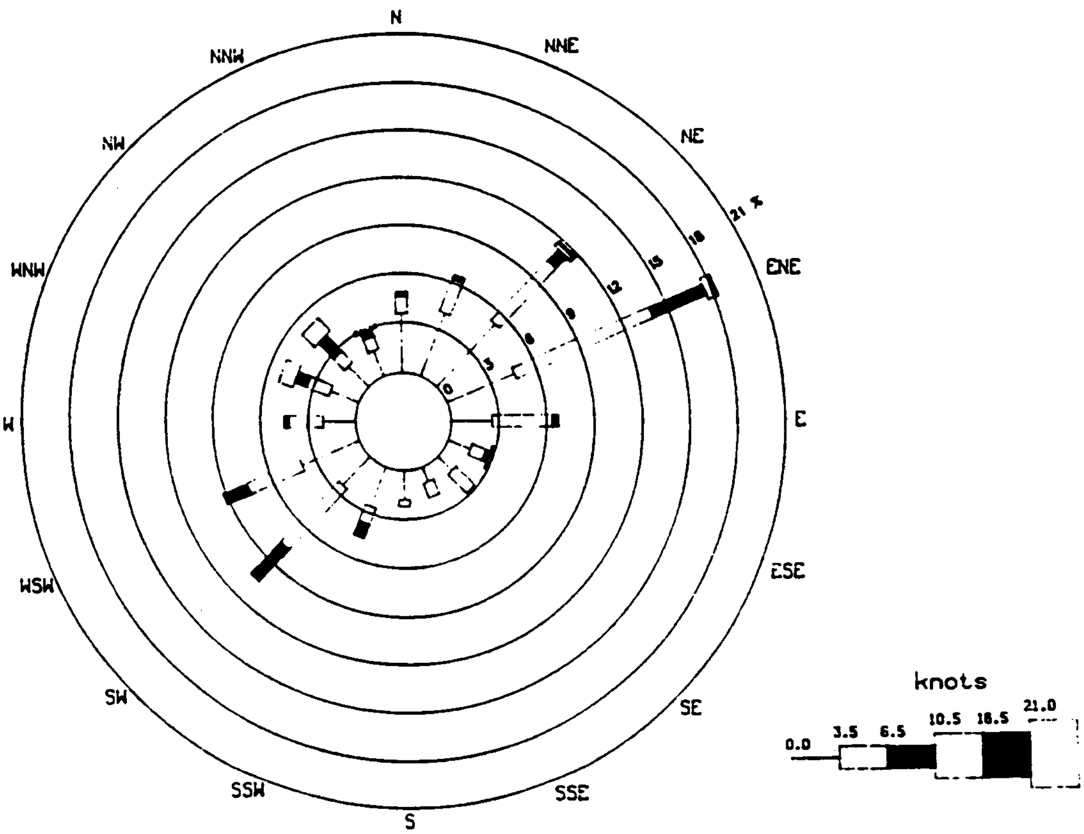


Figure B.1. Continued

WIND ROSE Tower K (@60m) for Sep., 1992

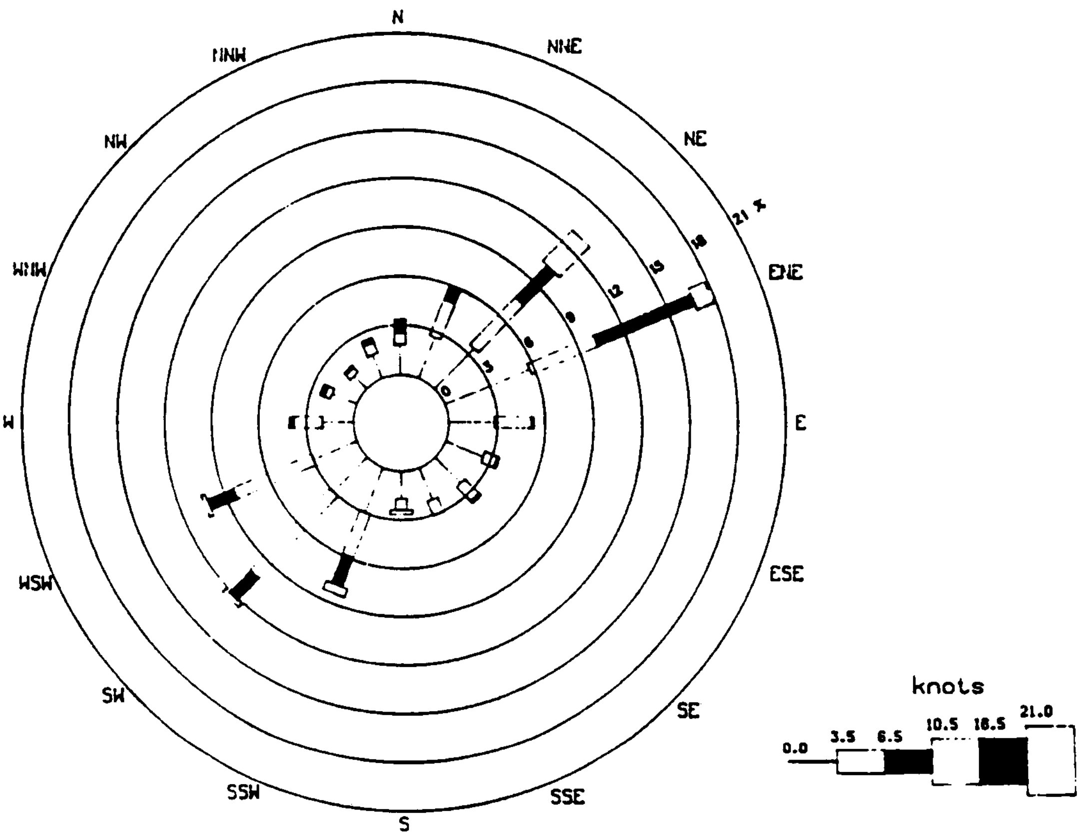


Figure B.1. Continued

WIND ROSE Tower K (@60m) for Oct., 1992

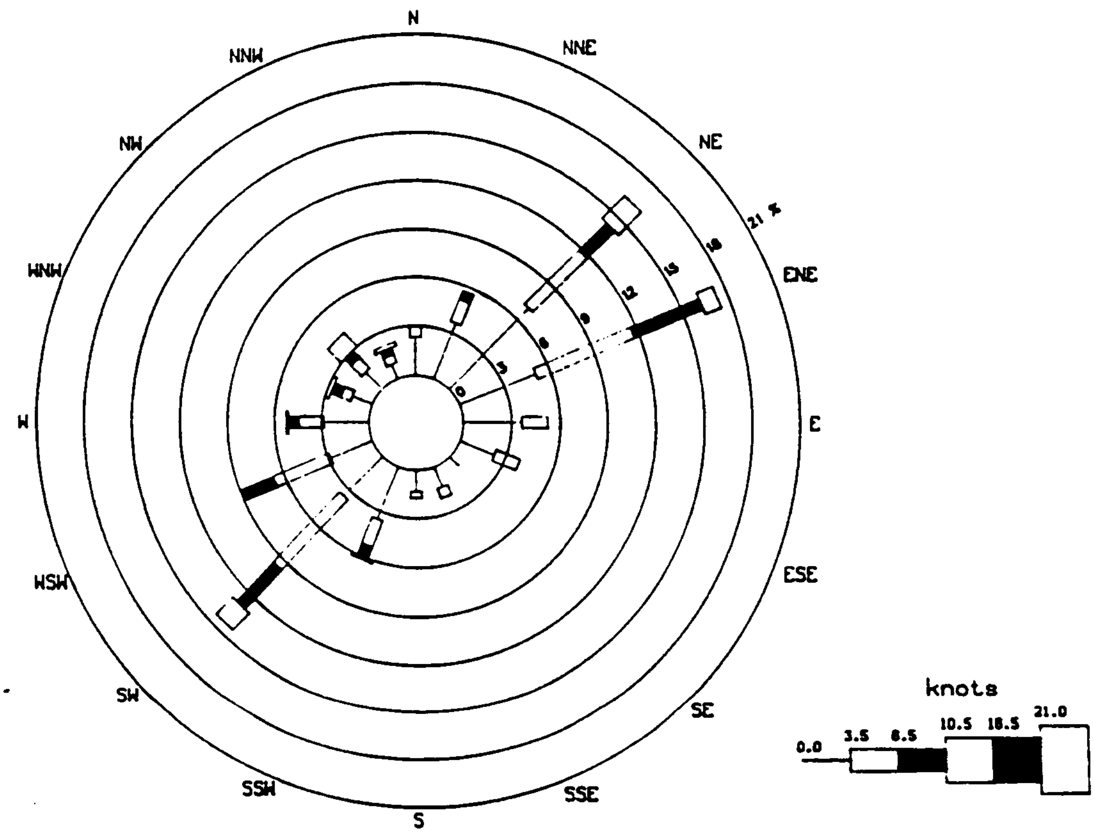


Figure B.1. Continued

WIND ROSE Tower K (@60m) for Dec., 1992

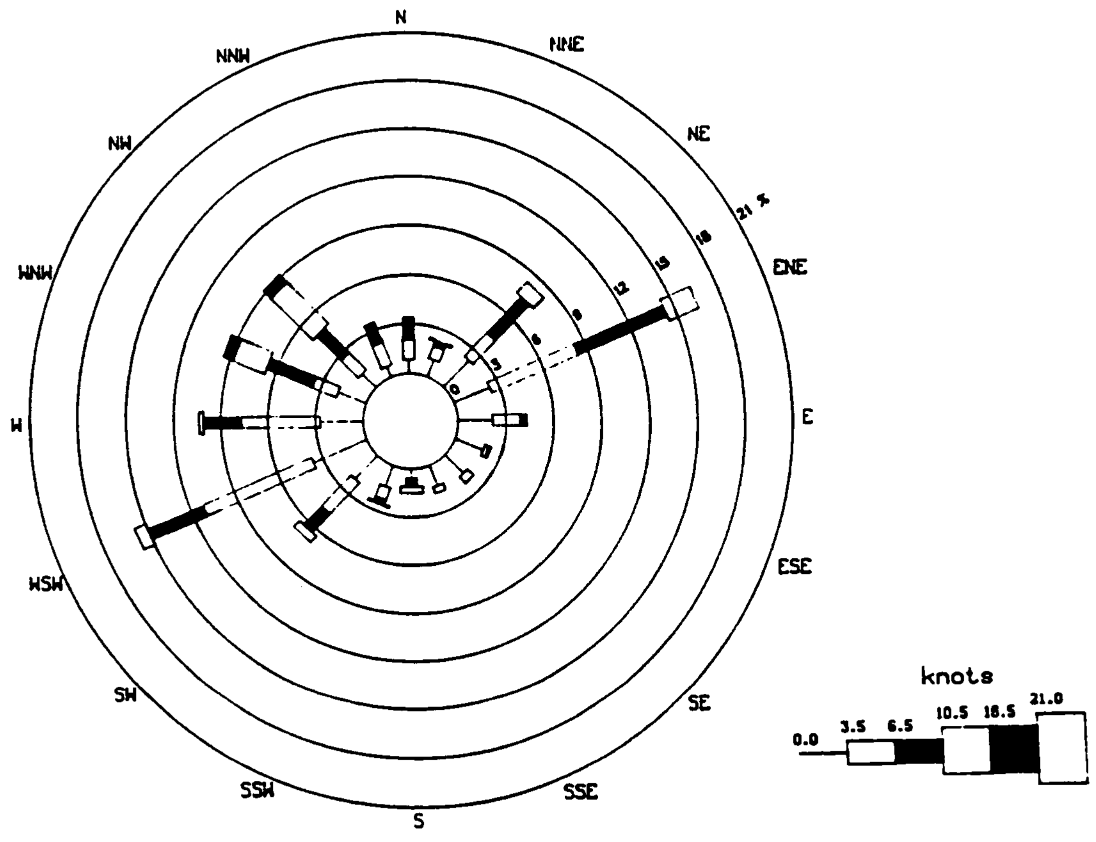


Figure B.1. Continued

WIND ROSE Tower K (@60m) for Jan., 1993

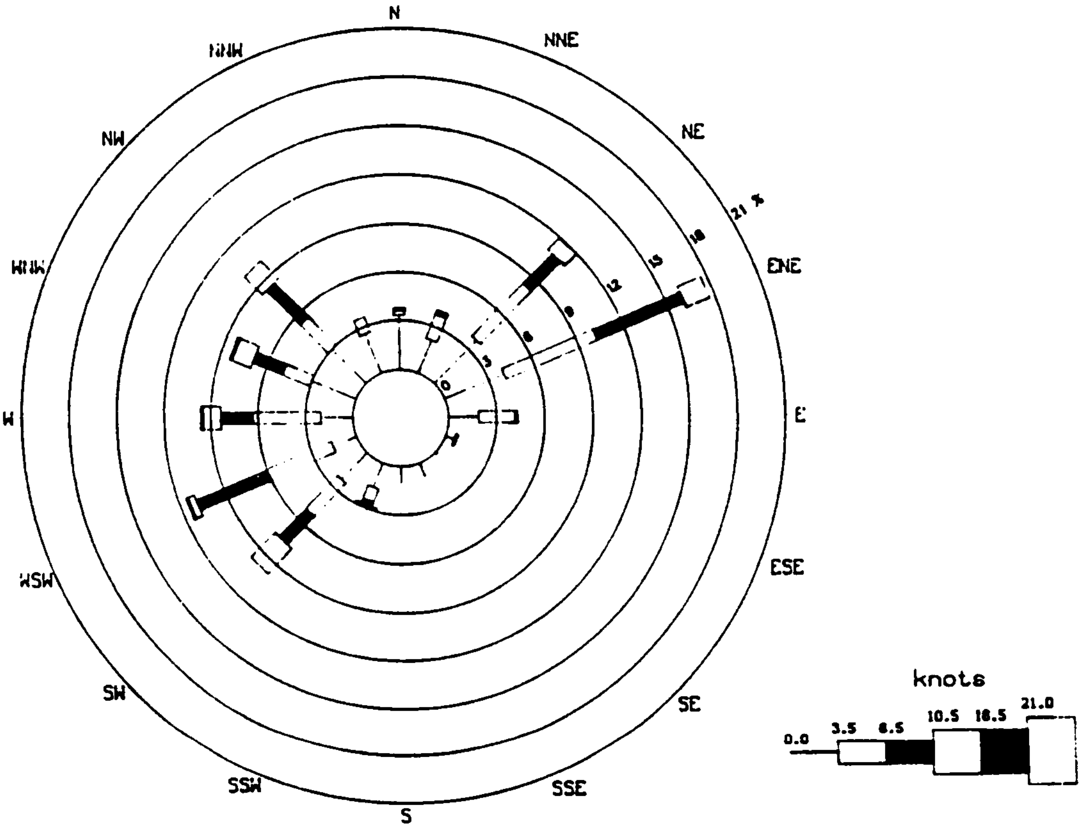


Figure B.1. Continued

WIND ROSE Tower K (@60m) for Feb., 1993

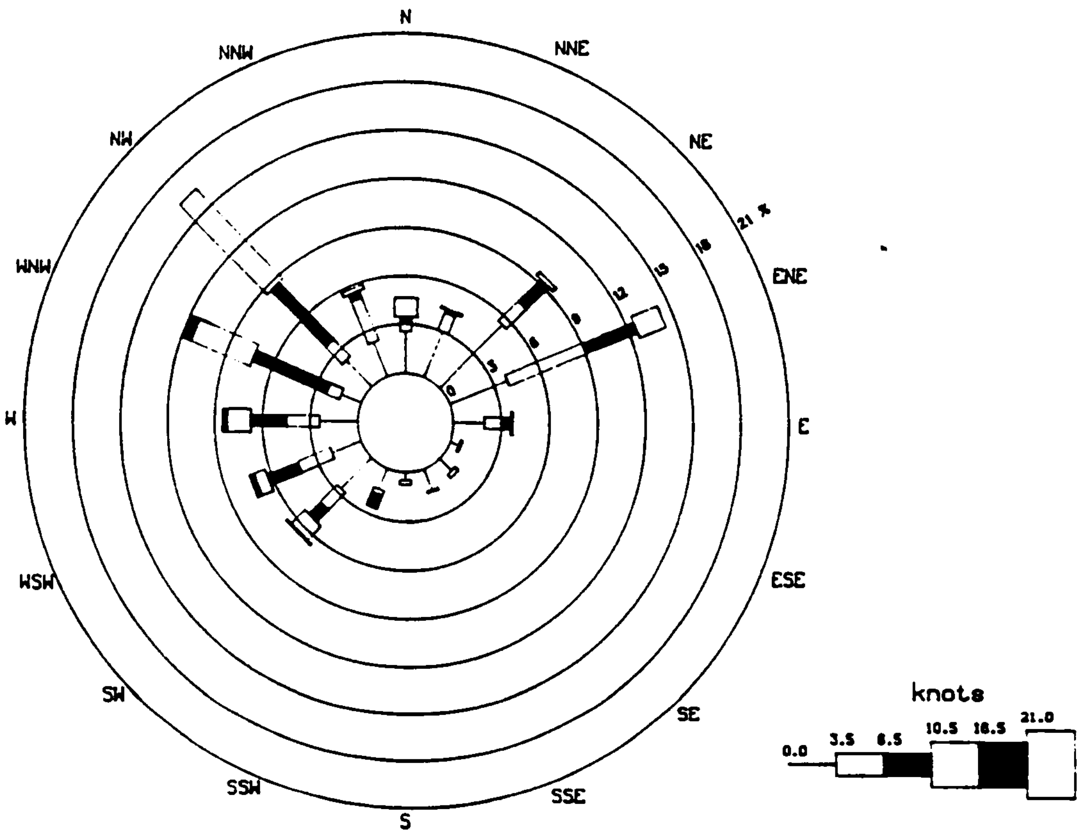


Figure B.1. Continued

WIND ROSE Tower K (@60m) for Mar., 1993

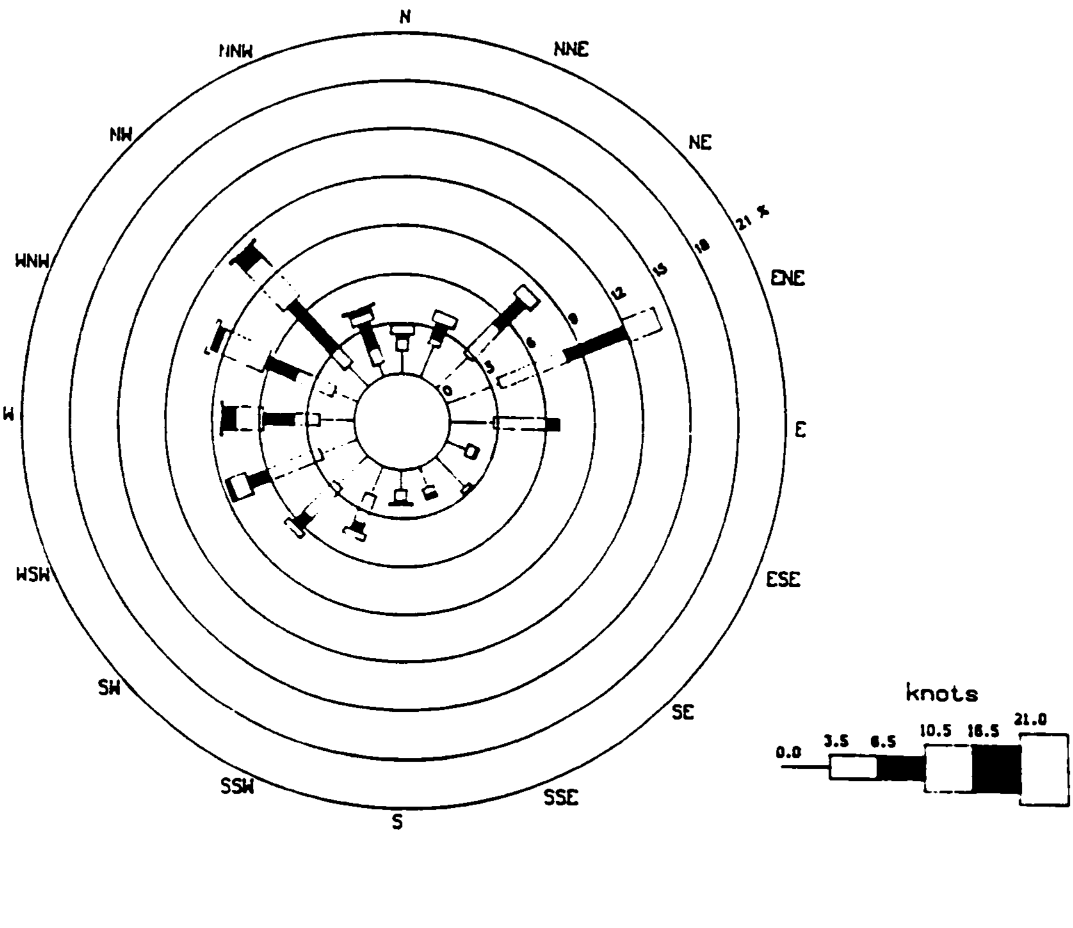


Figure B.1. Continued

WIND ROSE Tower K (@60m) for Apr., 1993

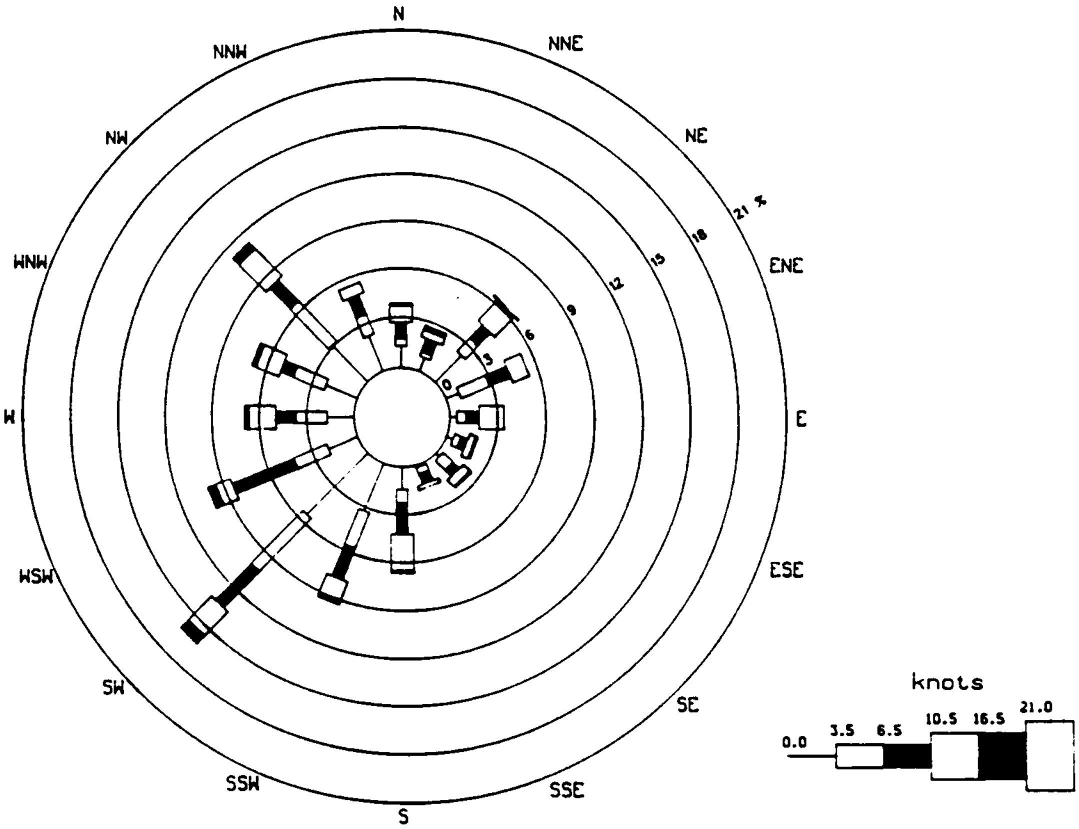


Figure B.1. Continued

WIND ROSE Tower K (@60m) for May, 1993

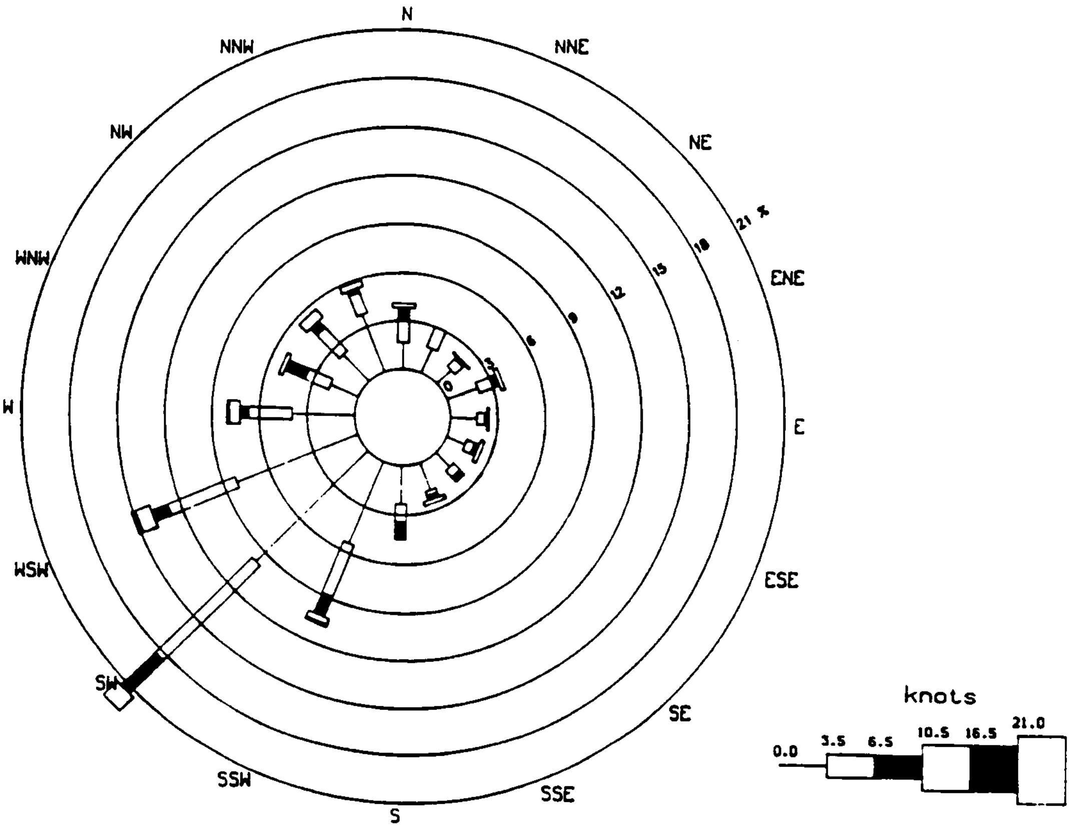


Figure B.1. Continued

WIND ROSE Tower K (@60m) for June, 1993

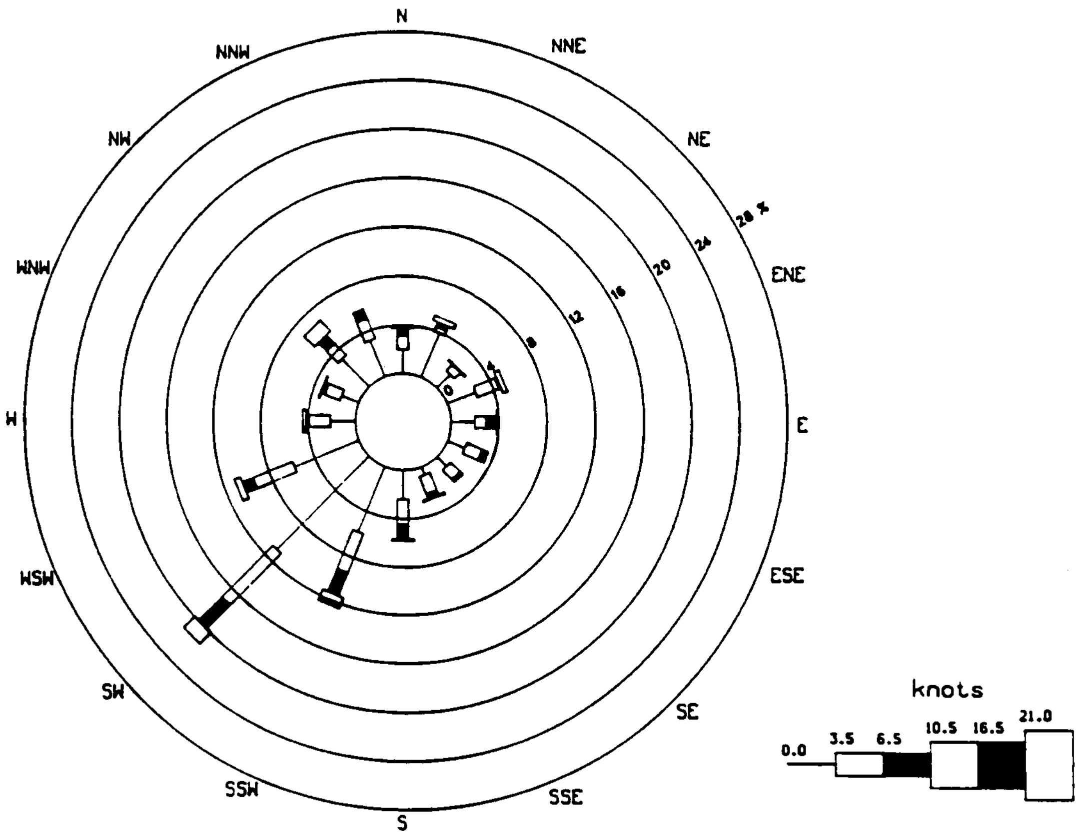


Figure B.1. Continued

WIND ROSE Tower K (@60m) for July, 1993

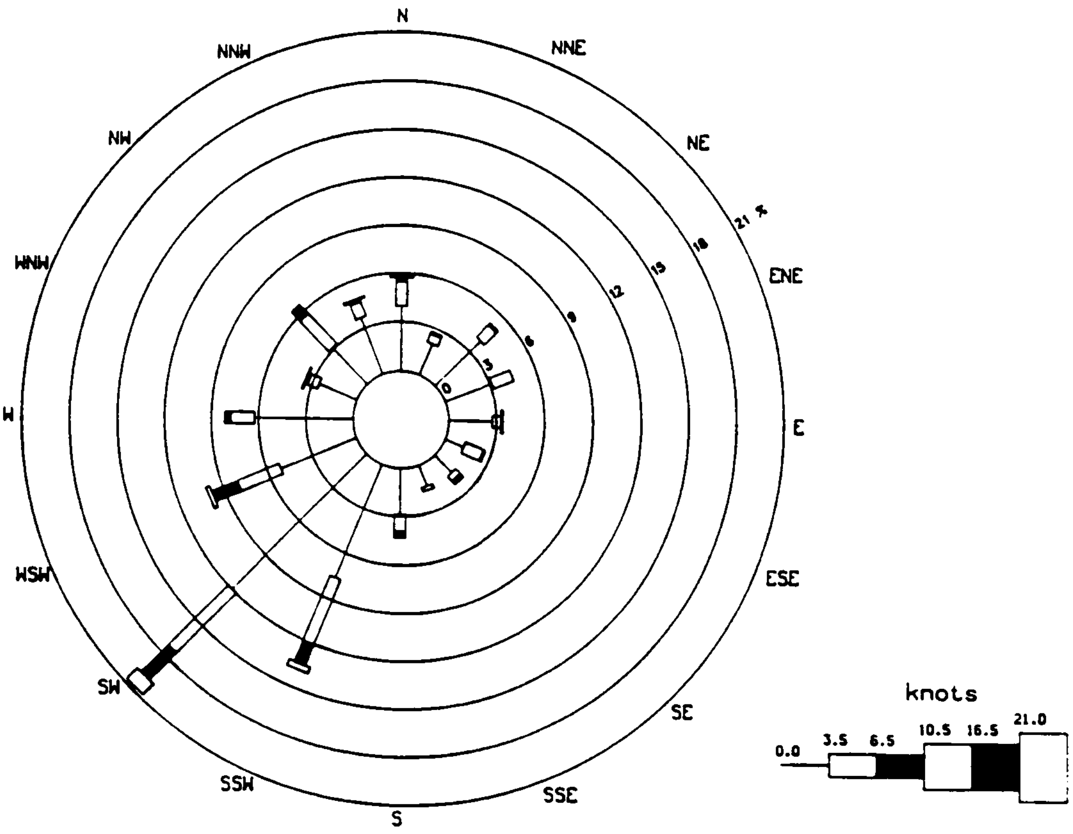


Figure B.1. Continued

WIND ROSE Tower K (@60m) for Aug., 1993

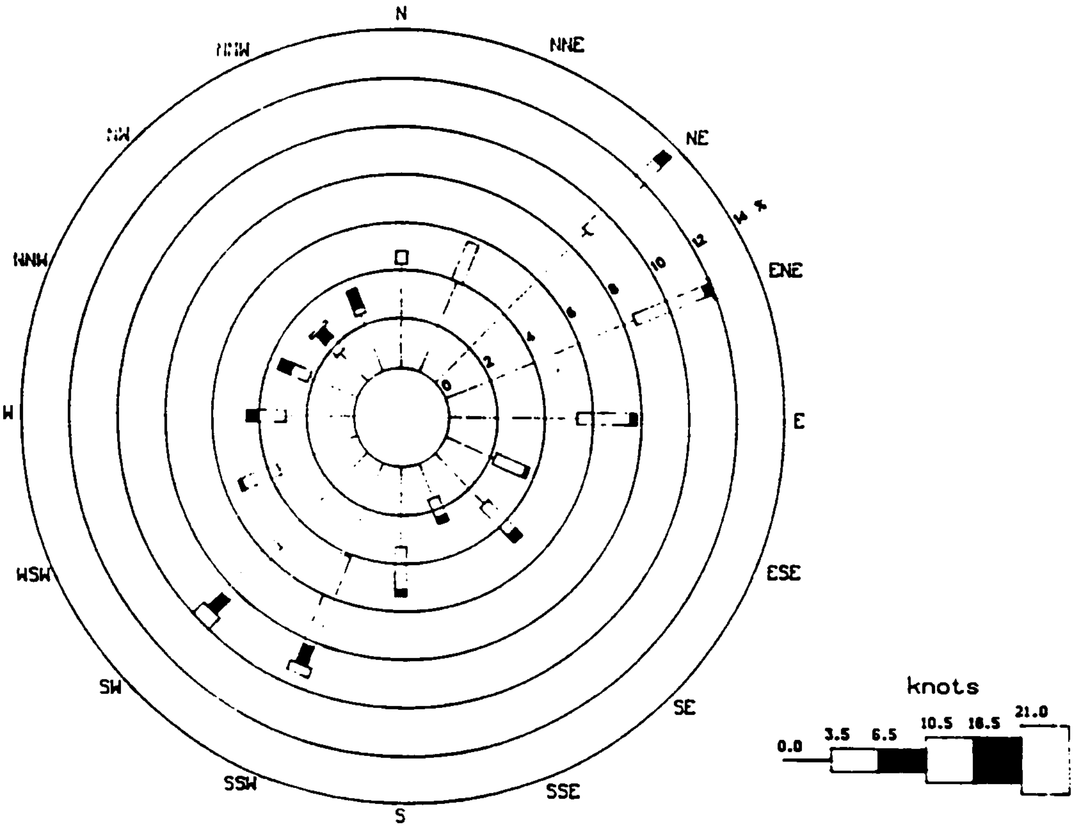


Figure B.1. Continued

WIND ROSE Tower K (@60m) for Sep., 1993

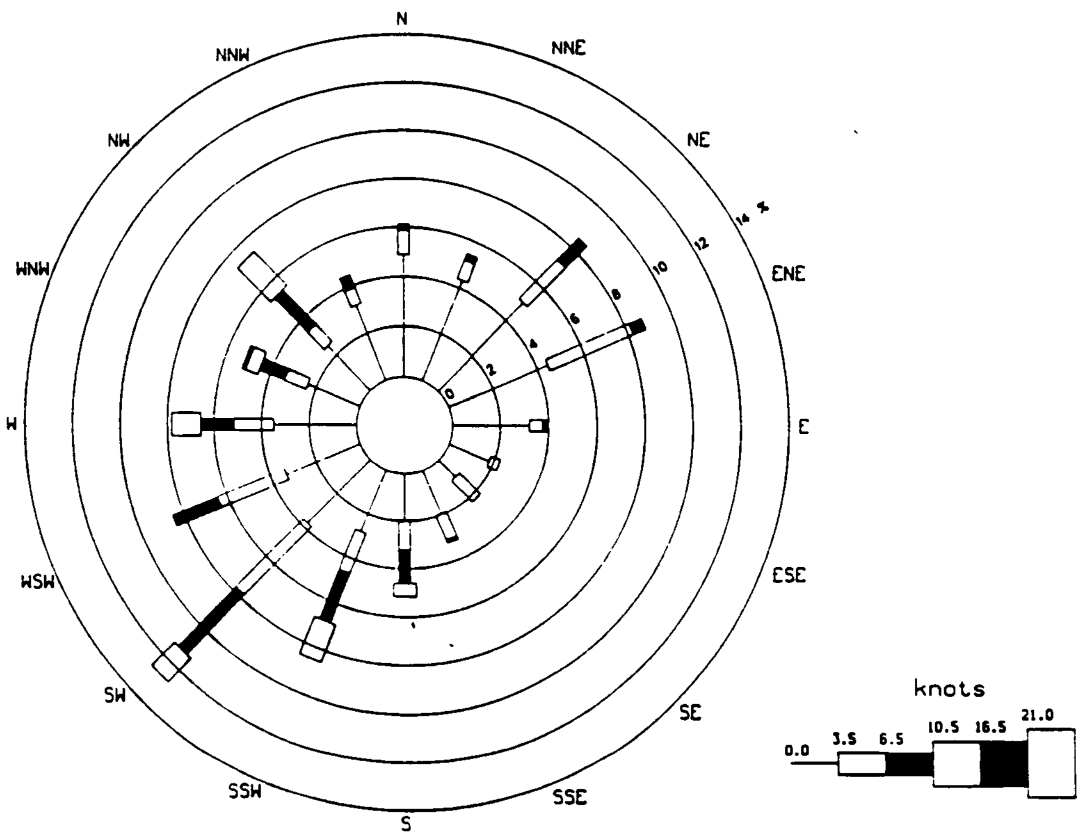


Figure B.1. Continued

WIND ROSE Tower K (@60m) for Nov., 1993

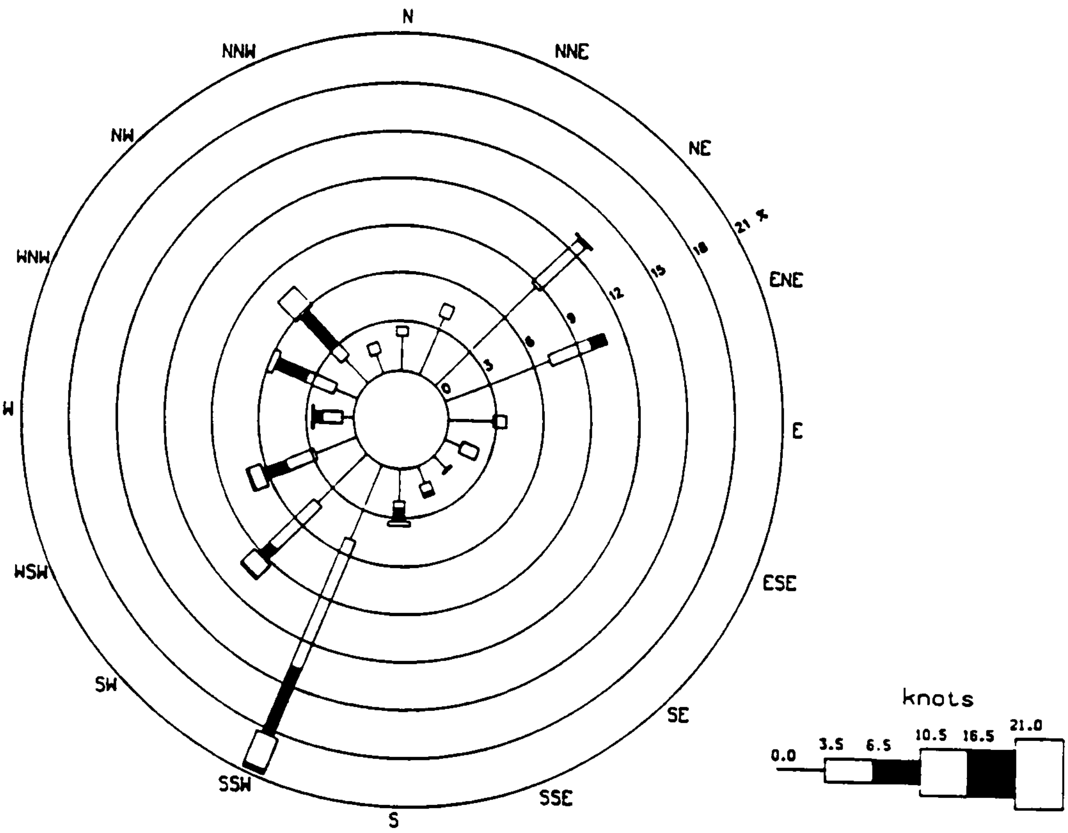


Figure B.1. Continued

WIND ROSE Tower K (@60m) for Dec., 1993

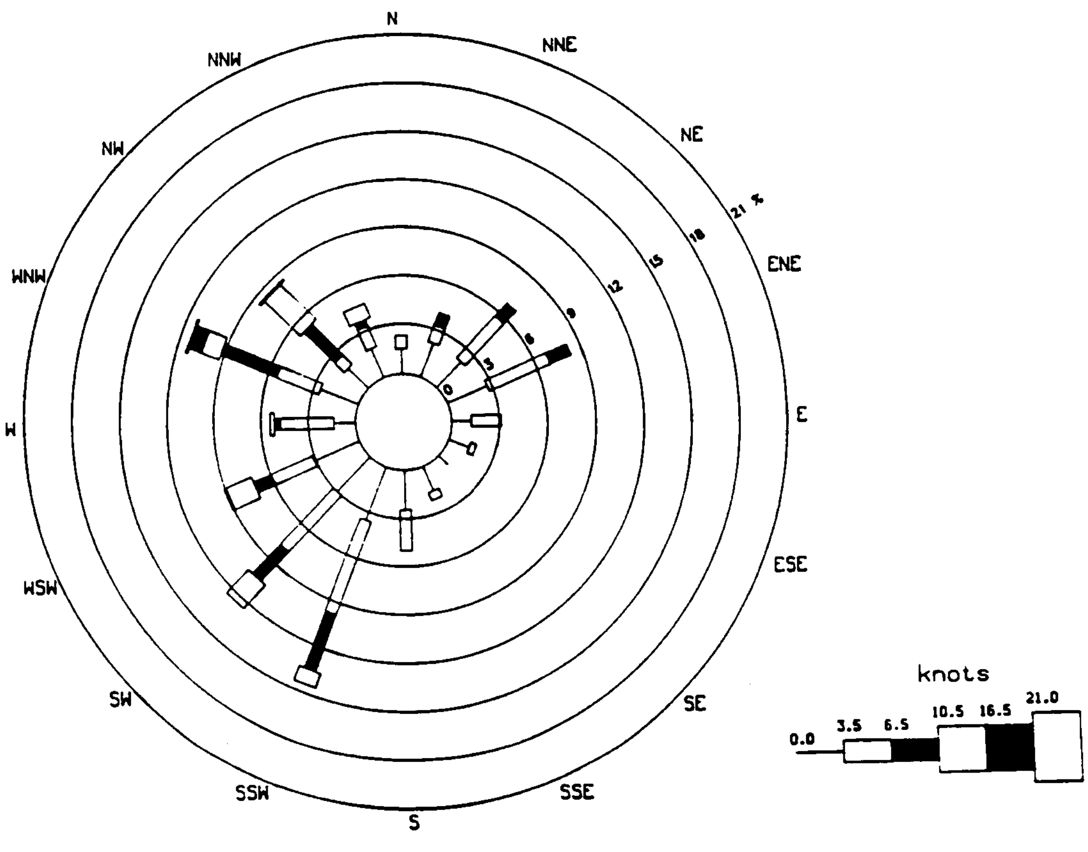


Figure B.1. Continued

WIND ROSE Tower K (@60m) for Jan., 1994

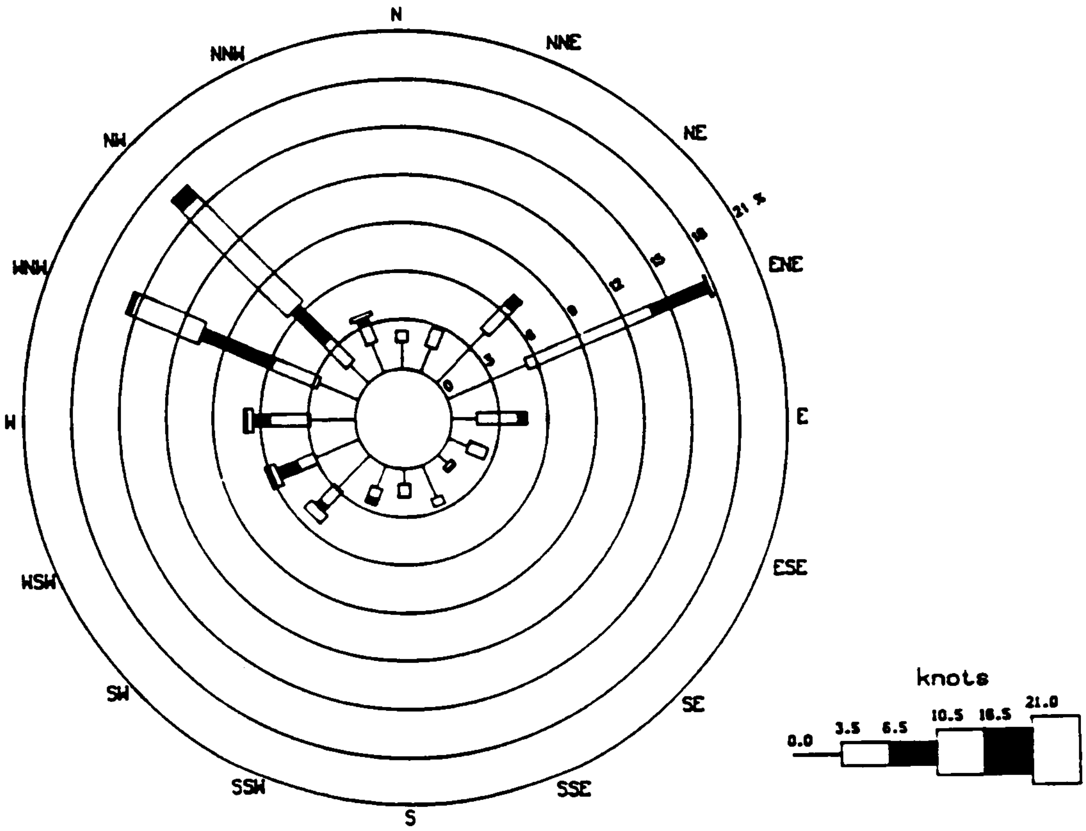


Figure B.1. Continued

WIND ROSE Tower K (@60m) for Feb., 1994

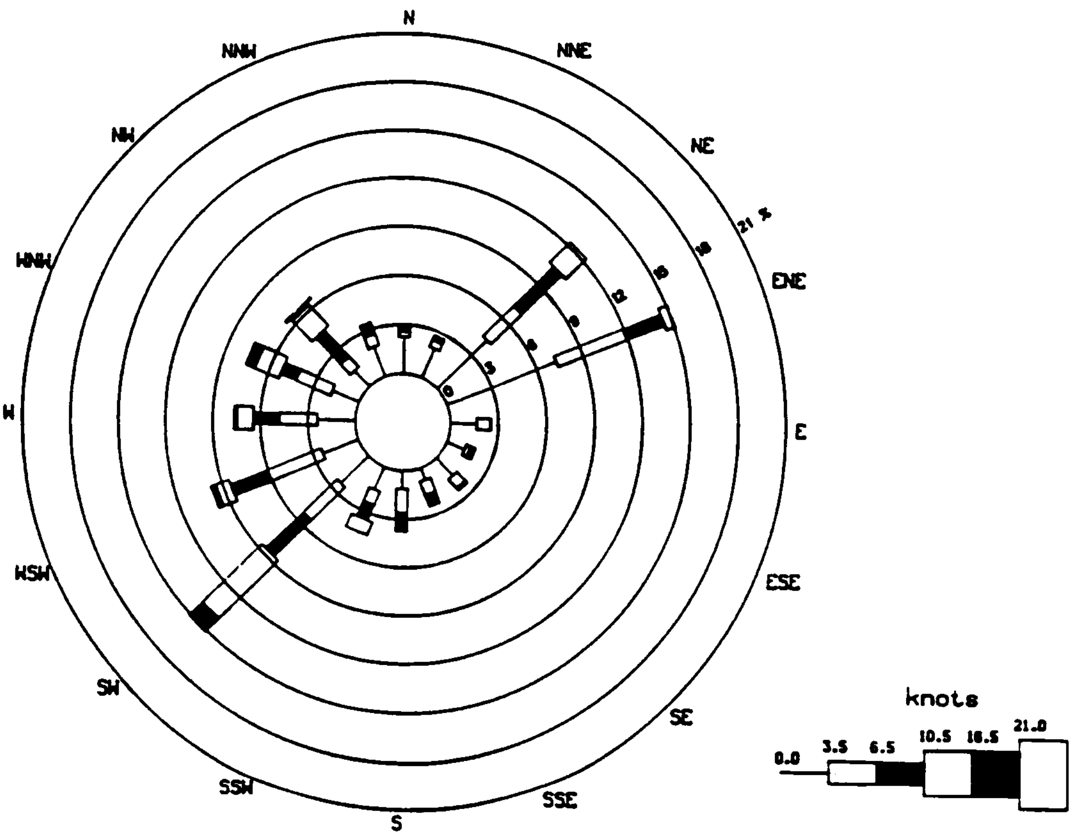


Figure B.1. Continued

WIND ROSE Tower K (@60m) for Mar., 1994

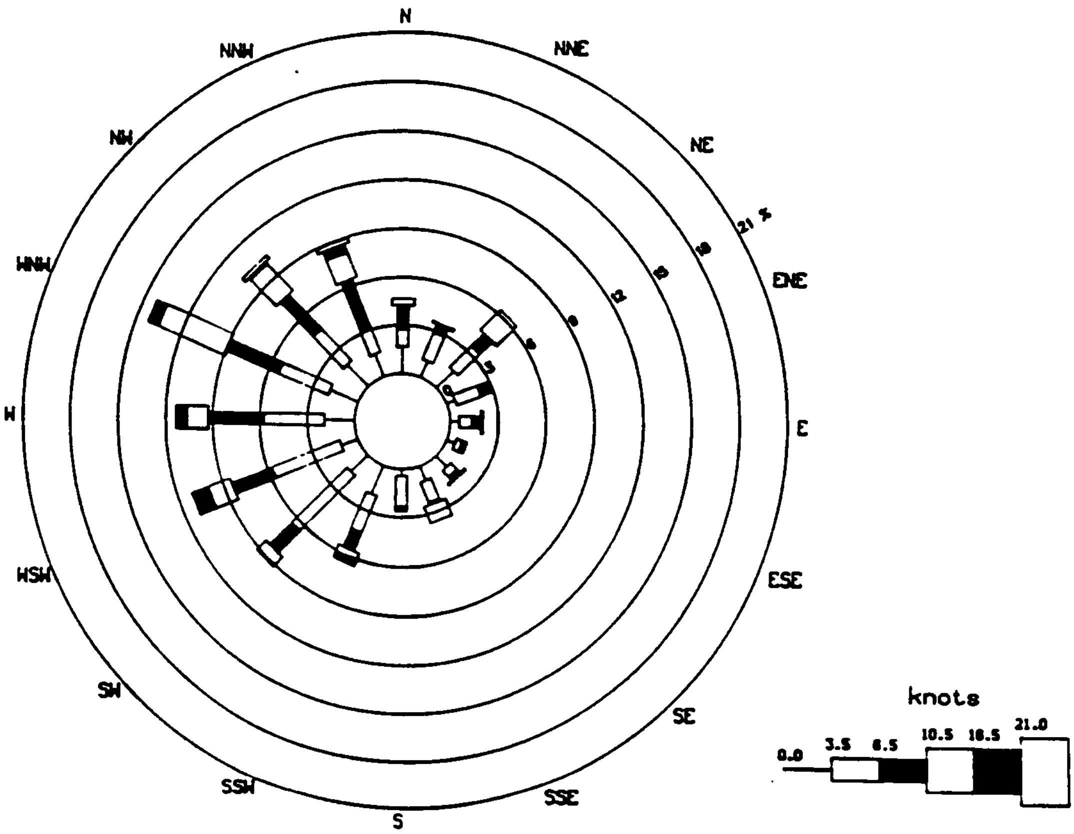


Figure B.1. Continued

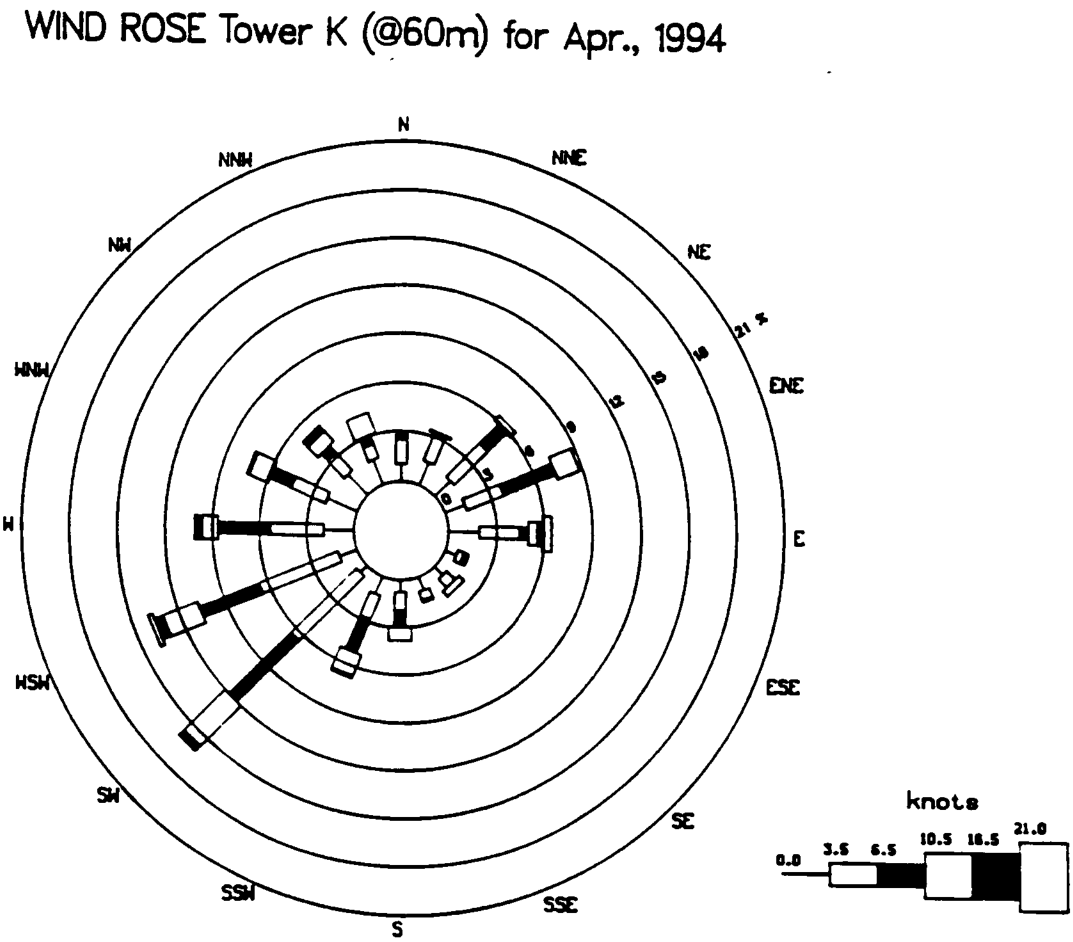


Figure B.1. Continued

WIND ROSE Tower K (@60m) for May, 1994

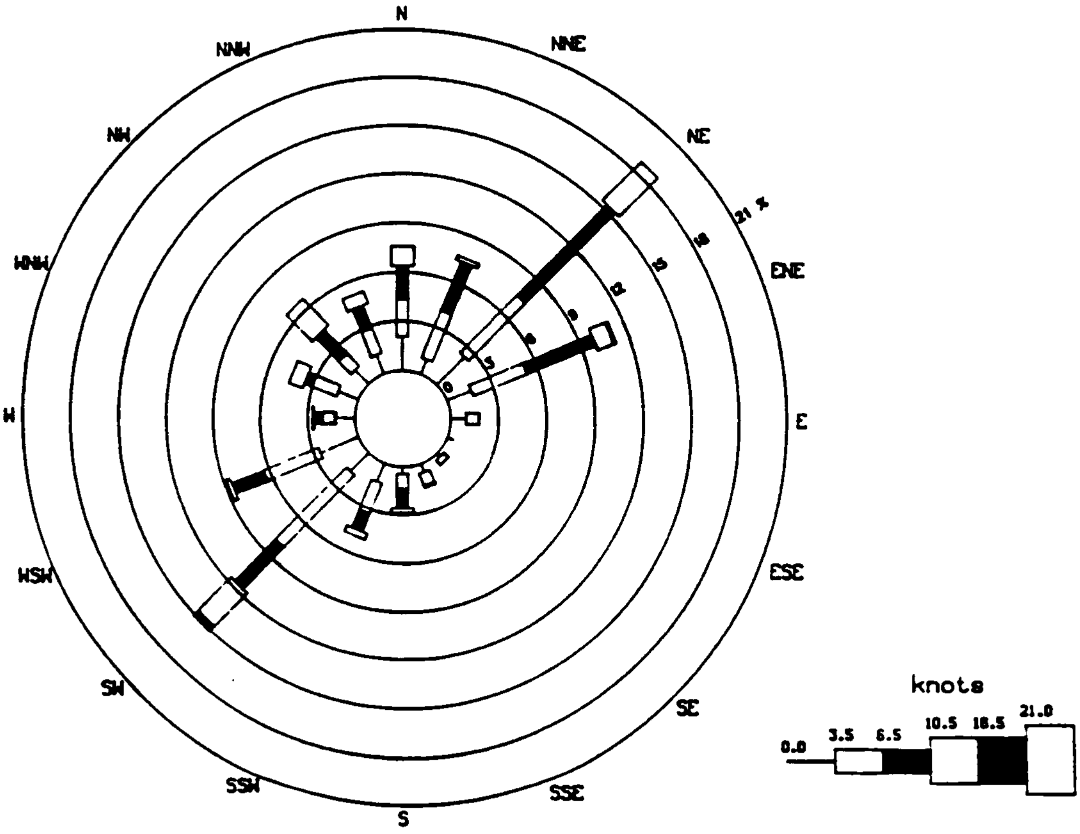


Figure B.1. Continued

WIND ROSE Tower K (@60m) for June, 1994

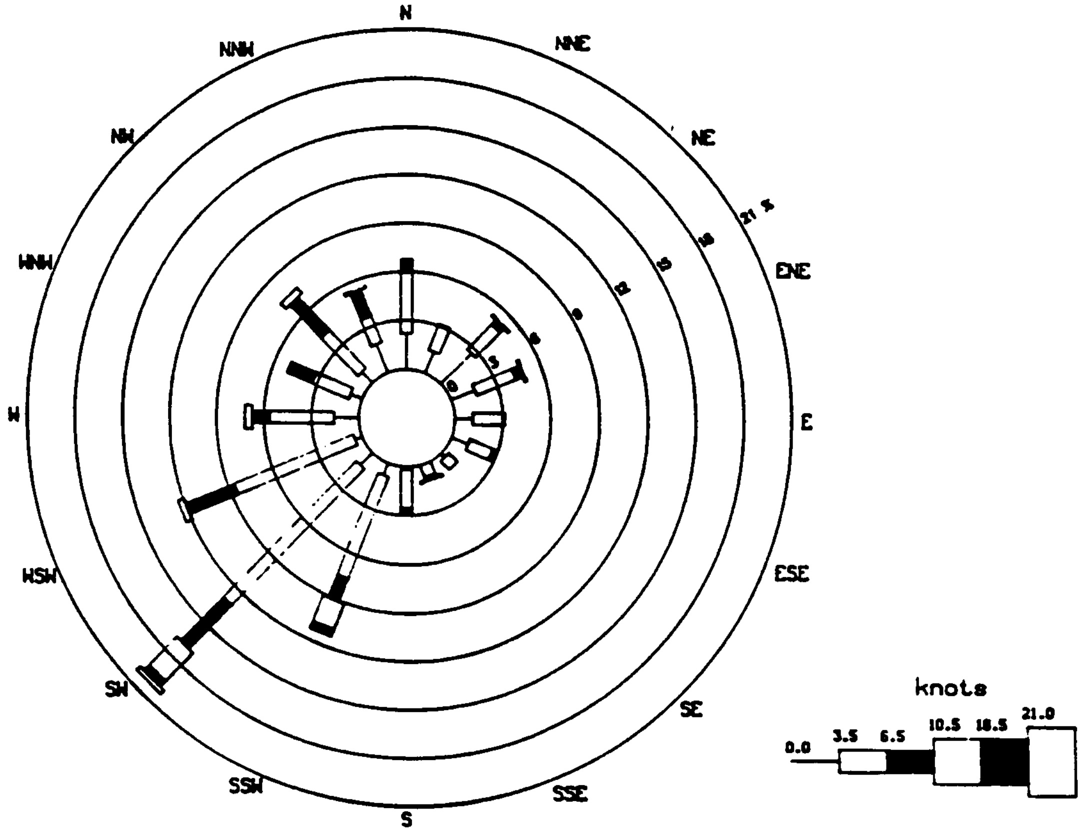


Figure B.1. Continued

WIND ROSE Tower K (@60m) for July, 1994

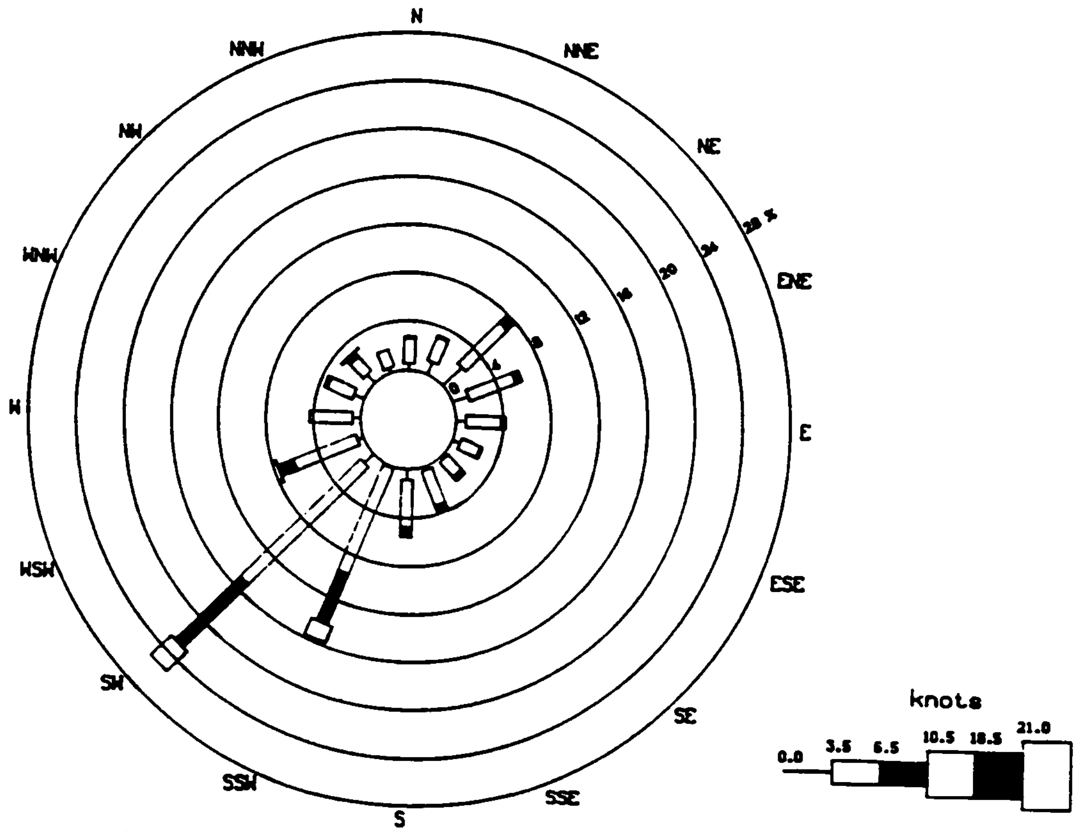


Figure B.1. Continued

WIND ROSE Tower K (@60m) for Aug., 1994

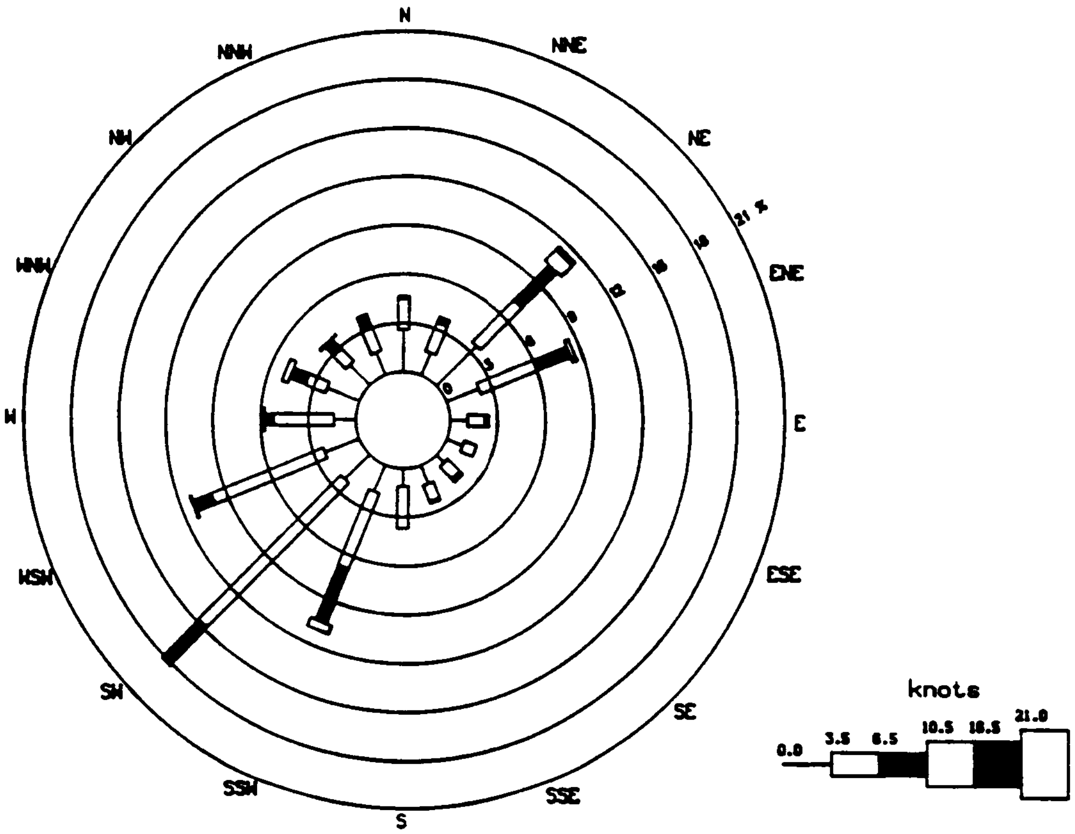


Figure B.1. Continued

APPENDIX C

Results of Concentration Calculations

Table C.1. Radionuclide Concentrations for 1990 (pCi/m^3)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
CE141												
CE144												
CS137					3.583E-08	2.250E-07	1.417E-07	4.083E-07	3.167E-07		5.250E-06	3.750E-07
CO57												
CO60												
NP237							1.000E-08				6.333E-08	6.500E-09
NB95												
PU238											1.583E-08	1.167E-09
PU239											4.500E-10	9.167E-10
K40												
PA234M								9.167E-11	1.417E-09			
RU106												
TC99								6.833E-06				2.750E-05
TH228							1.000E-07				5.167E-09	1.167E-08
TH230											1.000E-08	
TH232												3.083E-10
TH234							7.750E-08	5.917E-06	9.167E-07			2.583E-07
U234			2.500E-10	2.333E-08	2.083E-08	2.917E-07	1.750E-07	7.083E-07	1.083E-06		3.417E-07	3.000E-07
U235			1.250E-11	1.167E-09	1.000E-09	1.667E-08	1.083E-08	4.333E-08	5.500E-08		1.667E-08	1.667E-08
U238			2.417E-10	2.333E-08	2.000E-08	4.500E-07	3.833E-07	1.583E-06	1.083E-06		3.333E-07	4.500E-07

Table C.2. Radionuclide Concentrations for 1991 (pCi/m^3)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
CE141												
CE144												
CS137	2.167E-06	6.500E-09	3.833E-07	3.500E-07	9.167E-07	7.667E-08	2.333E-07	3.750E-08	7.667E-08			
CO57					3.500E-09							
CO60			8.333E-09									
NP237	3.000E-07	6.083E-09	4.583E-08	1.167E-06	7.417E-07	1.250E-09	8.333E-08	2.417E-06	7.167E-07	2.083E-08	1.667E-07	1.583E-07
NB95			7.750E-09									
PU238	2.167E-09	4.167E-09	8.333E-11			1.000E-10			2.417E-09		2.750E-09	1.667E-09
PU239		1.667E-08	2.083E-09	2.500E-07	6.250E-09		5.333E-10		1.417E-08		9.167E-10	7.667E-09
K40												
PA234M	8.333E-10	9.167E-09	6.083E-09	3.167E-09	2.417E-09	5.583E-10	1.000E-09	2.667E-09	6.250E-09		1.417E-09	2.417E-09
RU106												
TC99	3.583E-05			3.667E-05	8.333E-05	7.667E-06	8.250E-05	4.500E-06		5.167E-06	2.917E-05	5.167E-05
TH228	3.000E-08	6.000E-09			4.583E-09	1.833E-09	1.083E-09	2.917E-05	7.167E-10		2.000E-10	9.167E-09
TH230	1.500E-08	5.833E-08	3.250E-08	2.250E-07	7.167E-09	8.250E-09	5.667E-09		6.750E-08	4.417E-09	1.833E-08	4.167E-08
TH232	1.667E-08	7.250E-09	1.167E-08	3.917E-08	4.917E-09	6.167E-10	2.833E-09		2.500E-08	2.083E-09	7.250E-09	2.417E-08
TH234	1.333E-05	8.250E-06	1.333E-05	5.000E-05	2.583E-05	8.083E-07	1.750E-05	5.750E-05	3.750E-05	5.833E-07	2.417E-05	5.583E-05
U234	4.417E-06	3.250E-06	9.167E-06	2.167E-05	1.417E-05	1.167E-06	1.333E-06	1.000E-06	5.583E-06	9.167E-07	2.833E-06	1.417E-06
U235	2.000E-07	2.000E-07	4.500E-07	1.000E-06	6.583E-07	5.250E-08	6.250E-08	5.500E-08	2.333E-07	4.083E-08	1.667E-07	7.500E-08
U238	4.333E-06	9.167E-06	1.167E-05	2.333E-05	1.500E-05	1.083E-06	1.583E-06	2.000E-06	9.167E-06	9.167E-07	6.750E-06	2.500E-06

Table C.3. Radionuclide Concentrations for 1992 (pCi/m^3)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
CE141												
CE144									1.250E-08			
CS137			3.583E-07				2.250E-07	3.500E-07		5.000E-08		3.500E-08
CO57												
CO60												
NP237	7.500E-09	1.917E-08		9.167E-08		1.083E-07	1.083E-07	2.250E-07	3.000E-08	7.083E-09		3.500E-09
NB95												
PU238	4.000E-09	1.667E-08		2.167E-09	1.083E-07	1.417E-08	1.667E-09					
PU239	1.417E-09	1.167E-08	6.333E-09		1.417E-09	2.000E-08		2.500E-09	2.250E-09			4.917E-10
K40									1.083E-05			
PA234M	3.500E-08	7.917E-09	3.333E-09	2.250E-09	4.667E-10	2.833E-09	1.083E-14	2.333E-09	5.333E-09	1.417E-09		2.250E-09
RU106										5.000E-06		
TC99	1.917E-05	6.167E-05	2.417E-05	4.250E-07	9.167E-07	8.333E-06				1.083E-05		6.000E-05
TH228	1.583E-08		1.083E-07	5.500E-09	9.167E-06		7.750E-09			5.333E-10		4.250E-09
TH230	5.667E-09	5.750E-08	7.167E-08	1.000E-08	6.333E-09	9.167E-09	2.917E-08	1.750E-07	1.667E-08	6.750E-08		
TH232	5.833E-09	9.167E-08	1.000E-07	8.333E-09	1.250E-09		1.000E-08	6.750E-08	7.917E-09	5.167E-10		
TH234			6.500E-07	6.667E-06						2.083E-05		
U234	4.583E-06	3.500E-06	2.250E-06	7.167E-07	1.833E-06	8.000E-08	5.167E-07	3.833E-06				
U235	1.750E-07	1.333E-07	8.333E-08	3.167E-08	8.333E-08	3.500E-09	2.333E-08	1.750E-07				
U238	7.667E-06	5.917E-06	3.417E-06	7.583E-07	2.000E-06	9.167E-08	5.500E-07	4.167E-06				

Table C.4. Radionuclide Concentrations for 1993 (pCi/m^3)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
CE141	1.583E-06	7.583E-08					2.083E-08					
CE144												
CS137	1.083E-07	3.833E-07	3.500E-05		1.583E-07	7.167E-07	2.917E-08		4.167E-07		2.417E-06	2.750E-07
CO57			9.167E-07									
CO60			3.500E-05									
NP237	8.333E-09	1.000E-07	5.667E-08	9.167E-09	1.667E-07	1.750E-08	2.917E-08				1.417E-07	2.250E-06
NB95												
PU238	5.833E-09			4.750E-07	4.833E-09	1.250E-08		1.167E-09	1.667E-08			3.417E-08
PU239						1.167E-10	2.250E-09	2.500E-10			1.750E-09	5.083E-08
K40	2.500E-05	6.917E-09	2.833E-04			9.167E-06			4.750E-07			
PA234M	4.167E-09		1.417E-09	1.500E-09	7.750E-10		1.167E-09	3.333E-09	3.333E-09		7.167E-10	5.667E-10
RU106			3.500E-05	9.167E-08	4.833E-08						1.000E-07	
TC99	6.917E-05	8.333E-05	2.750E-04	1.917E-06	4.000E-05	2.083E-05	4.167E-05	4.417E-04			4.333E-05	
TH228	1.083E-08	1.667E-08	3.417E-07	2.417E-08			7.917E-09		1.000E-09		3.000E-06	1.000E-07
TH230	5.583E-09	9.167E-09	1.083E-07		1.167E-08	1.333E-08	2.750E-08	1.417E-08	1.333E-10			1.500E-07
TH232	7.250E-07			1.333E-09	2.833E-08	1.667E-08	2.583E-08	1.750E-08				3.750E-08
TH234		7.750E-06	4.583E-05	8.083E-06	2.000E-06	1.500E-05	7.583E-07	4.167E-05	3.583E-05		4.833E-06	4.917E-07
U234		3.083E-06	3.250E-06		2.250E-06	9.167E-07	1.250E-06	5.500E-07	1.083E-06		1.083E-05	1.667E-06
U235		1.333E-07	1.417E-07		9.167E-08	4.167E-08	5.583E-08	2.583E-08	5.167E-08		4.667E-07	7.750E-08
U238		3.583E-06	3.583E-06		3.083E-06	7.333E-07	1.167E-06	4.500E-07	1.000E-06		1.167E-05	1.500E-06

Table C.5. Radionuclide Concentrations for 1994 (pCi/m^3)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
CE141												
CE144												
CS137	1.583E-06		3.333E-07		3.667E-07							
CO57												
CO60						4.750E-07						
H3				1.500E-04	3.167E-04							
NP237	9.167E-08	3.417E-06	2.083E-09	2.167E-07	1.417E-07		1.333E-07	1.250E-07				
NB95												
PU238			1.583E-09		1.417E-07		6.083E-09					
PU239								5.333E-08				
K40				7.667E-08	8.250E-08		7.000E-08					
PA234M		1.833E-09	6.667E-10	1.583E-09	9.167E-09		1.500E-09	1.167E-08				
RU106												
TC99			1.667E-06	1.583E-04	1.333E-04	2.250E-06	4.583E-05	2.917E-05				
TH228	5.917E-08					1.167E-07		1.833E-09				
TH230	8.333E-09		3.167E-09	7.083E-07		1.833E-07	2.250E-07	1.000E-06				
TH232		7.167E-09		2.083E-07								
TH234	5.167E-05	4.250E-06		6.333E-07	2.000E-06	4.250E-07	8.333E-06	1.333E-05				
U234	1.667E-06	2.500E-06	3.083E-07	1.750E-07	1.917E-07	4.750E-07	6.917E-08	7.500E-07				
U235	7.583E-08	1.083E-07	1.417E-08	7.250E-09	9.167E-09	2.250E-08	3.250E-09	3.750E-08				
U238	1.667E-06	2.917E-06	2.750E-07	2.250E-07	1.500E-07	3.667E-07	5.750E-08	4.250E-07				

APPENDIX D

Normal, Lognormal, and Log-Log Plots

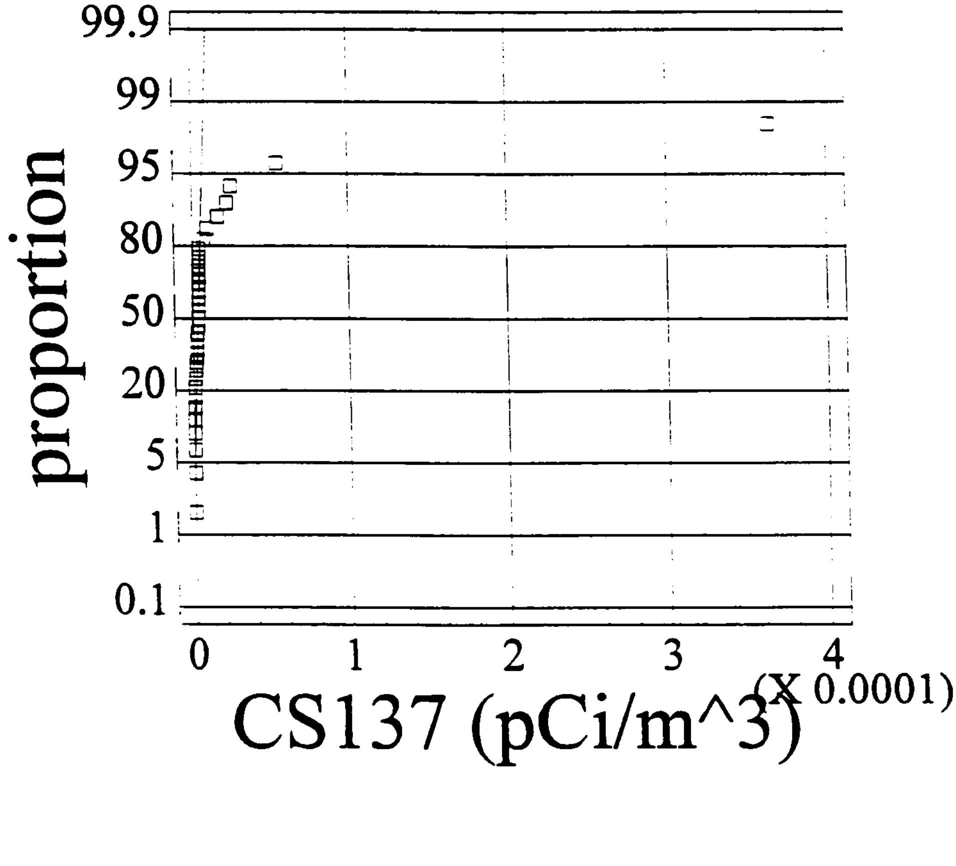


Figure D.1. Normal Probability Plot for Cs-137

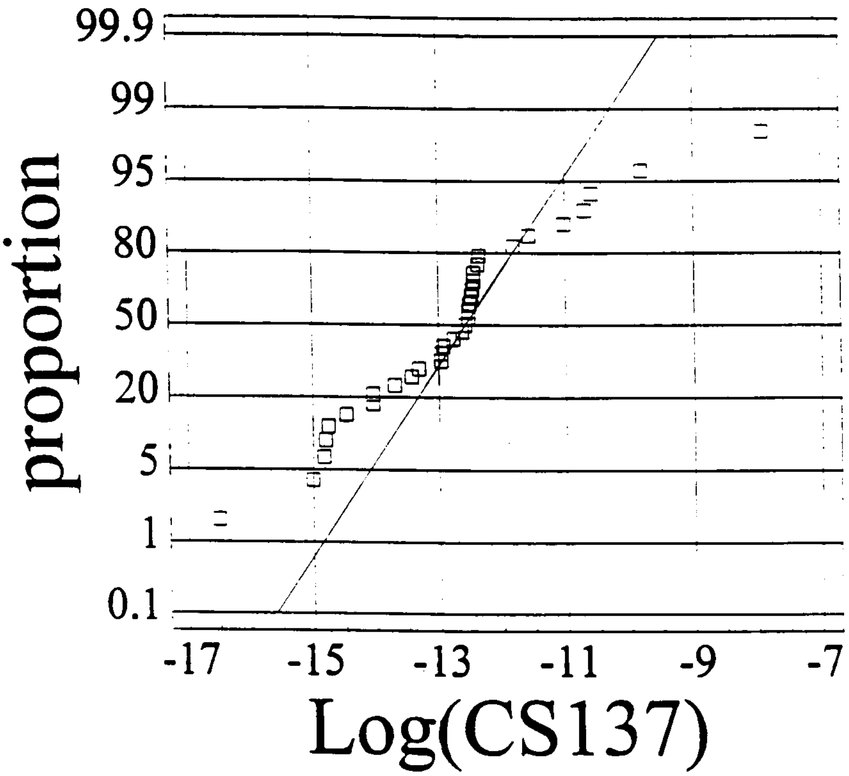


Figure D.2. Lognormal Probability Plot for Cs-137

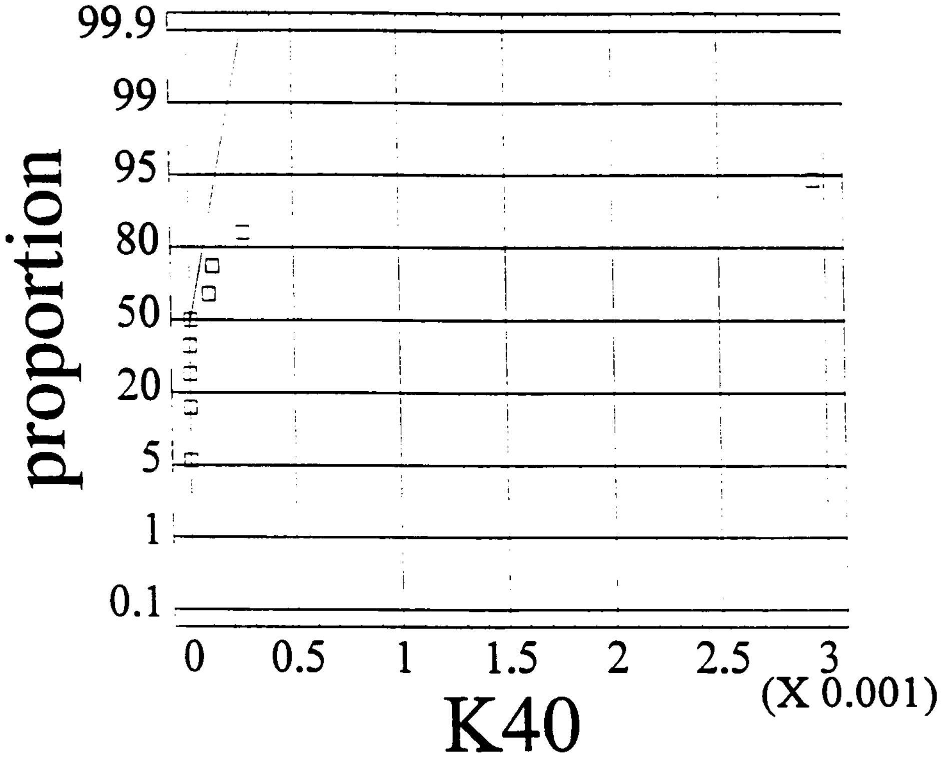


Figure D.3. Normal Probability Plot for K-40

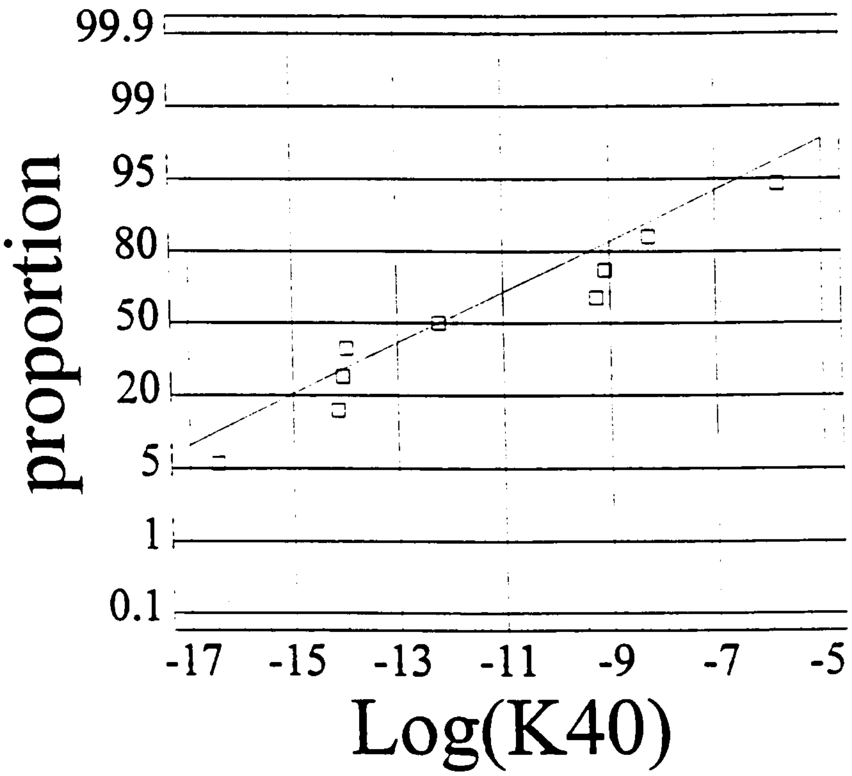


Figure D.4. Lognormal Probability Plot for K-40

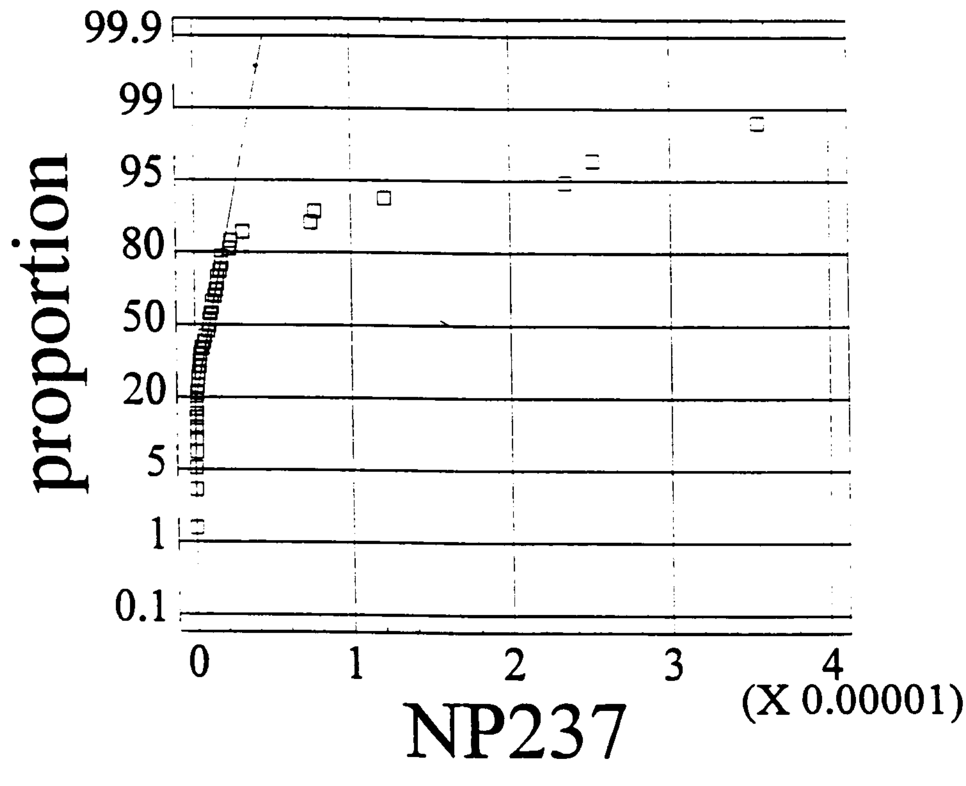


Figure D.5. Normal Probability Plot for Np-237

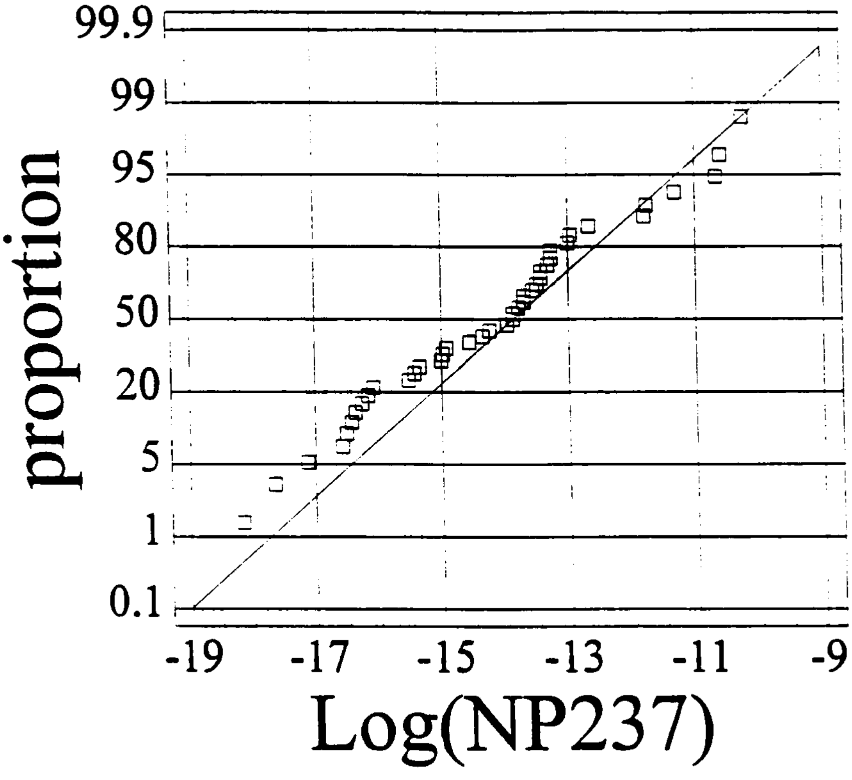


Figure D.6. Lognormal Probability Plot for Np-237

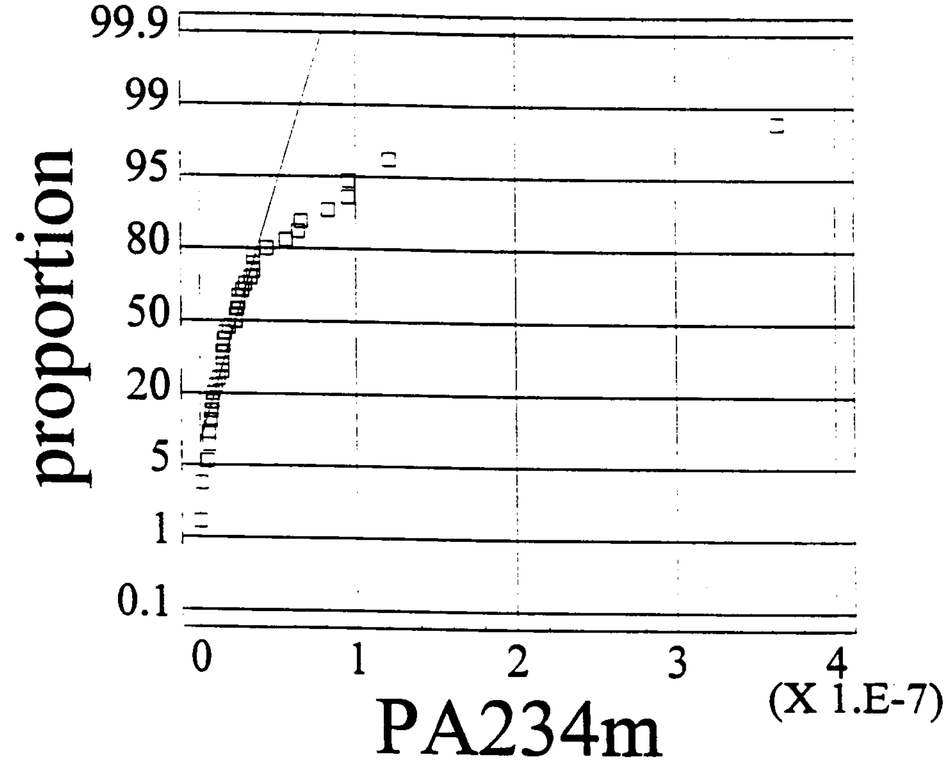


Figure D.7. Normal Probability Plot for Pa-234m

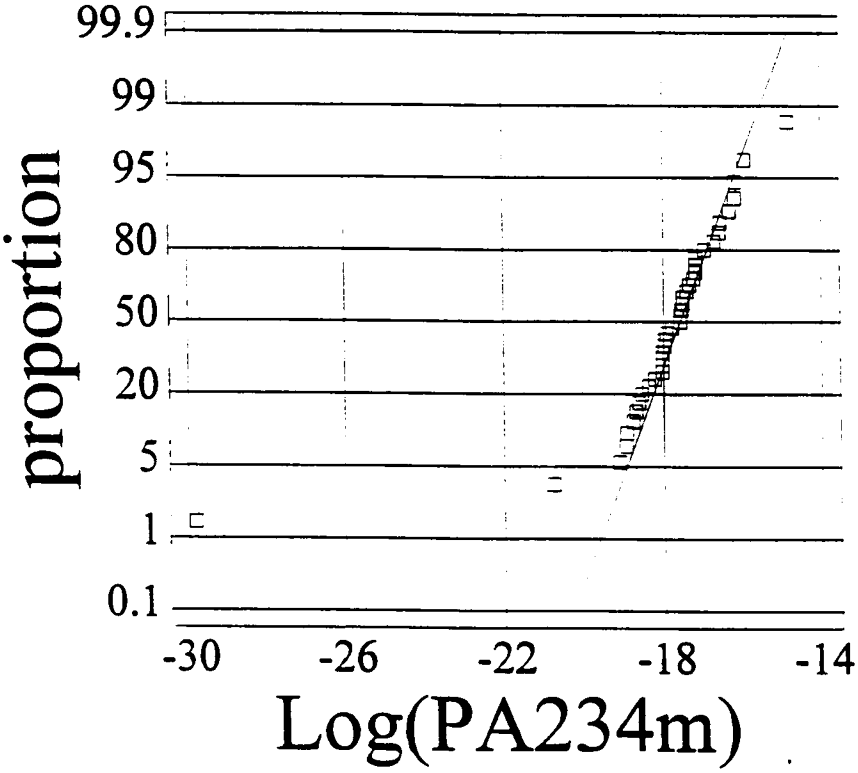


Figure D.8. Lognormal Probability Plot for Pa-234m

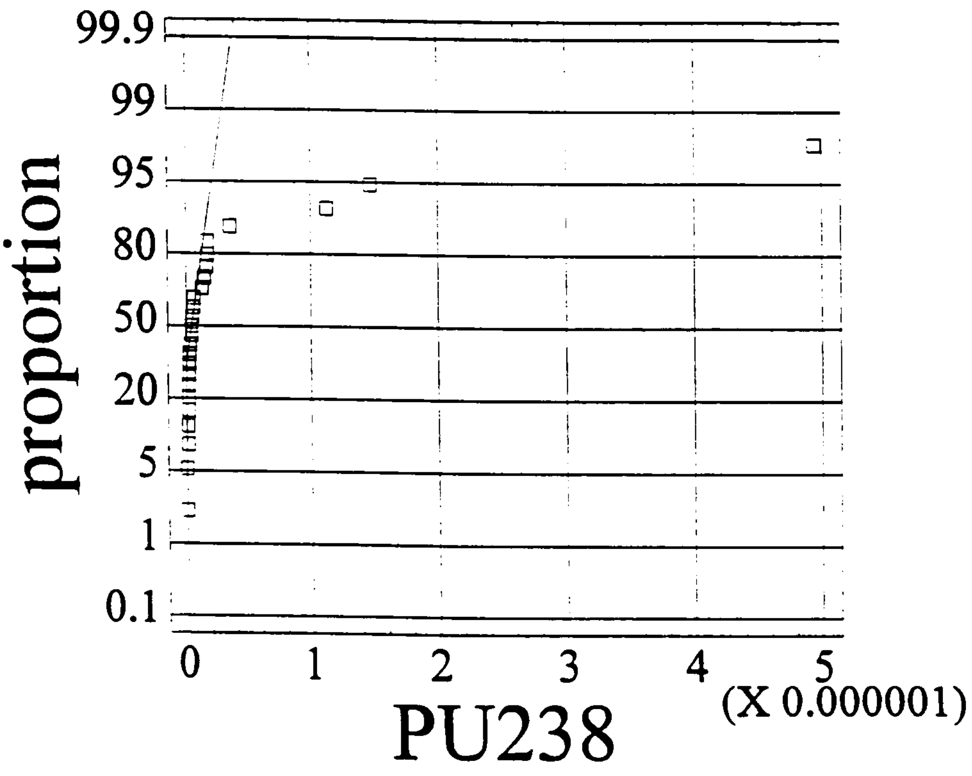


Figure D.9. Normal Probability Plot for Pu-238

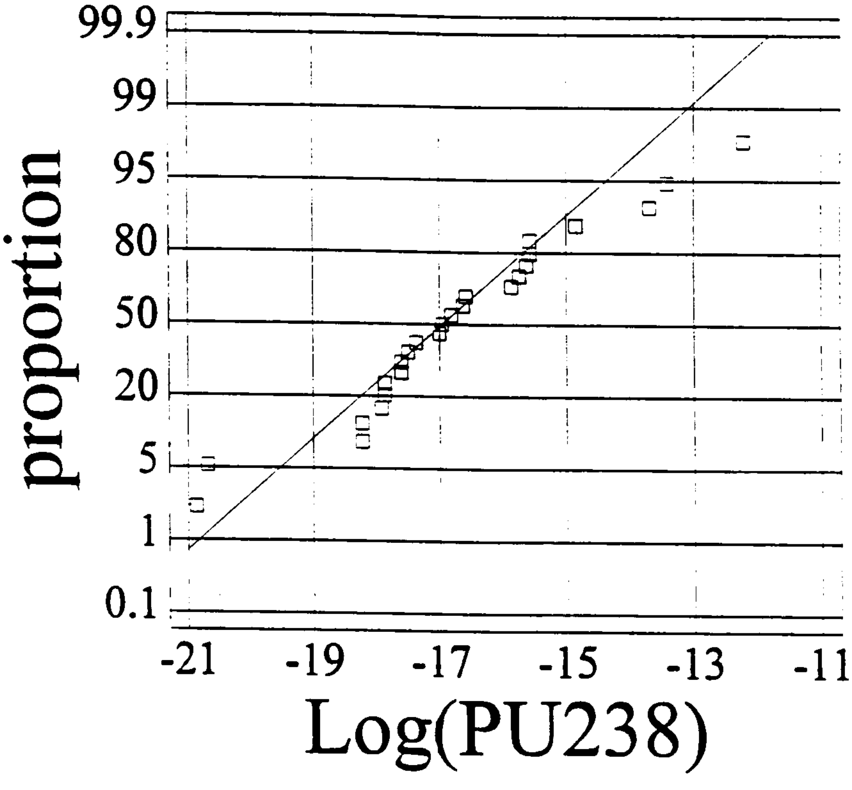


Figure D.10. Lognormal Probability Plot for Pu-238

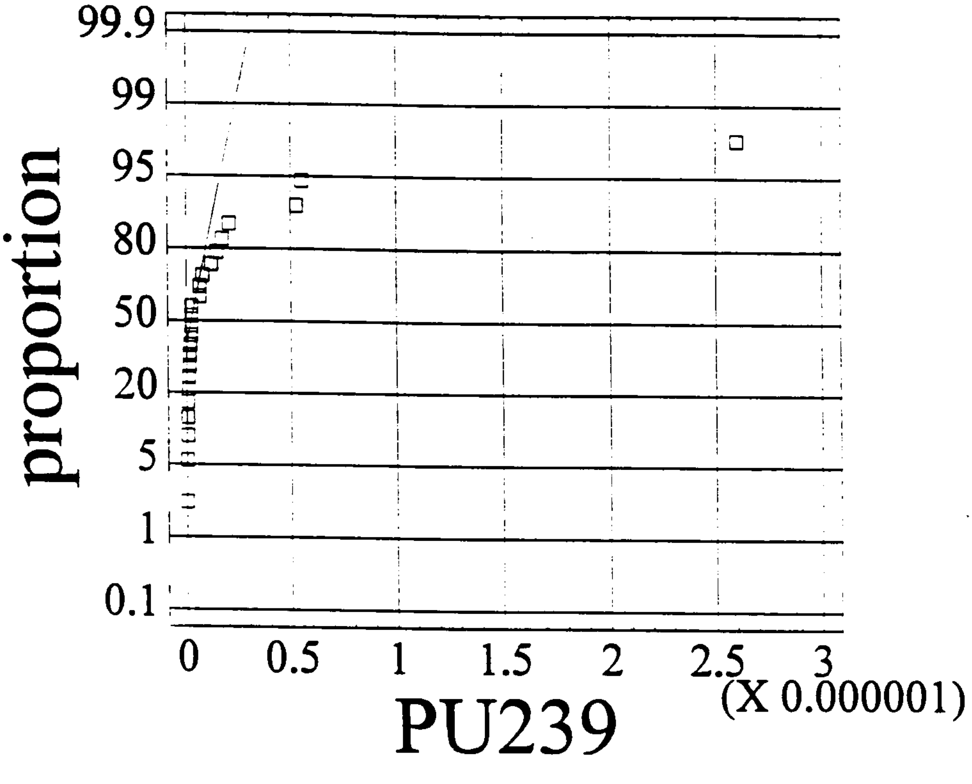


Figure D.11. Normal Probability Plot for Pu-239

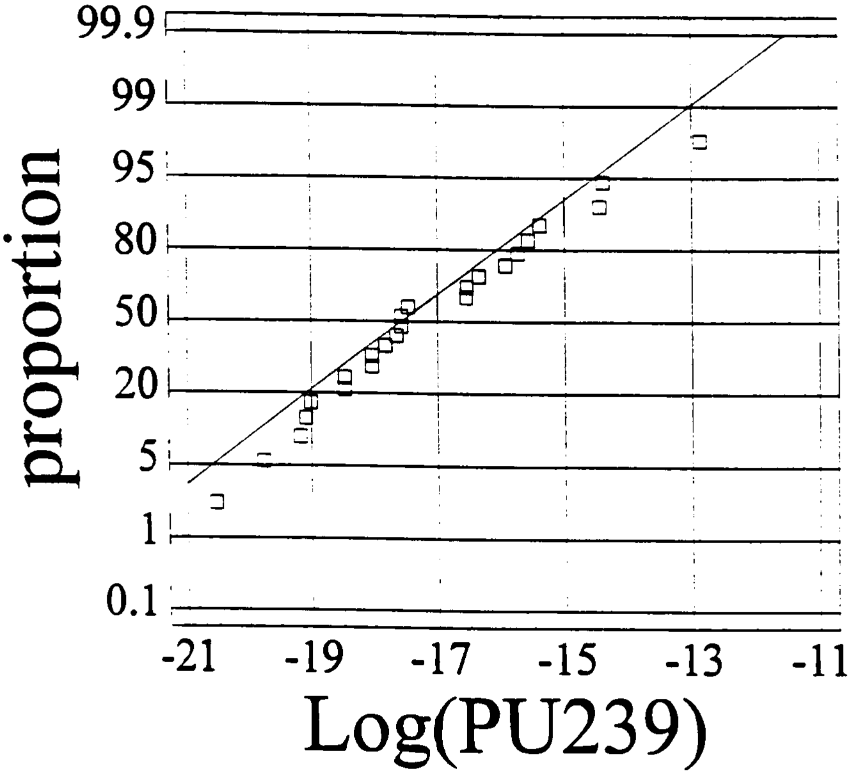


Figure D.12. Lognormal Probability Plot for Pu-239

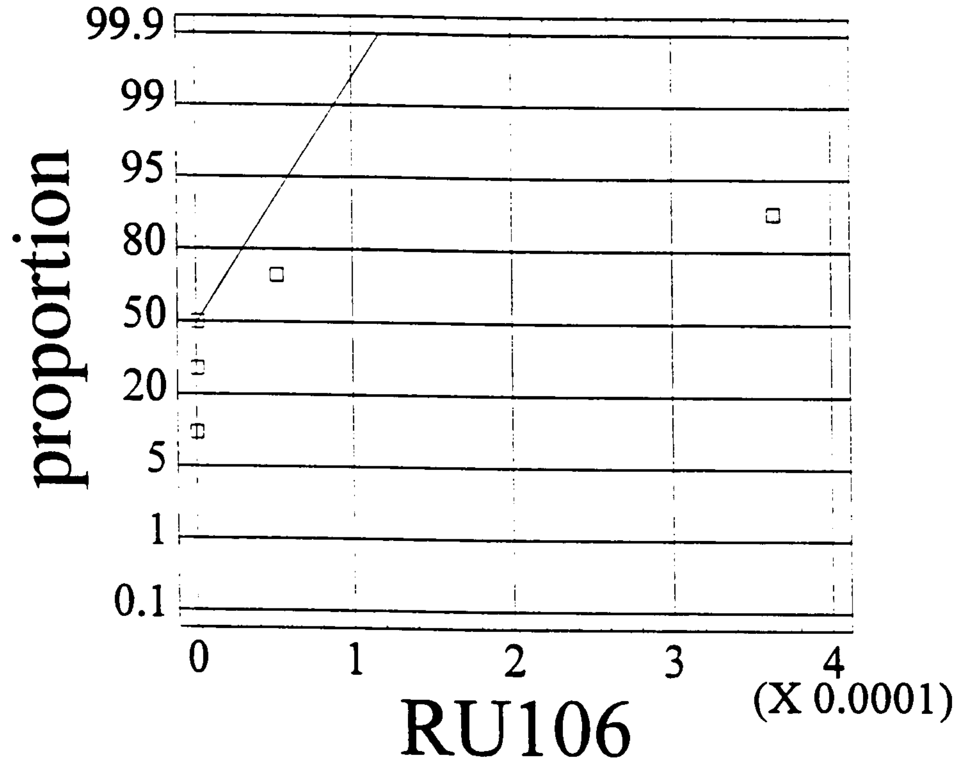


Figure D.13. Normal Probability Plot for Ru-106

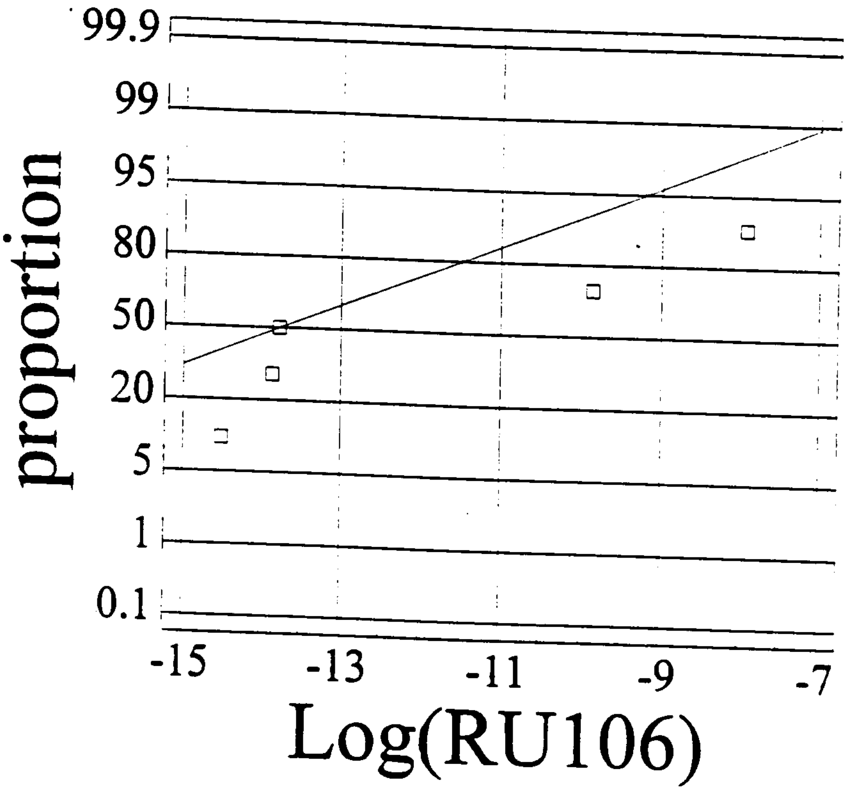


Figure D.14. Lognormal Probability Plot for Ru-106

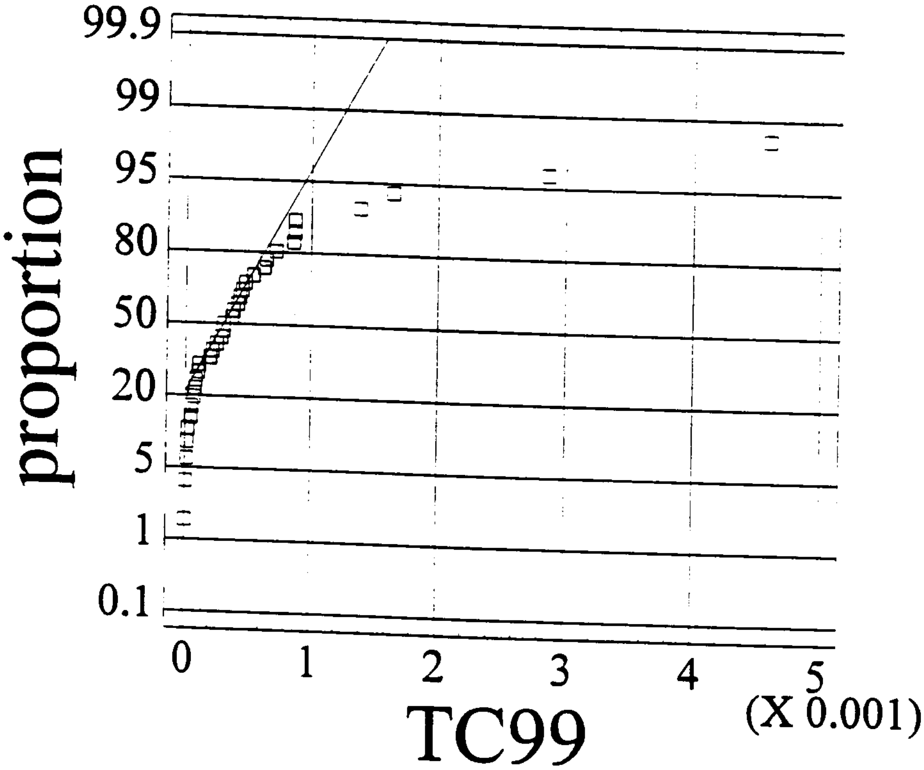


Figure D.15. Normal Probability Plot for Tc-99

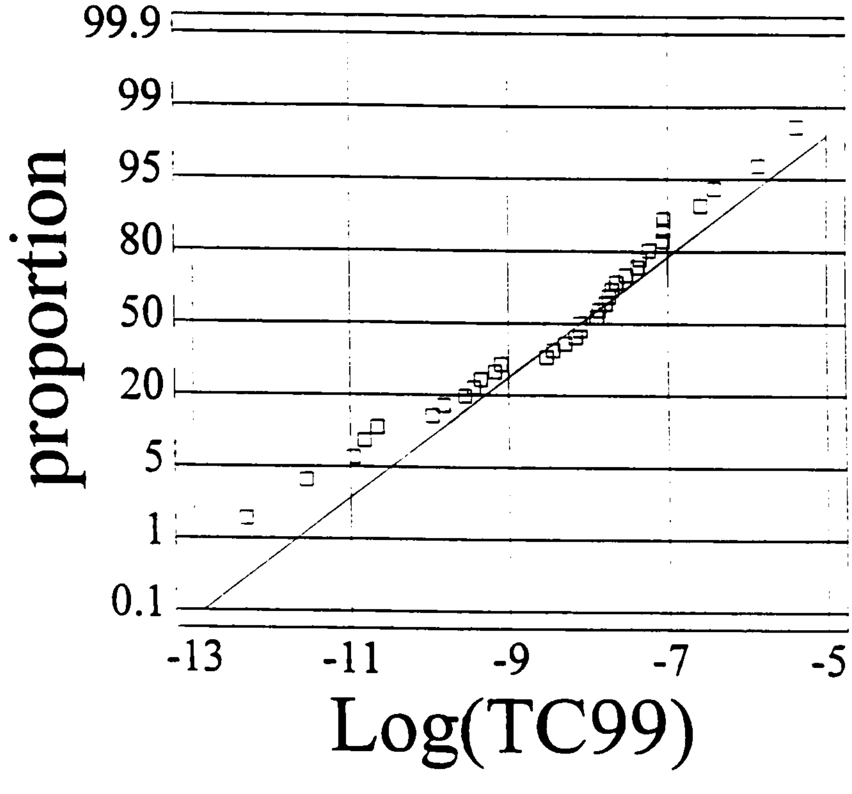


Figure D.16. Lognormal Probability Plot for Tc-99

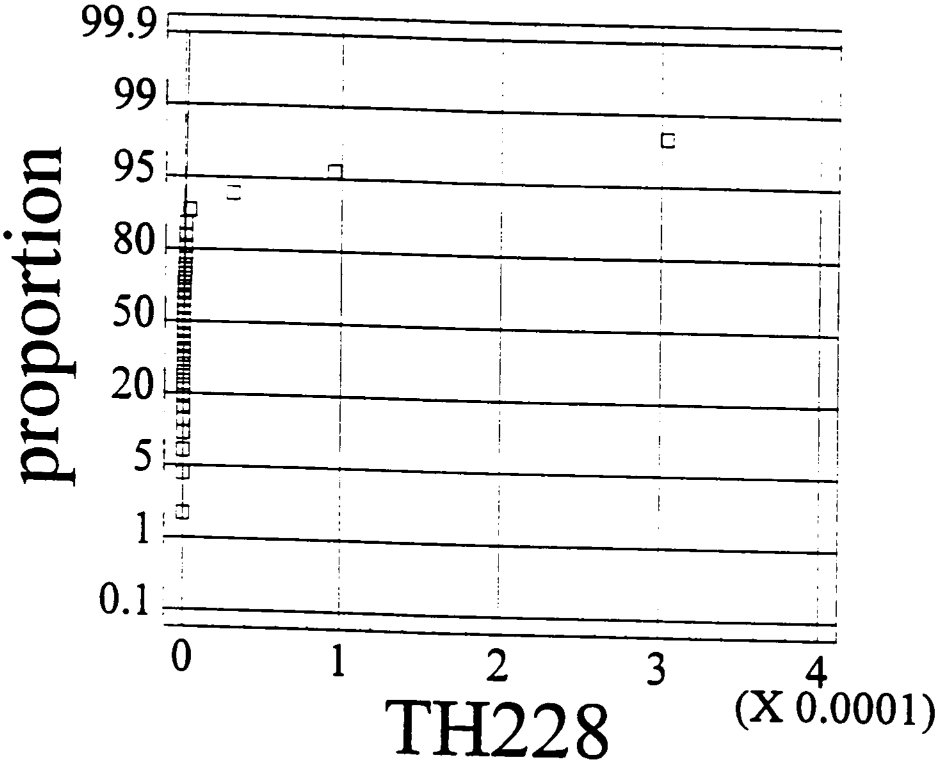


Figure D.17. Normal Probability Plot for Th-228

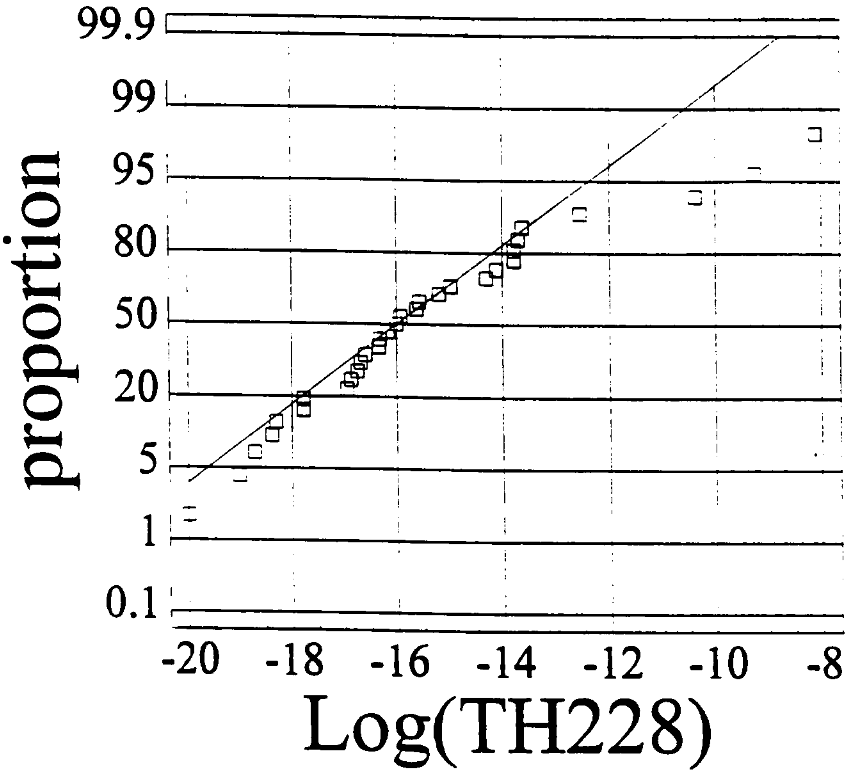


Figure D.18. Lognormal Probability Plot for Th-228

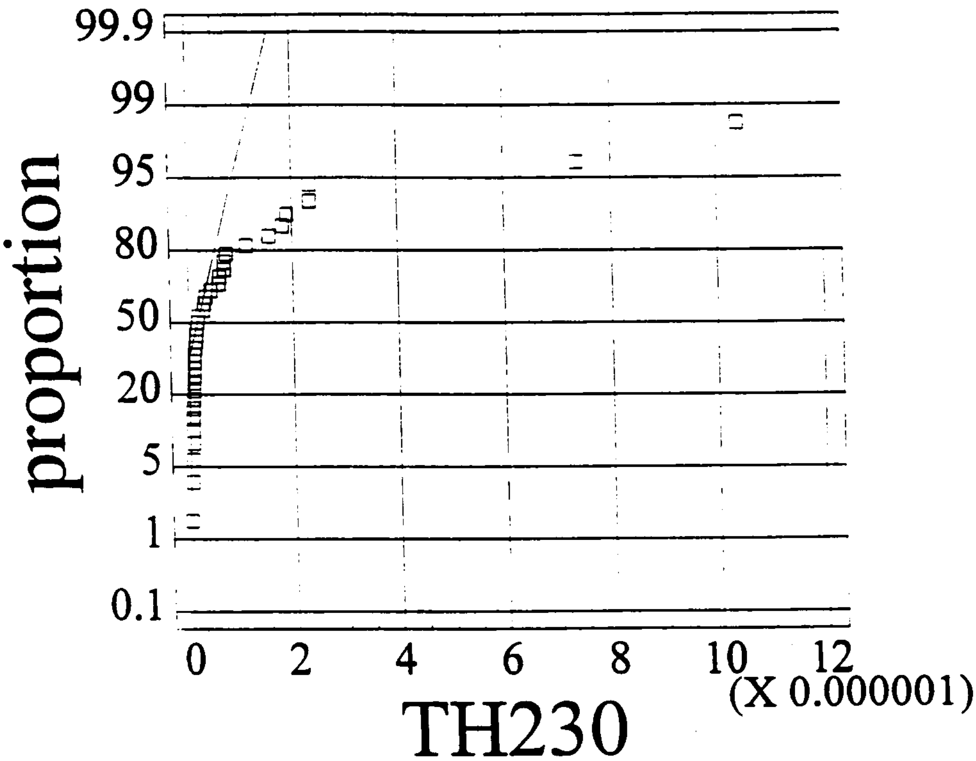


Figure D.19. Normal Probability Plot for Th-230

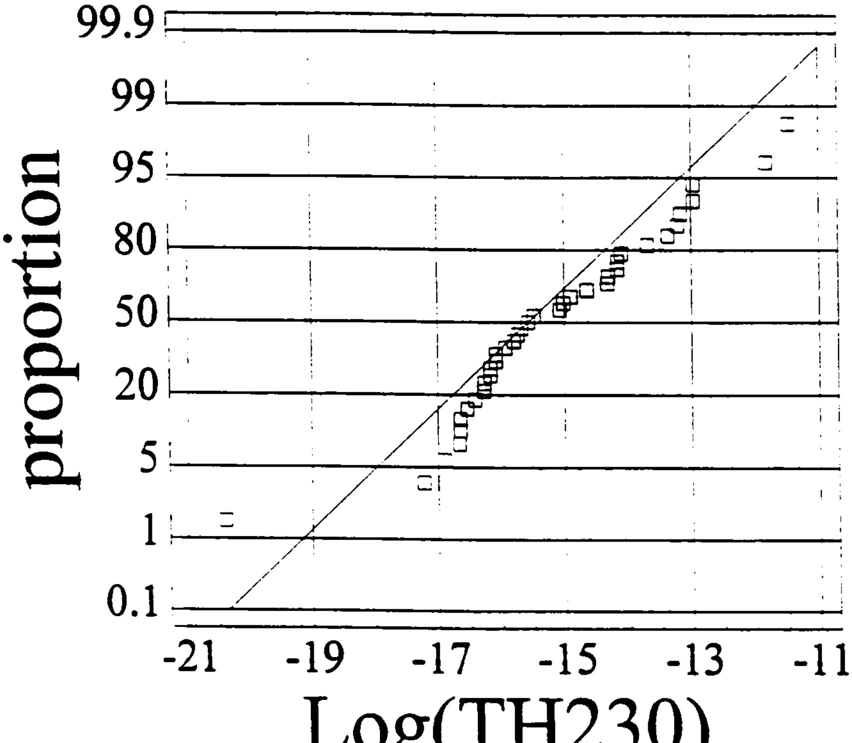


Figure D.20. Lognormal Probability Plot for Th-230

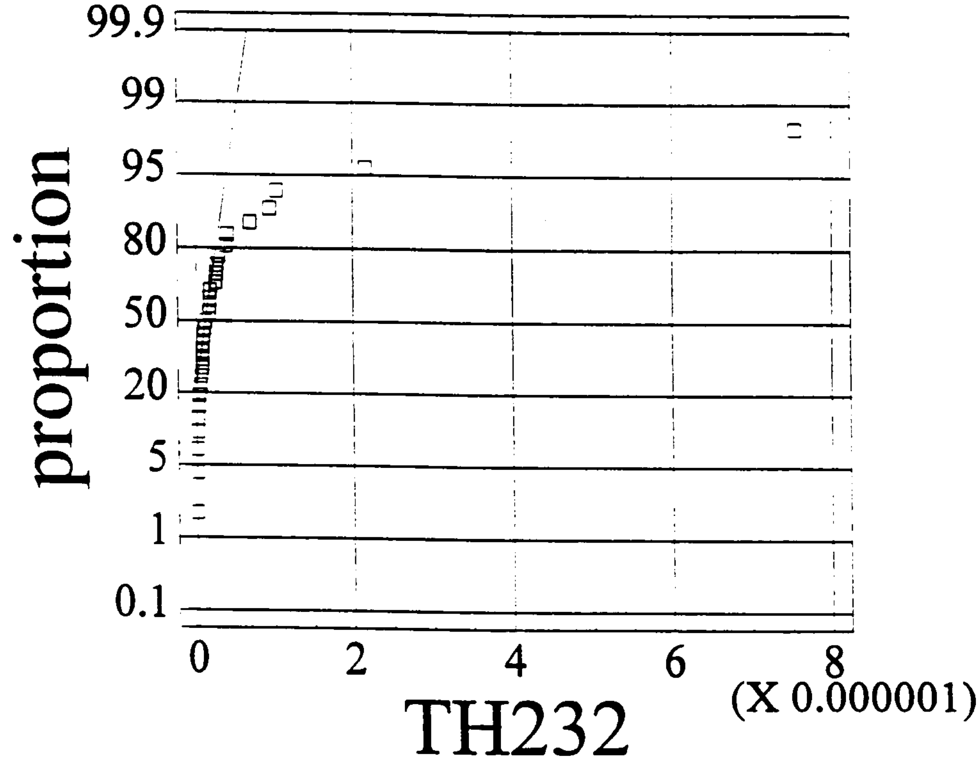


Figure D.21. Normal Probability Plot for Th-232

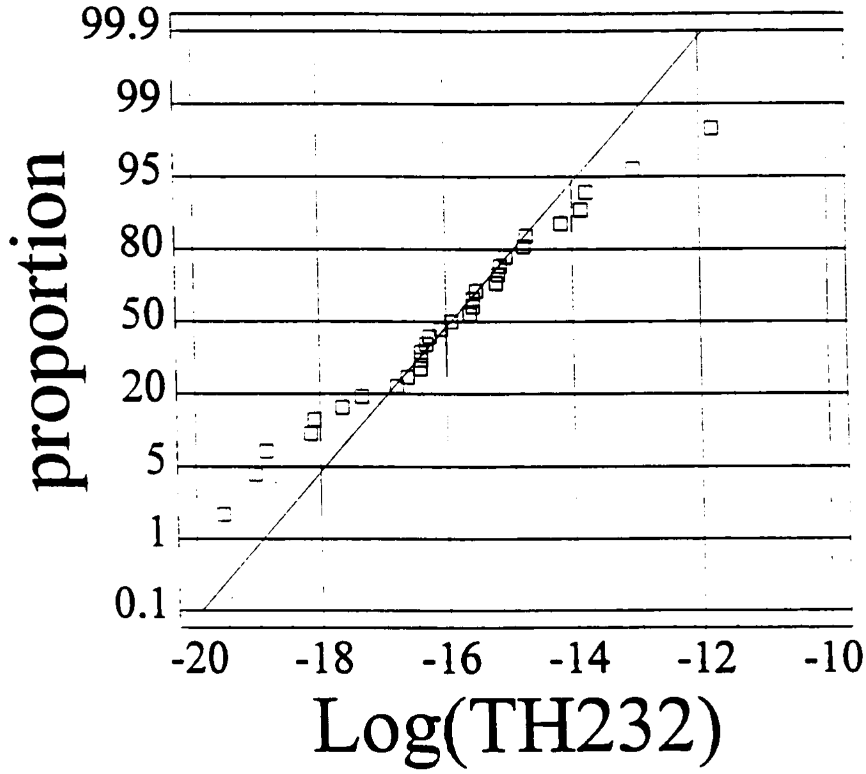


Figure D.22. Lognormal Probability Plot for Th-232

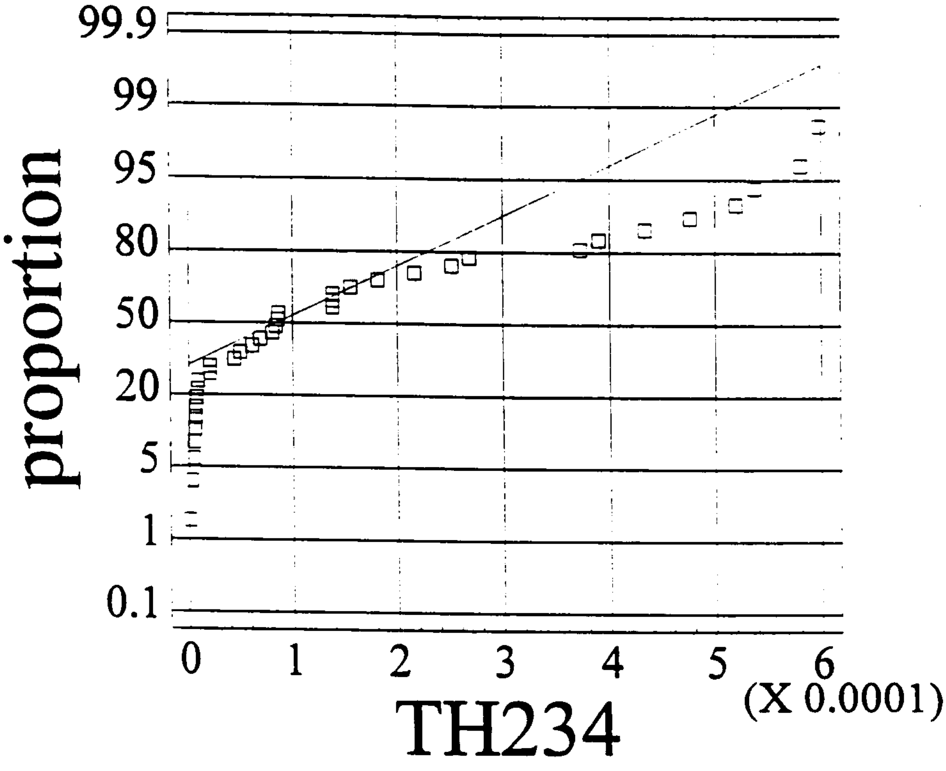


Figure D.23. Normal Probability Plot for Th-234

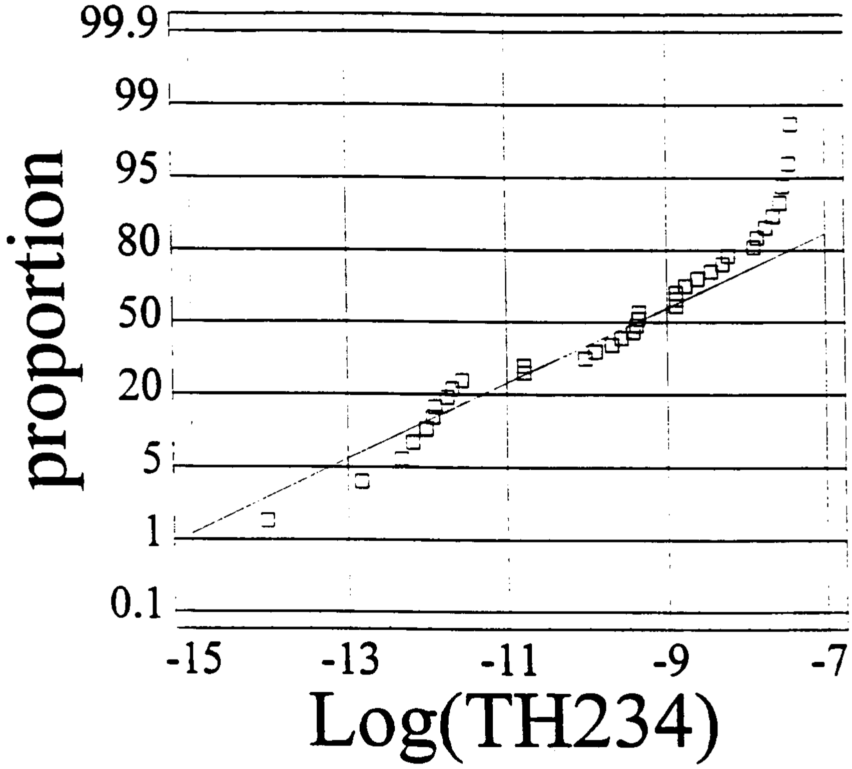


Figure D.24. Lognormal Probability Plot for Th-234

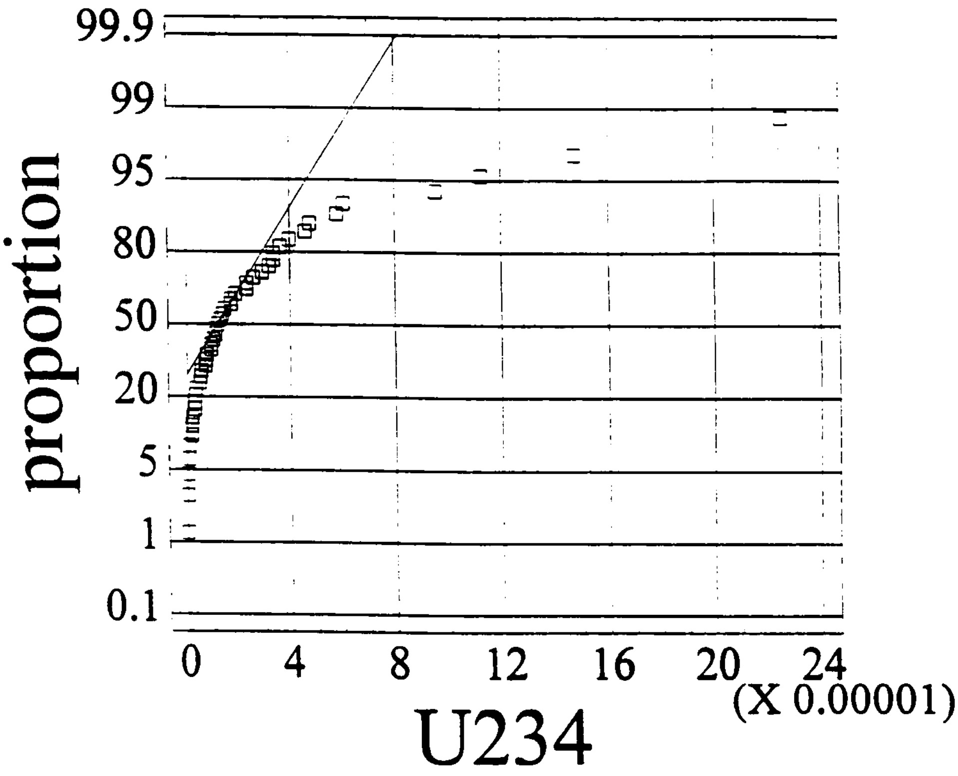


Figure D.25. Normal Probability Plot for U-234

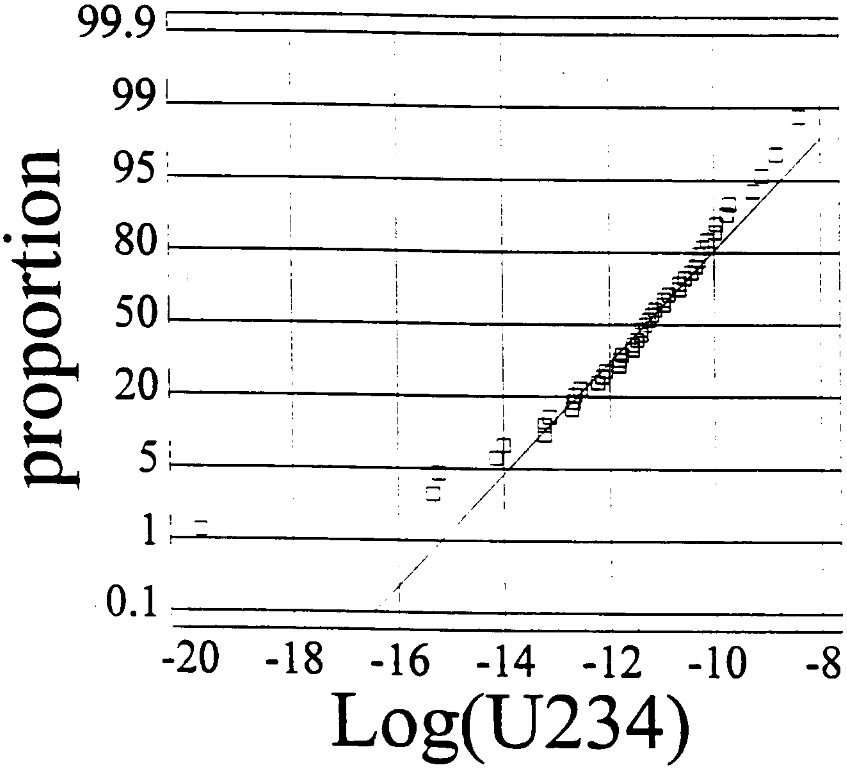


Figure D.26. Lognormal Probability Plot for U-234

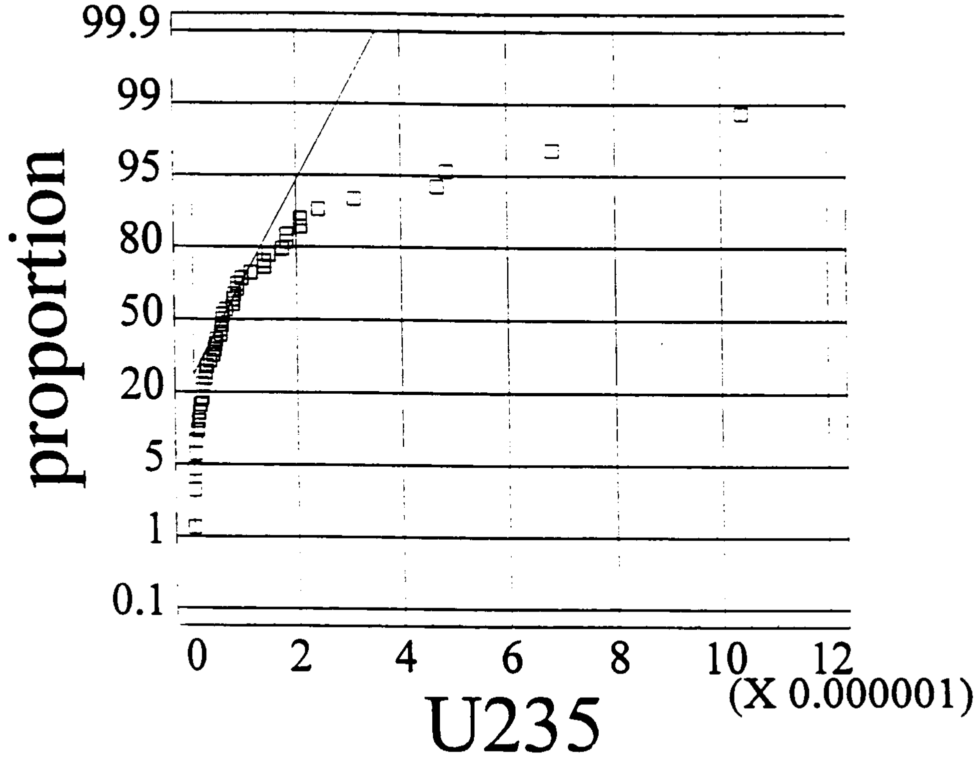


Figure D.27. Normal Probability Plot for U-235

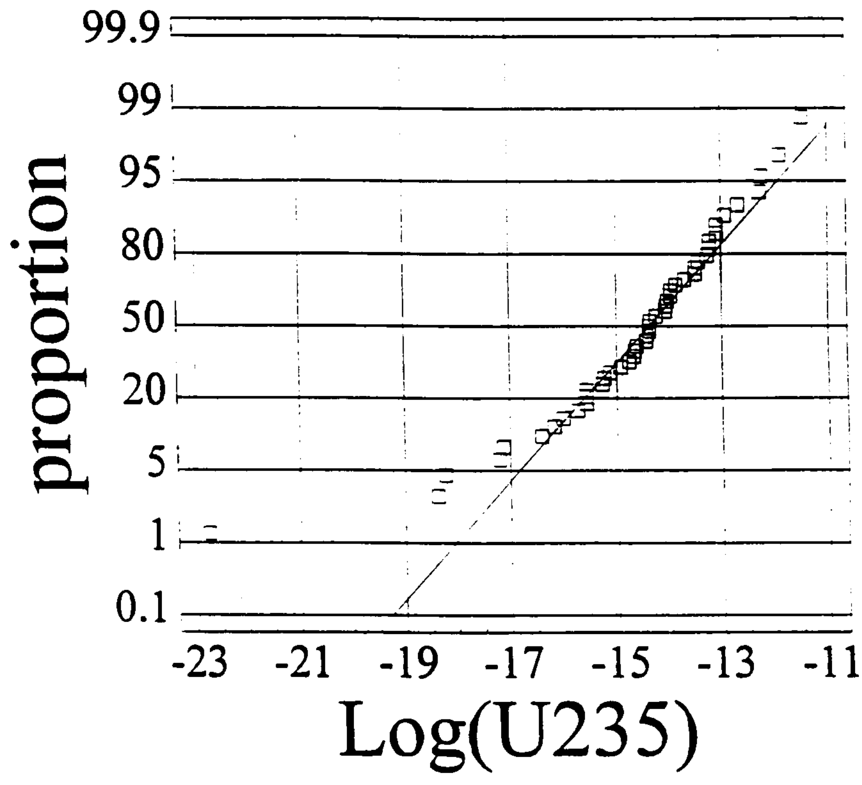


Figure D.28. Lognormal Probability Plot for U-235

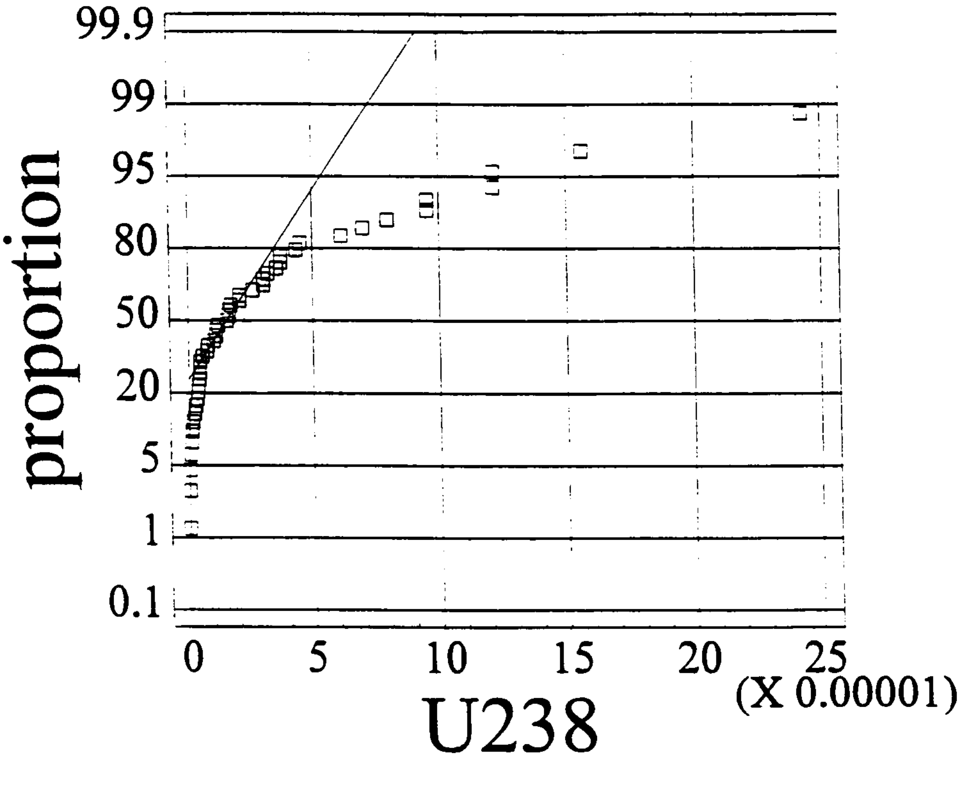


Figure D.29. Normal Probability Plot for U-238

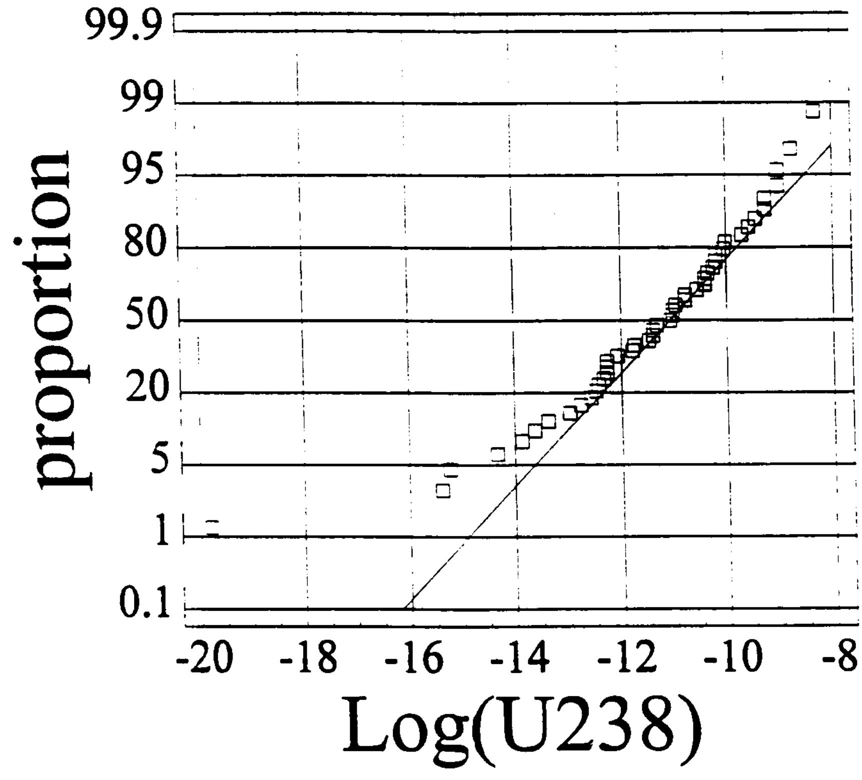


Figure D.30. Lognormal Probability Plot for U-238

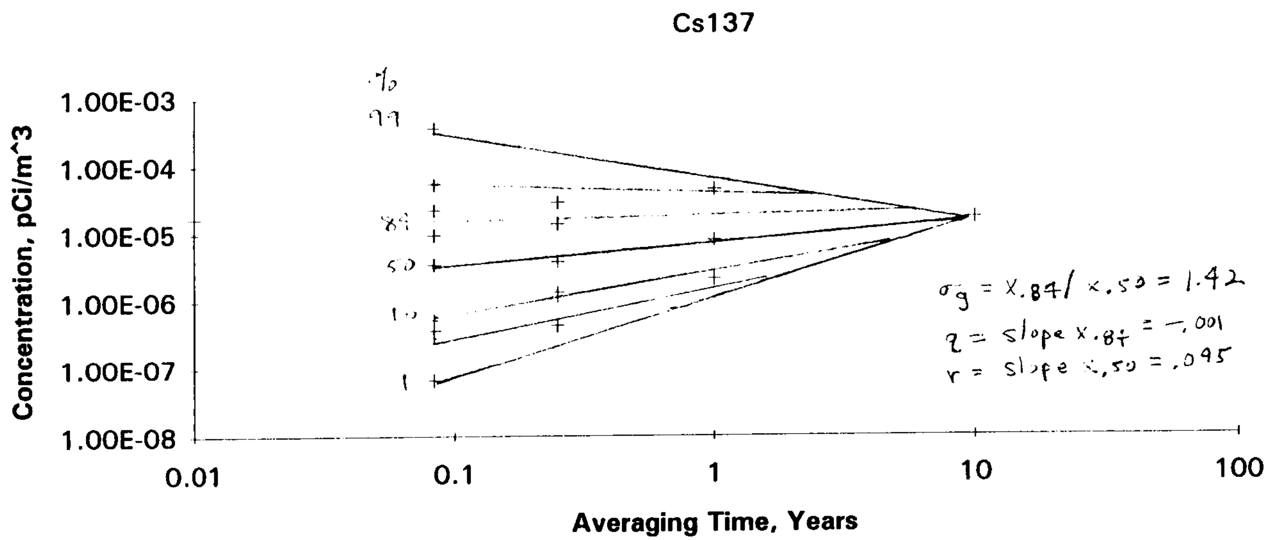


Figure D 31. Log-Log Plot of Concentration Percentiles Versus Averaging Time

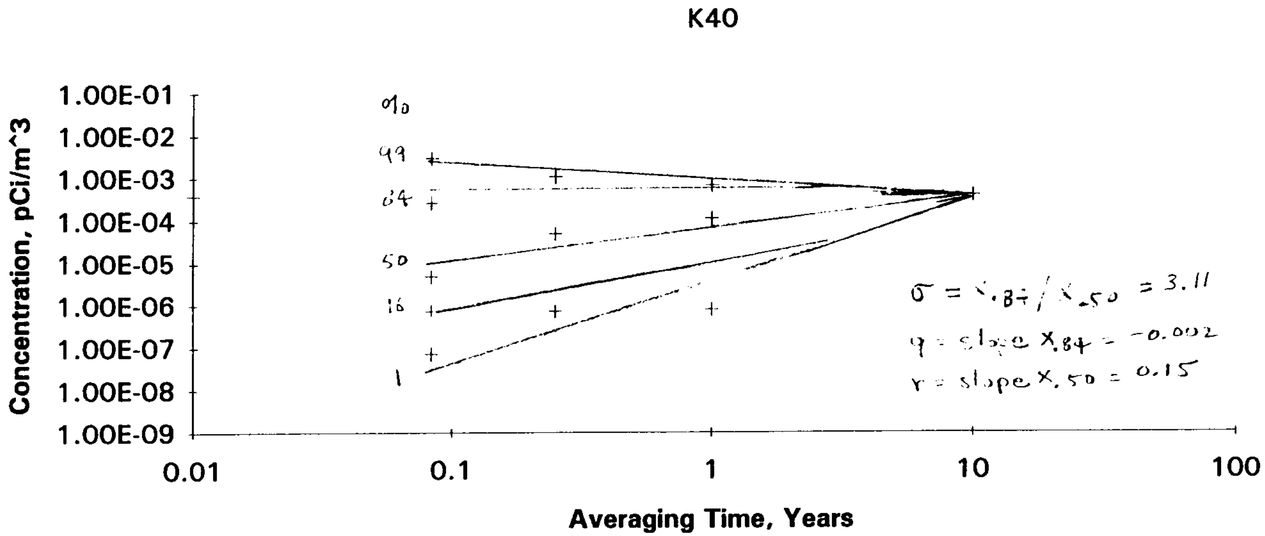


Figure D 31. Continued

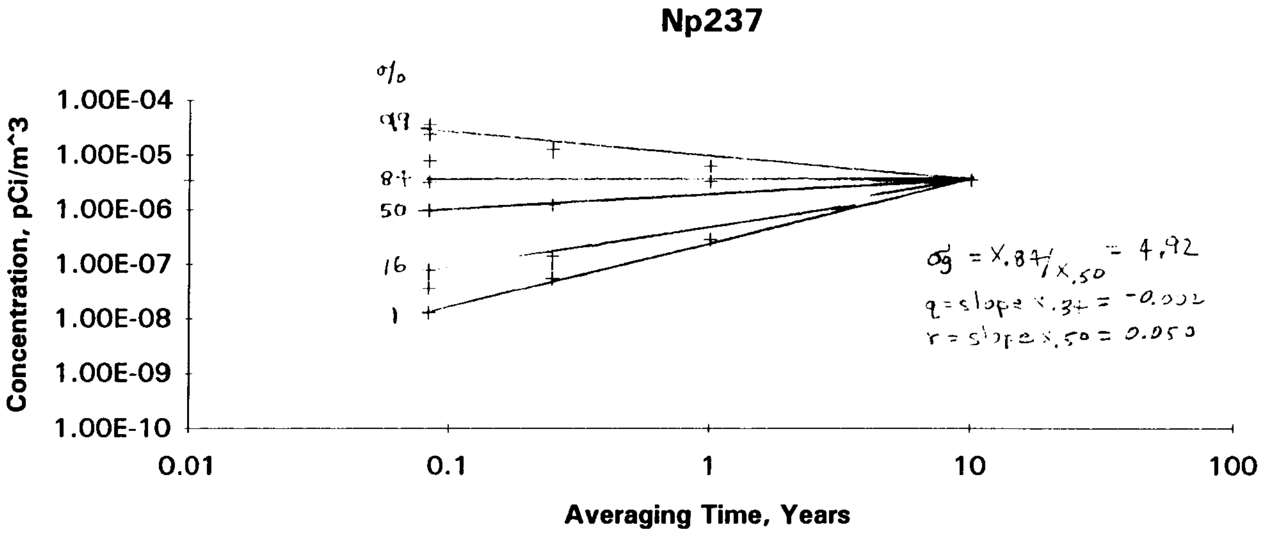


Figure D 31. Continued

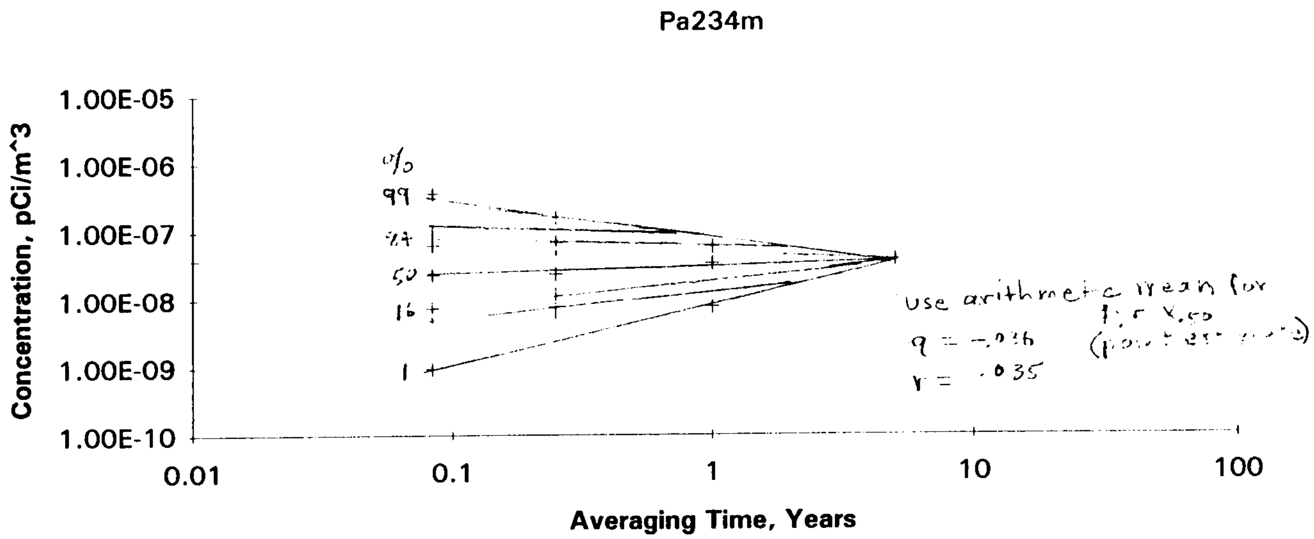


Figure D 31. Continued

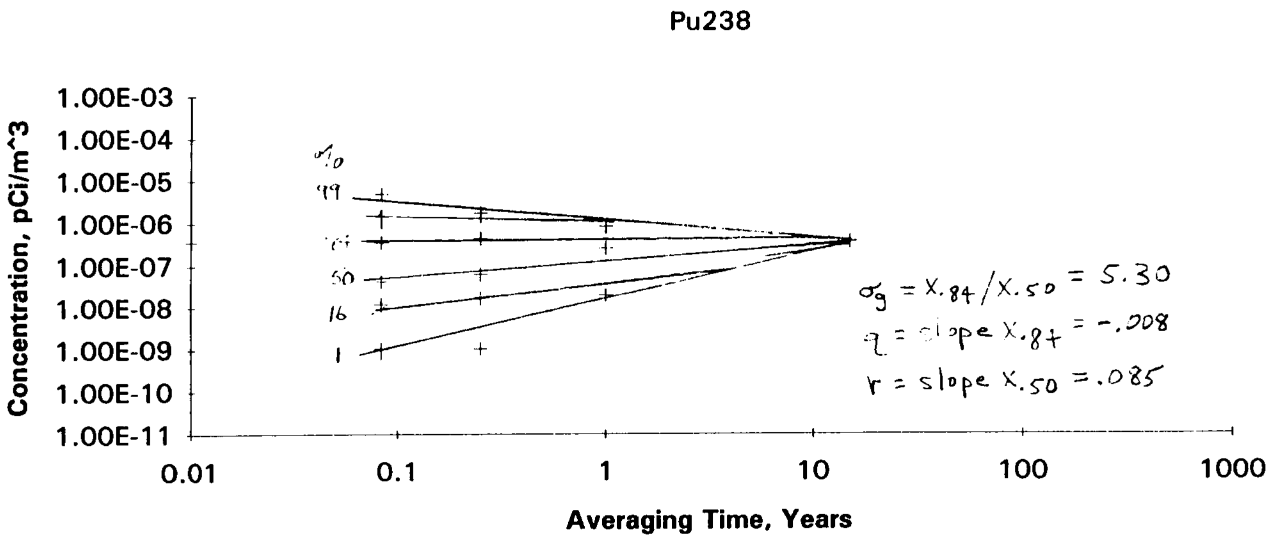


Figure D 31. Continued

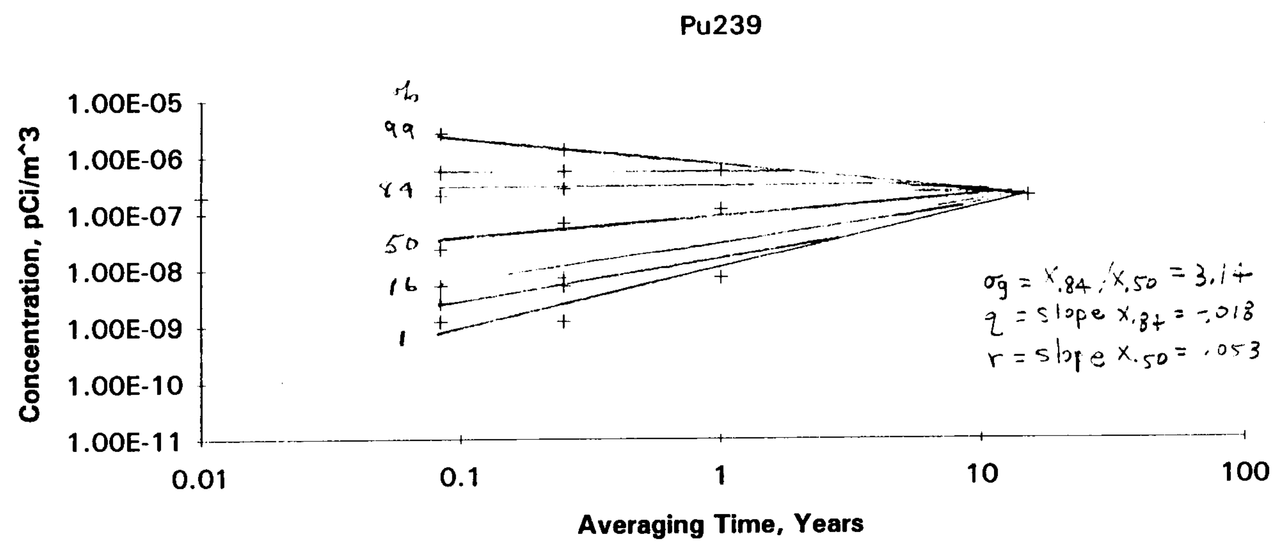


Figure D 31. Continued

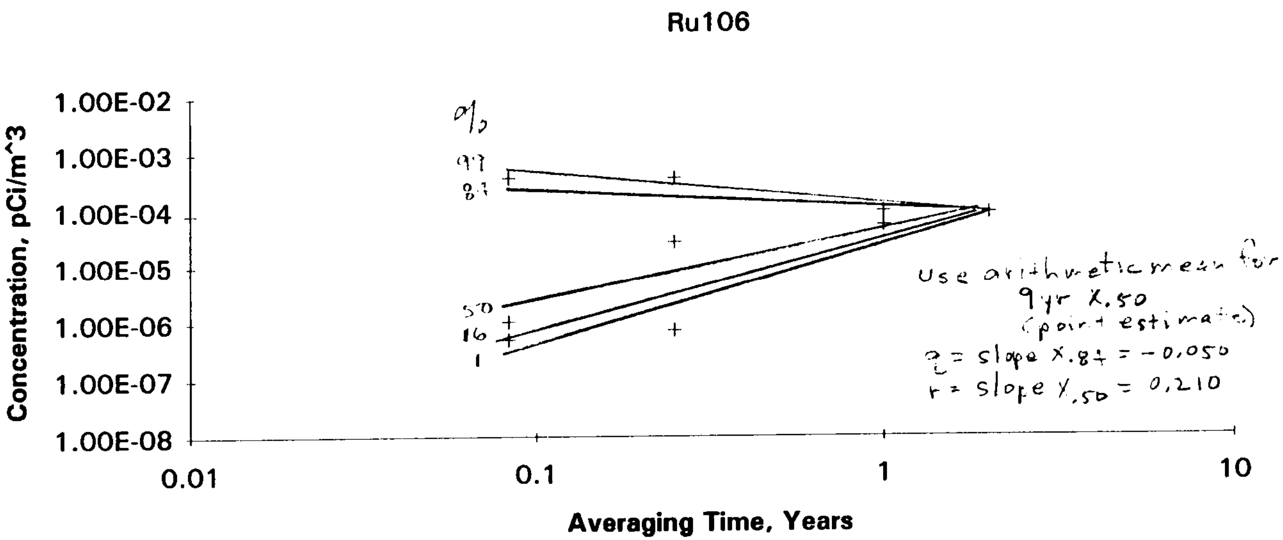


Figure D 31. Continued

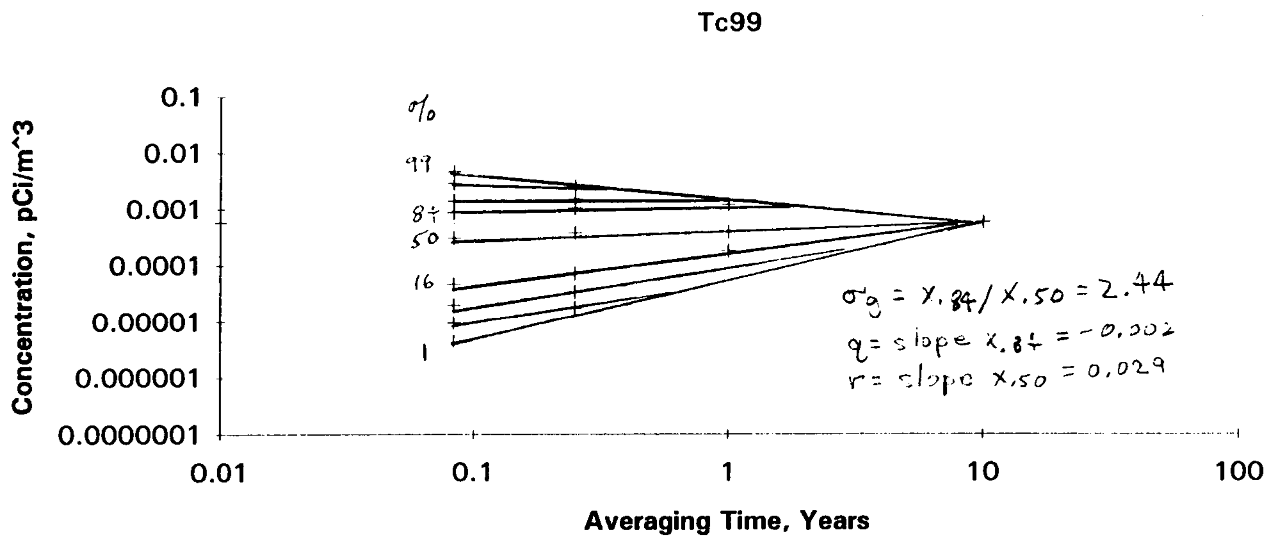


Figure D 31. Continued

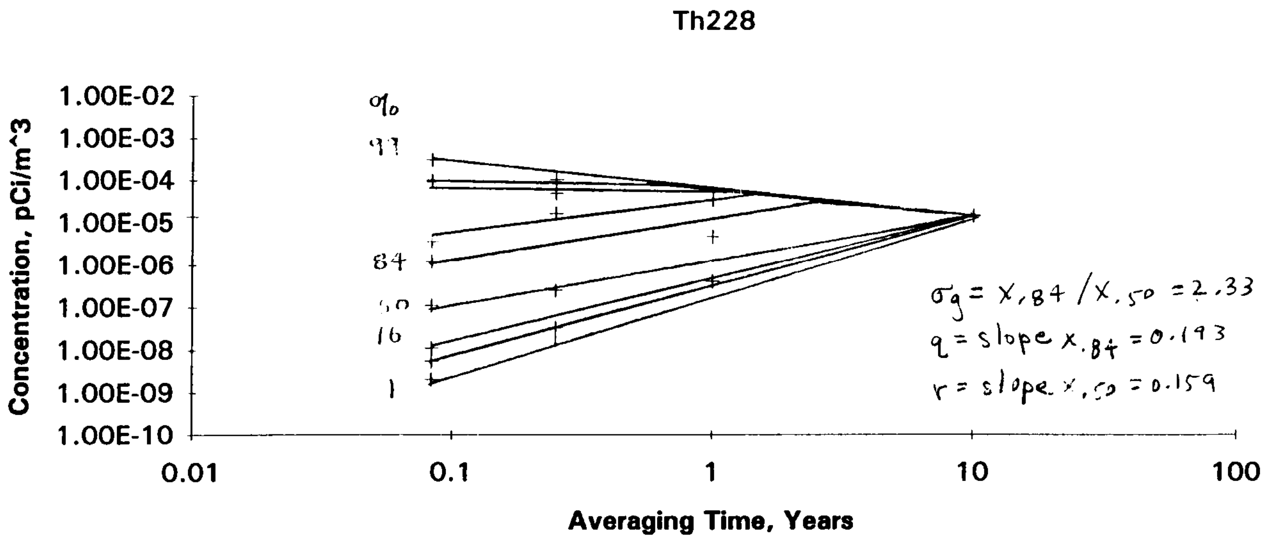


Figure D 31. Continued

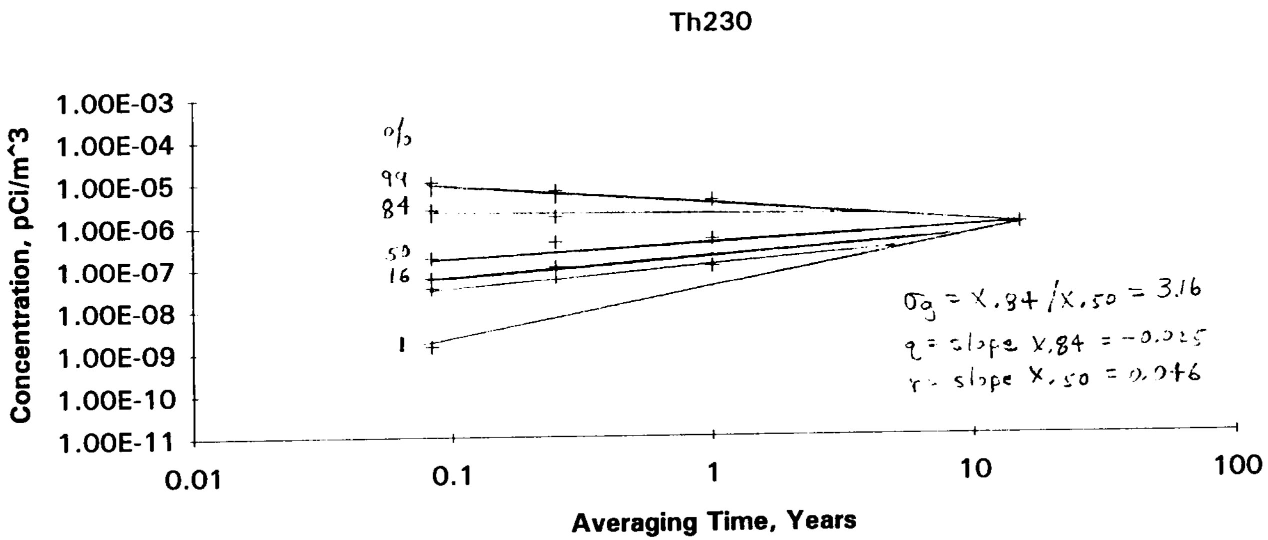


Figure D 31. Continued

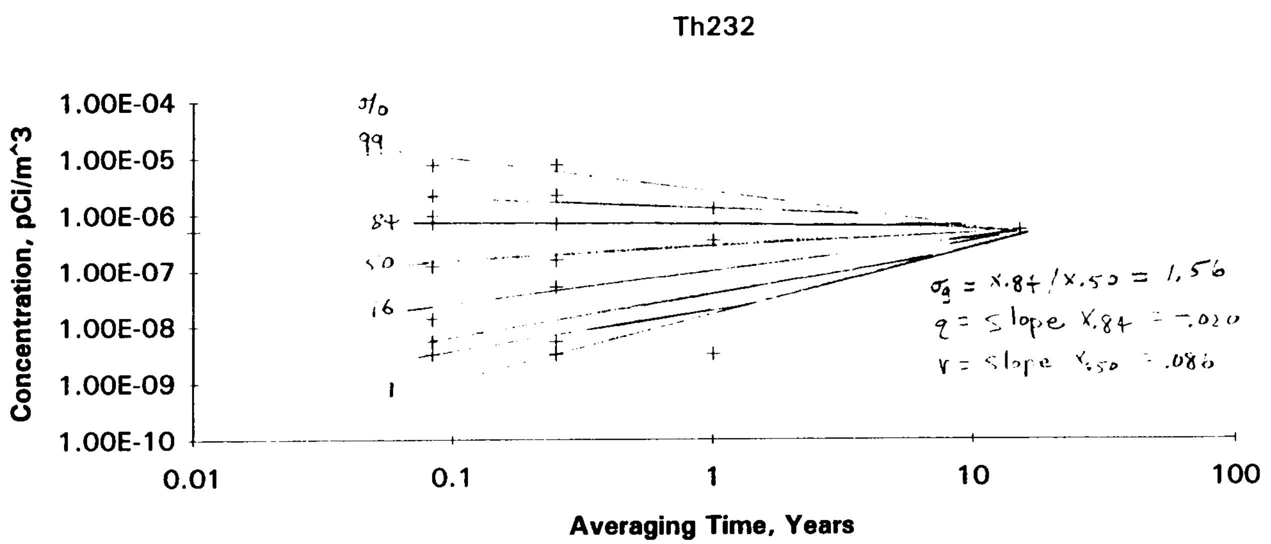


Figure D 31. Continued

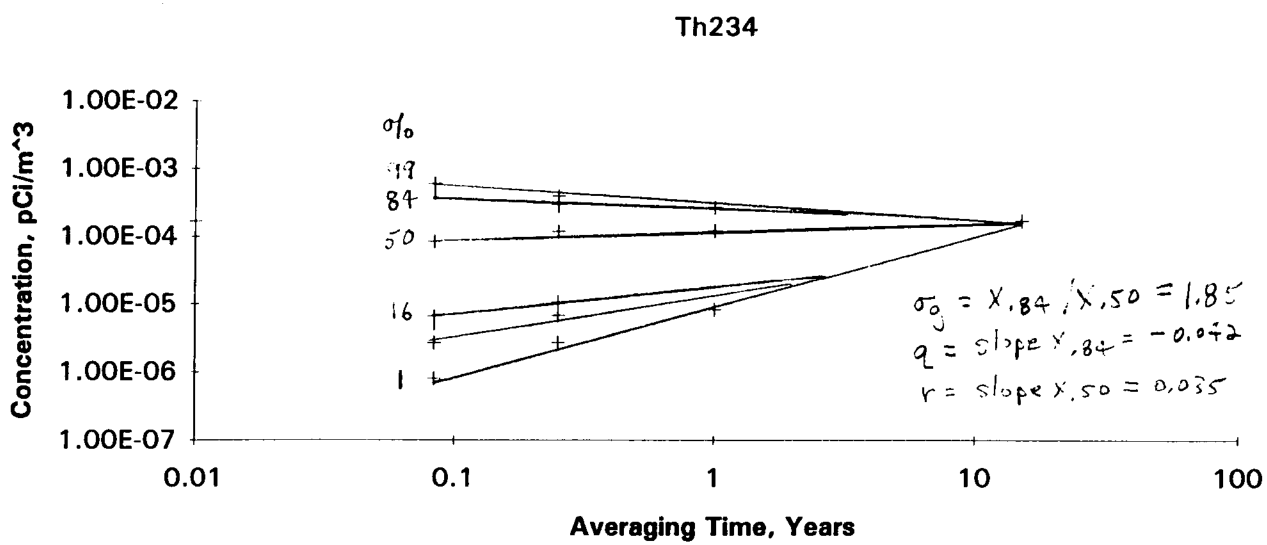


Figure D 31. Continued

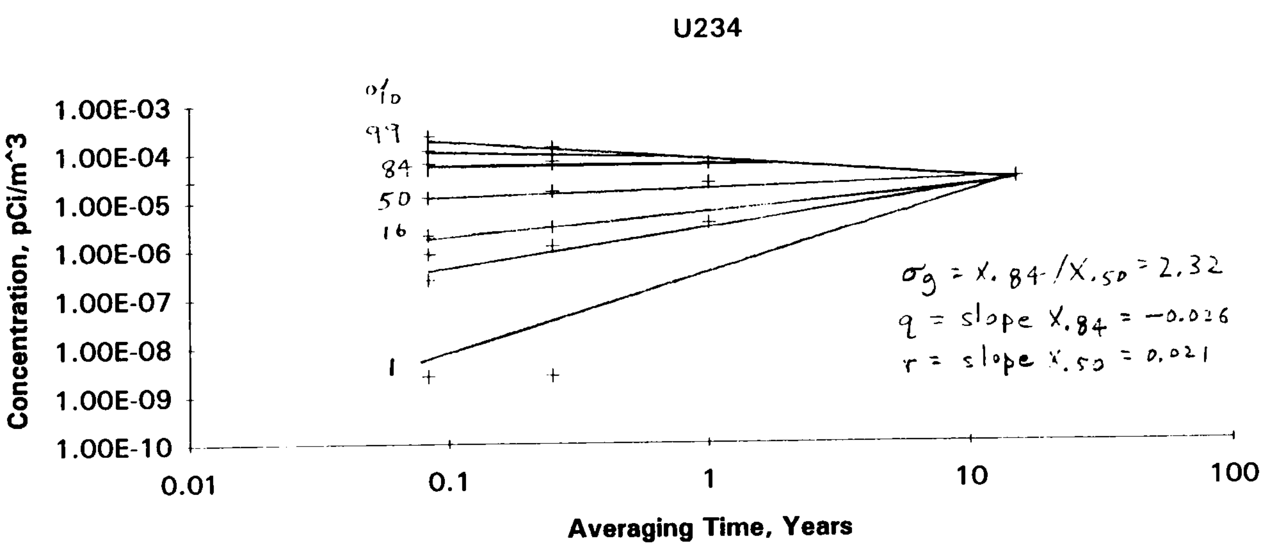


Figure D 31. Continued

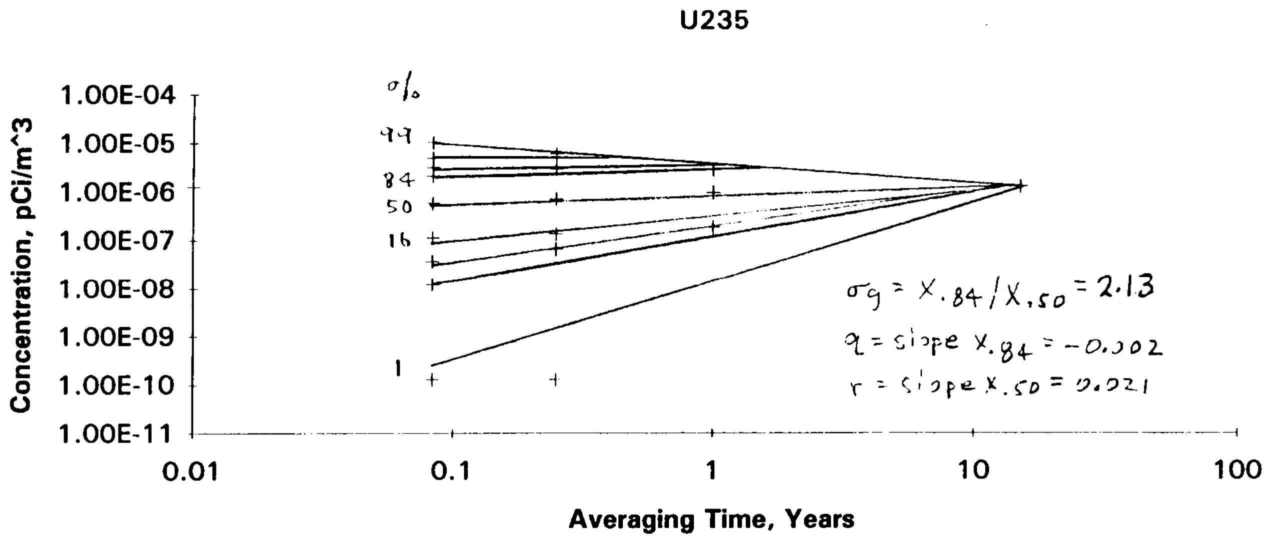


Figure D 31. Continued

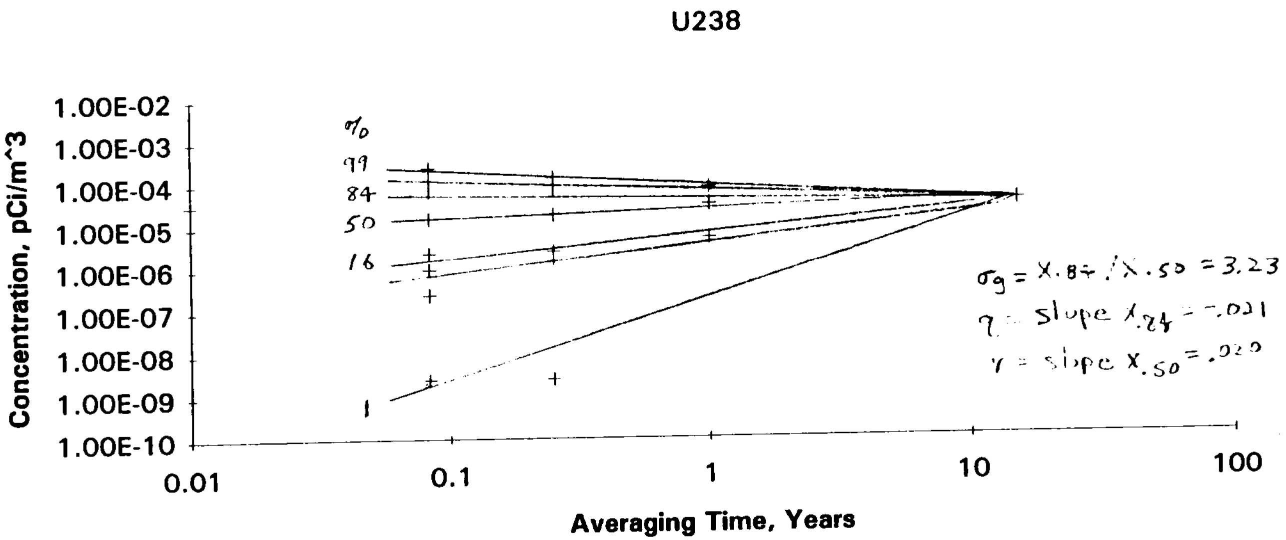


Figure D 31. Continued

APPENDIX E

Regression and Residual Plots

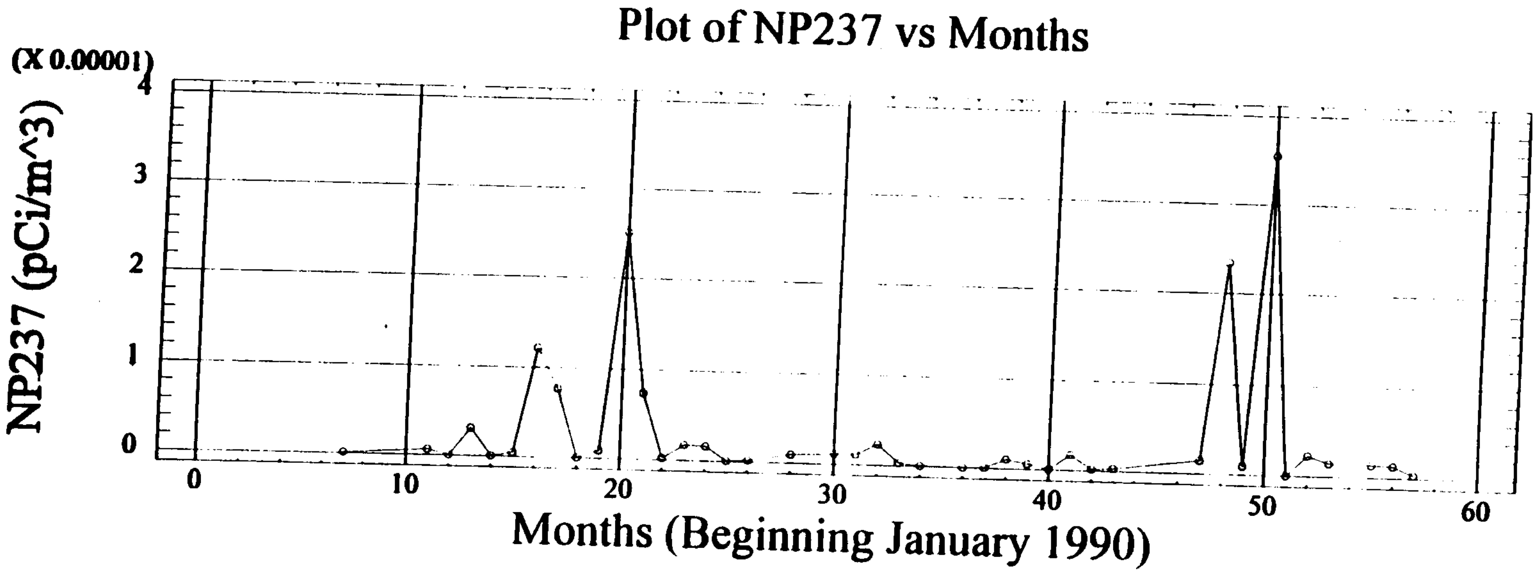


Figure E.1. Time Series Plots for Emissions for Selected Radionuclides

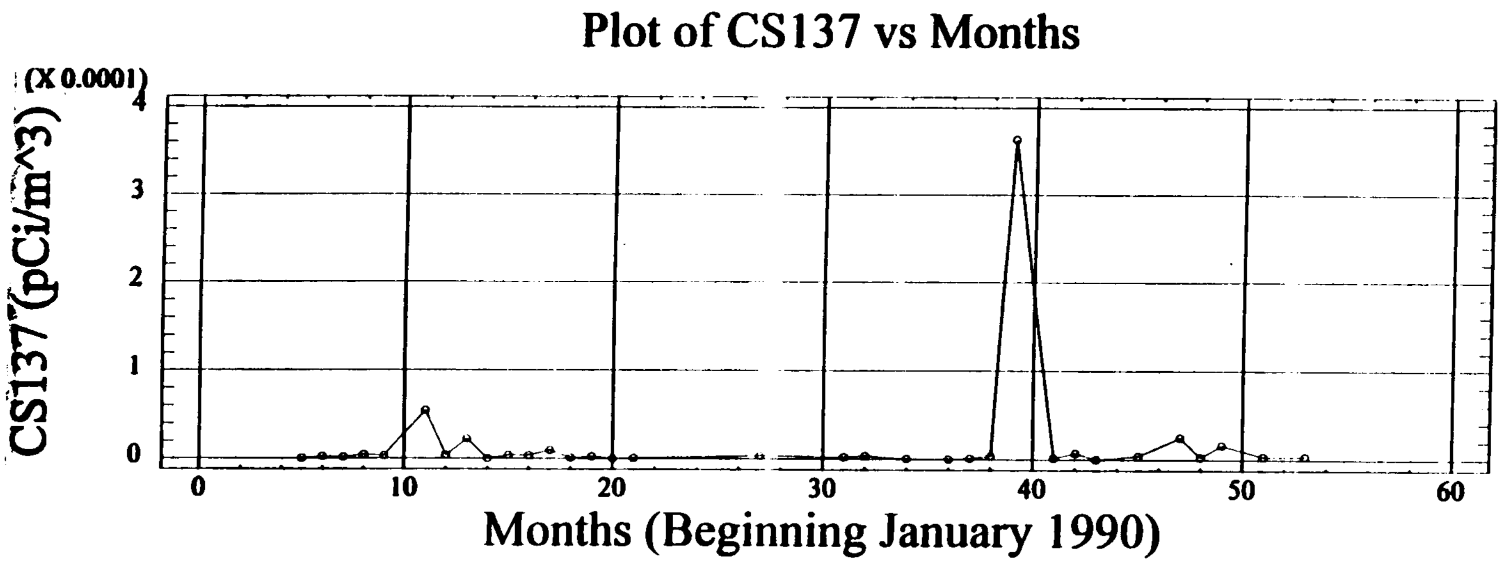


Figure E.1. Continued

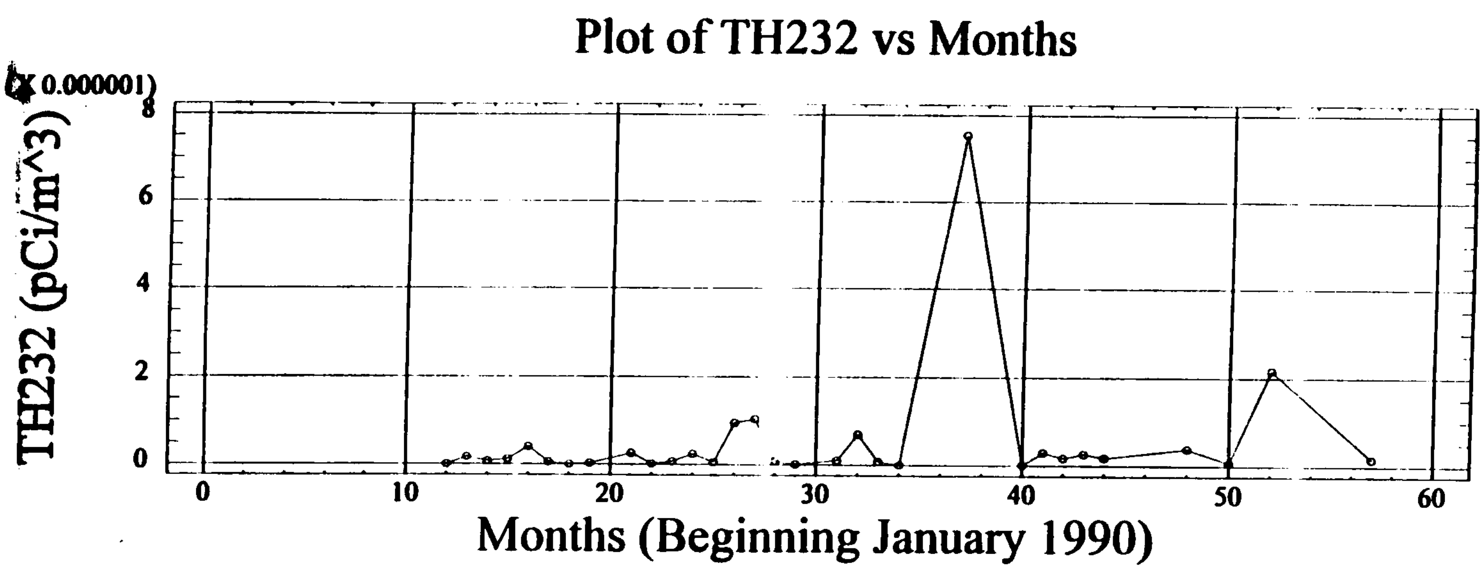


Figure E.1. Continued

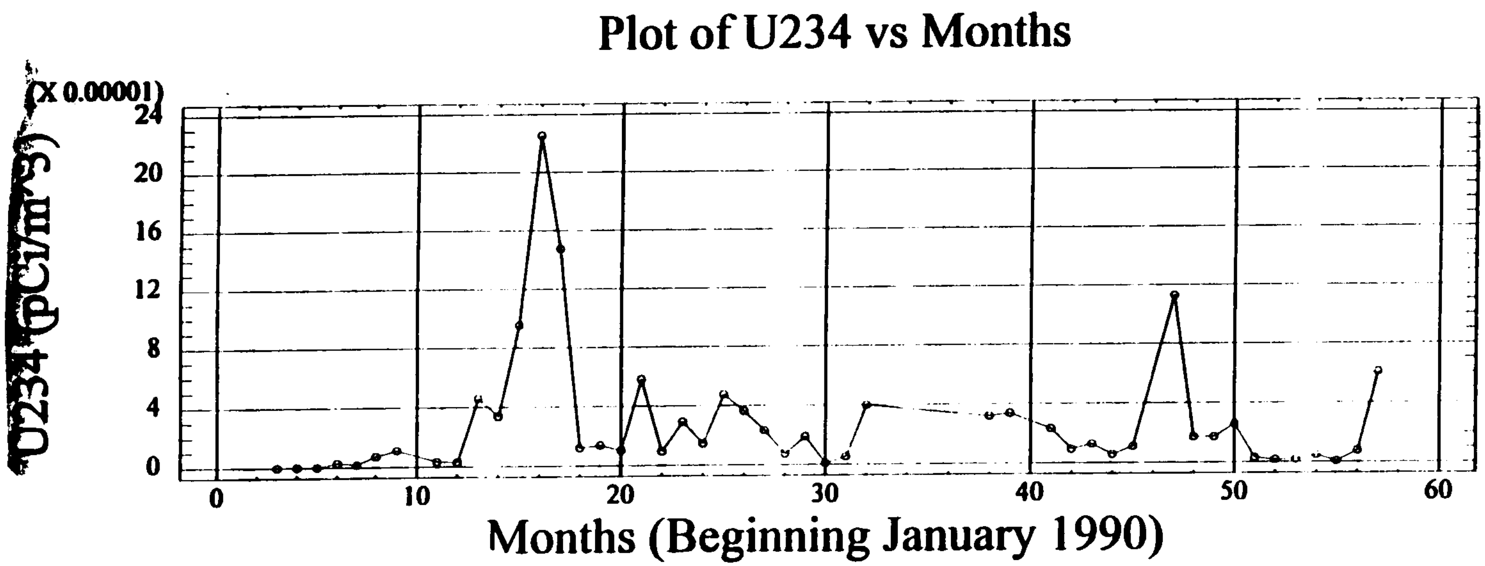


Figure E.1. Continued

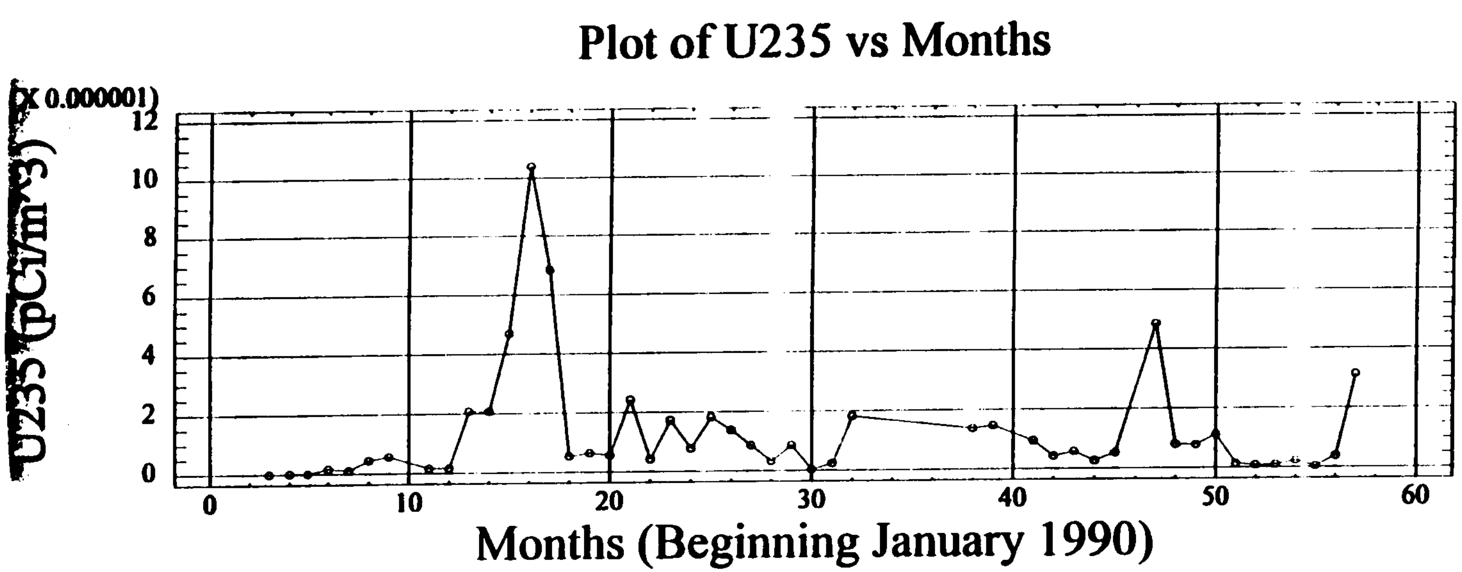


Figure E.1. Continued

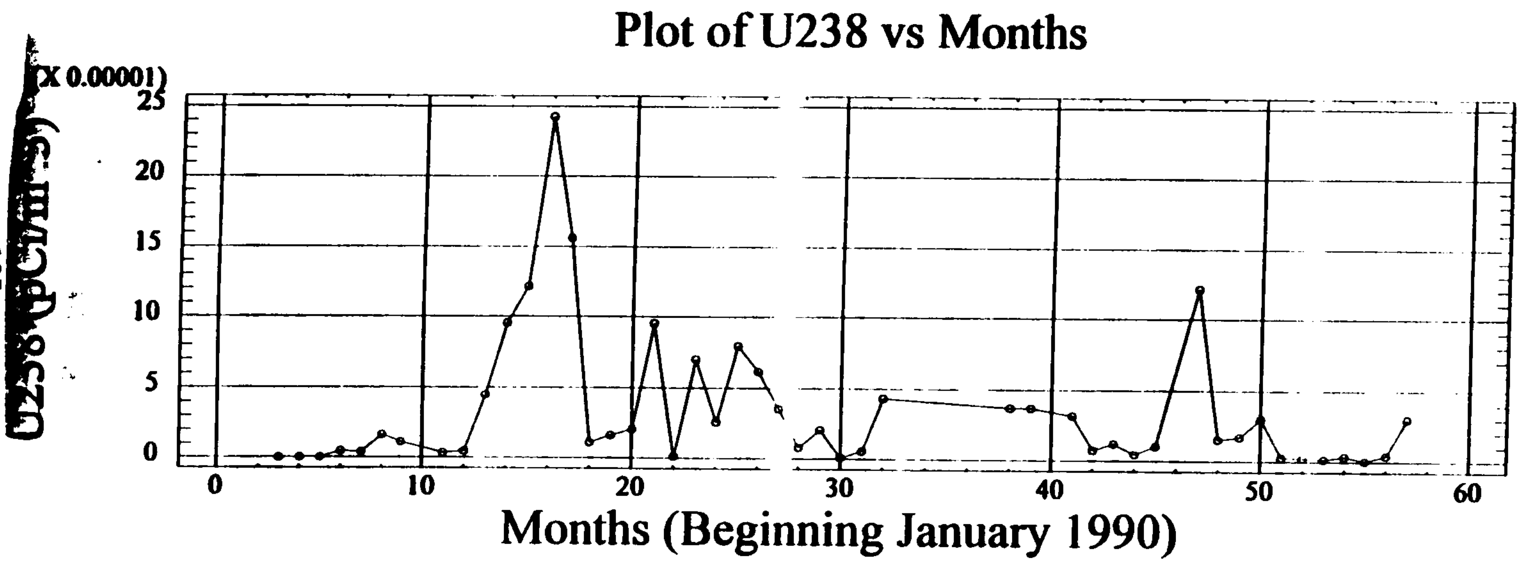


Figure E.1. Continued

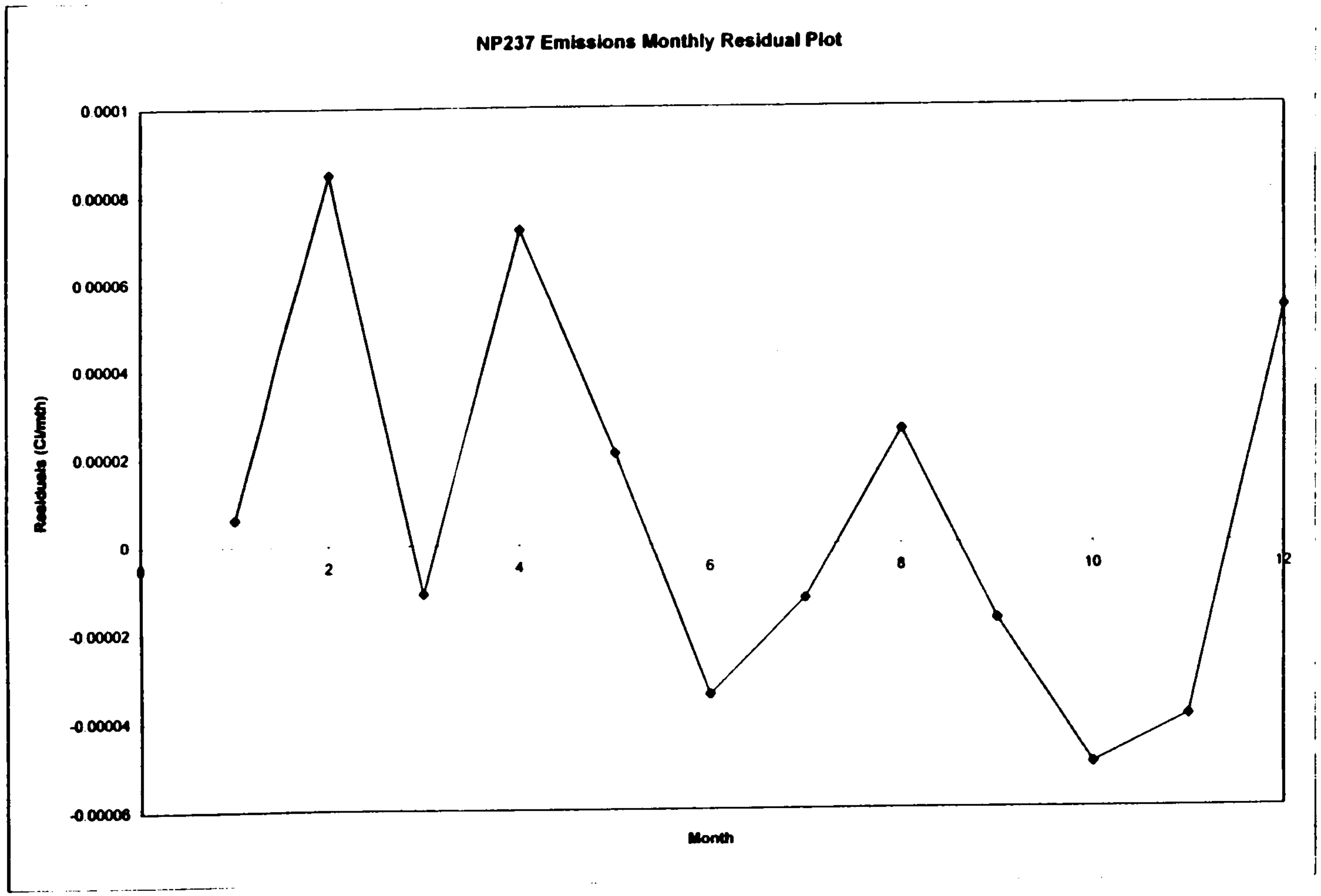


Figure E.2. Residuals Plots for Average Emissions and Concentrations for Selected Radionuclides

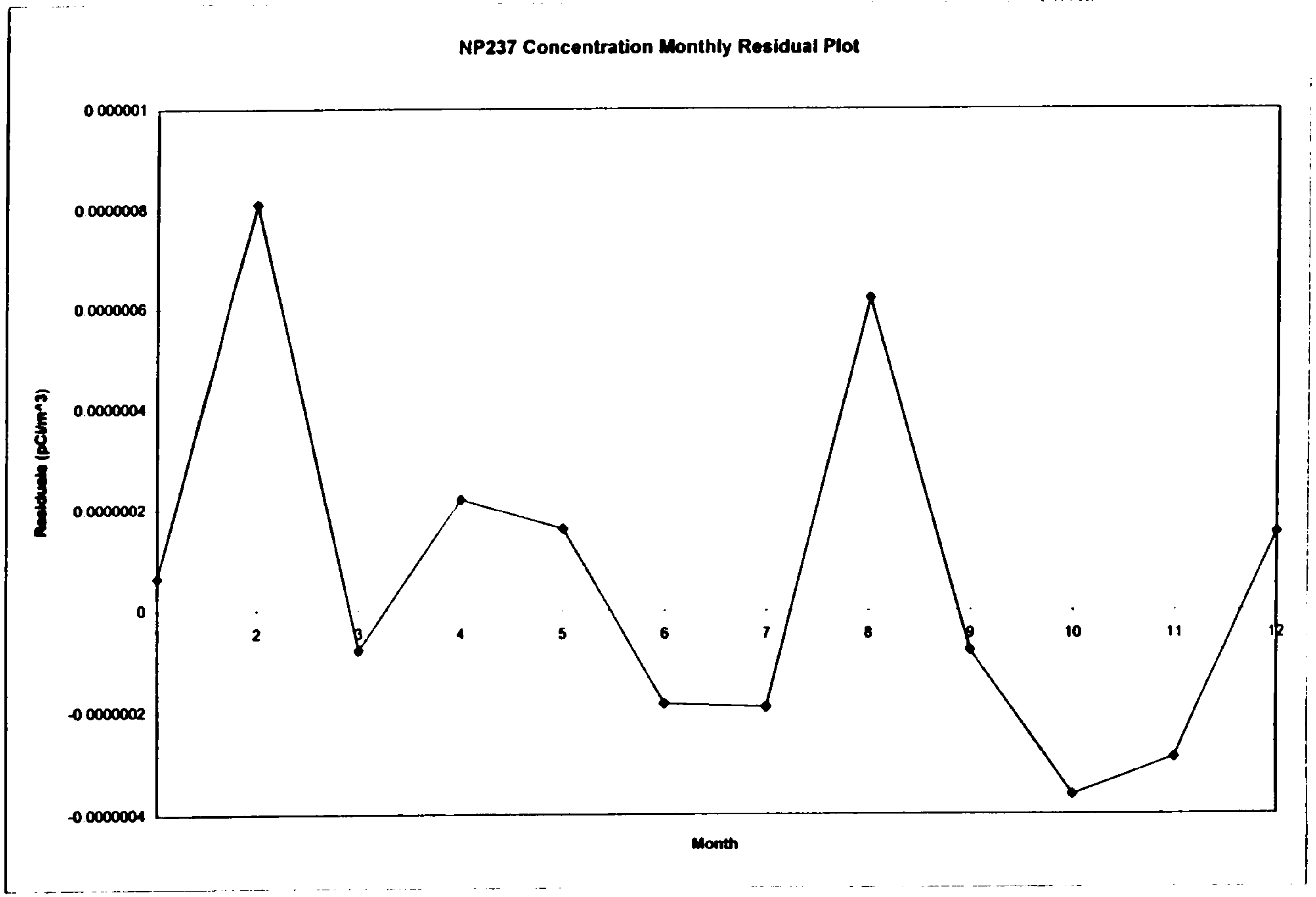


Figure E.2. Continued

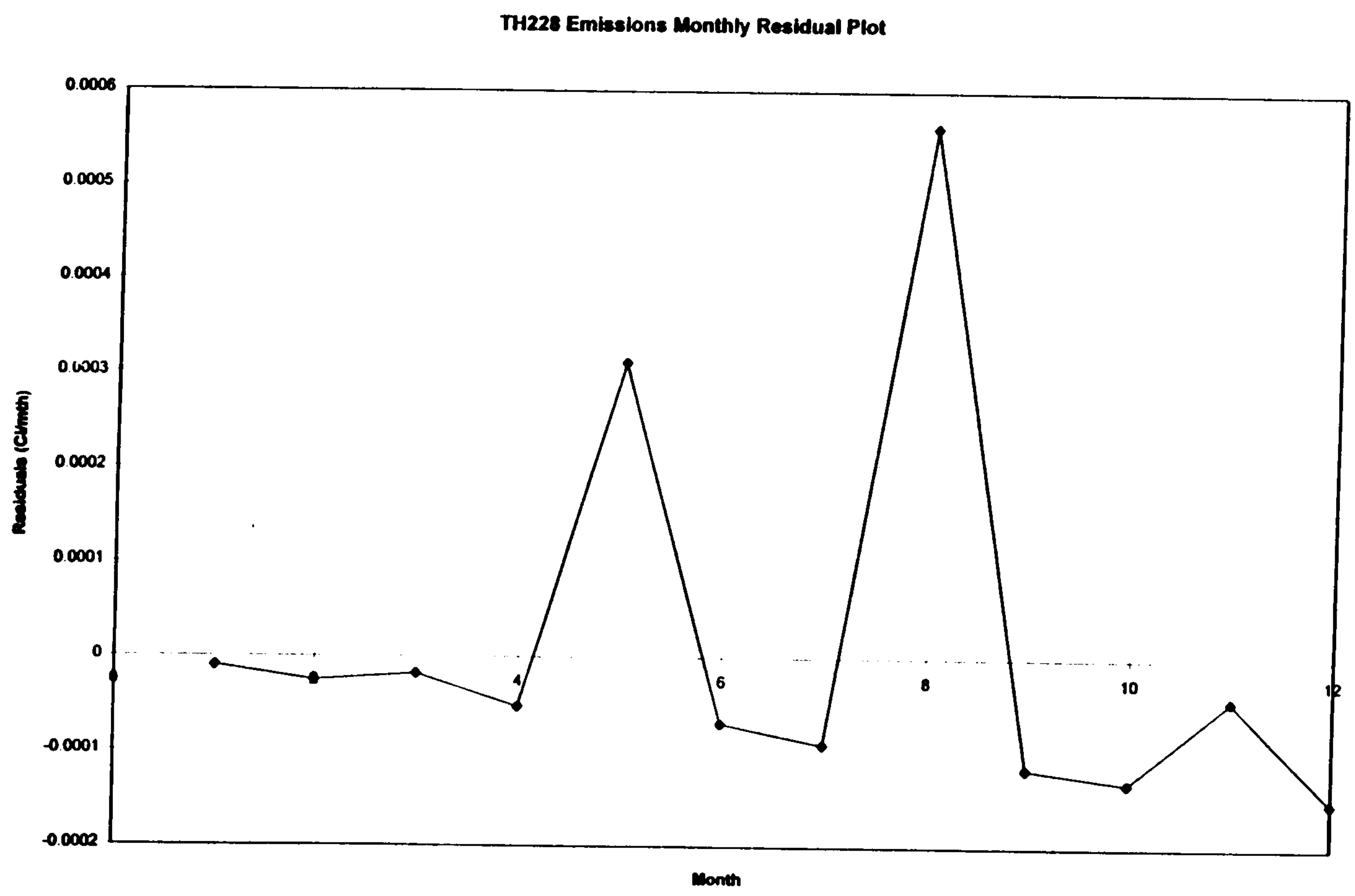


Figure E.2. Continued

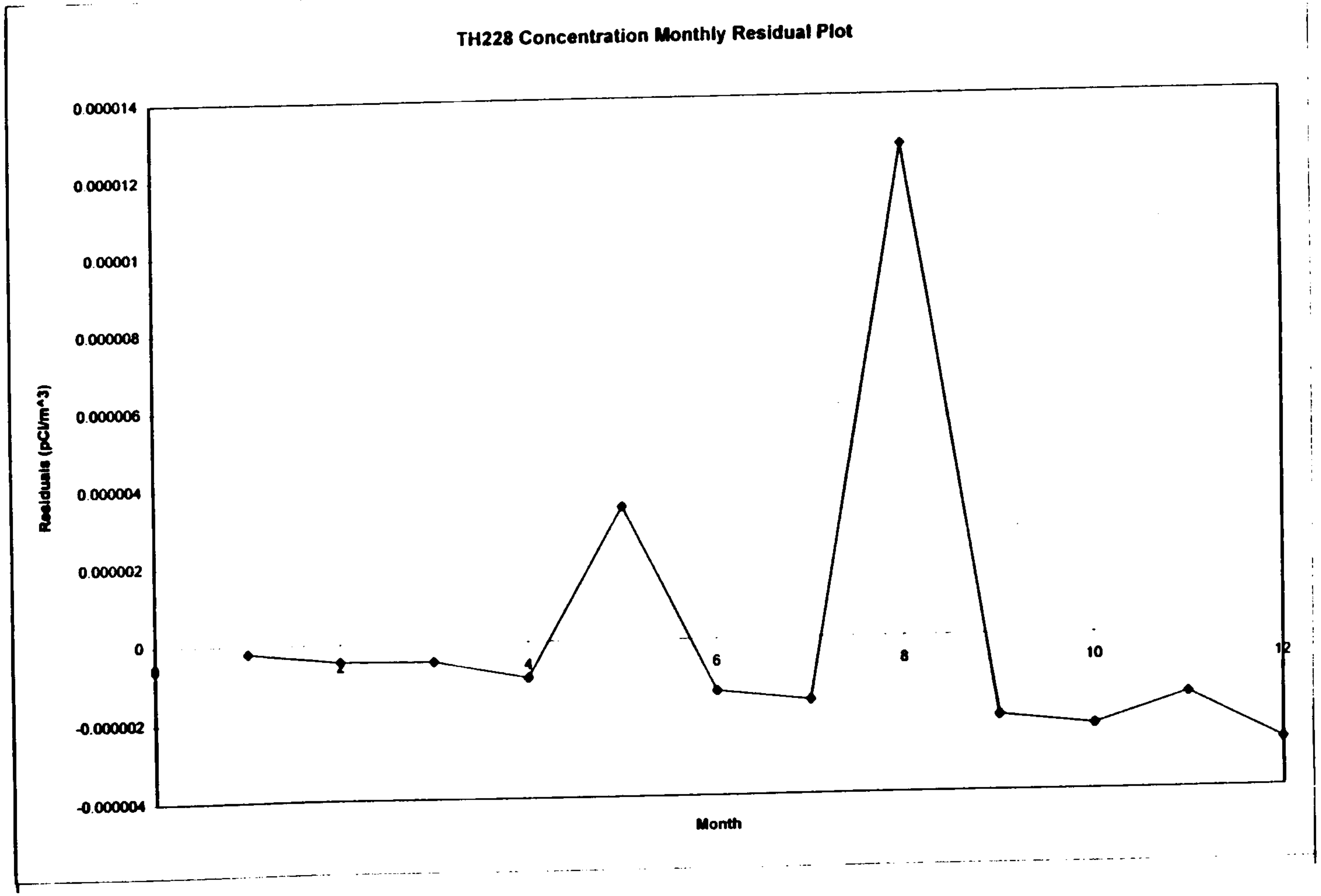


Figure E.2. Continued

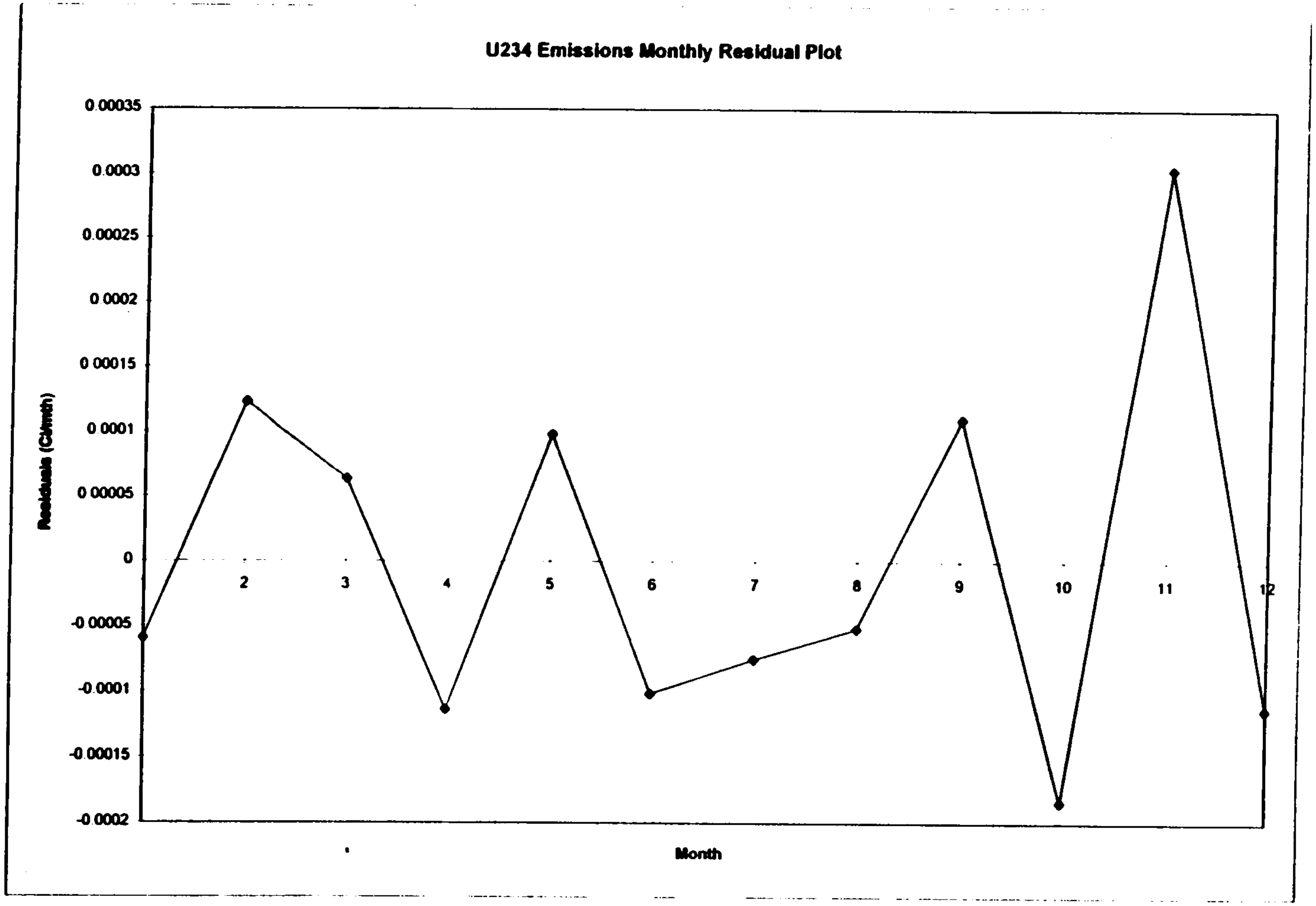


Figure E.2. Continued

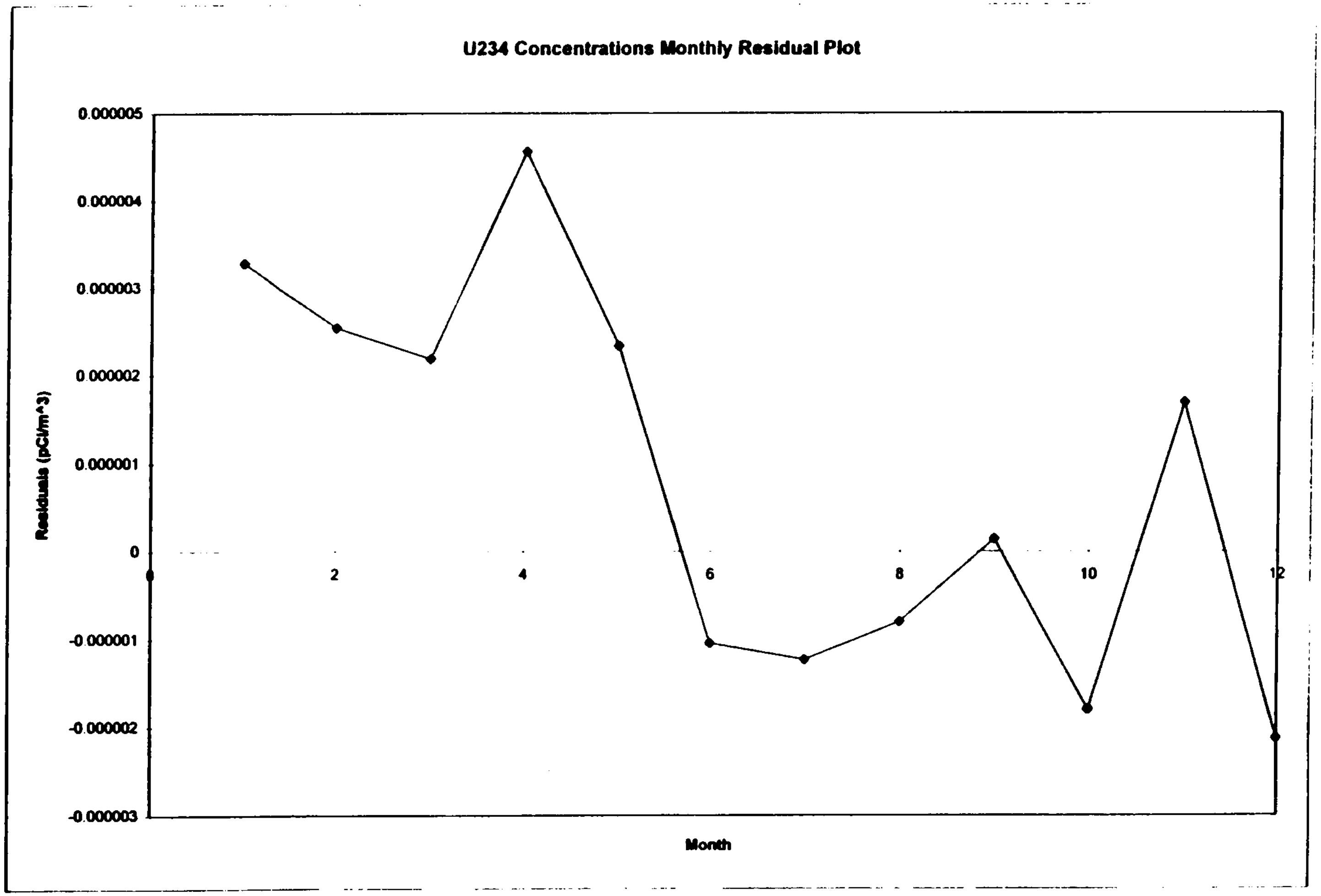


Figure E.2. Continued

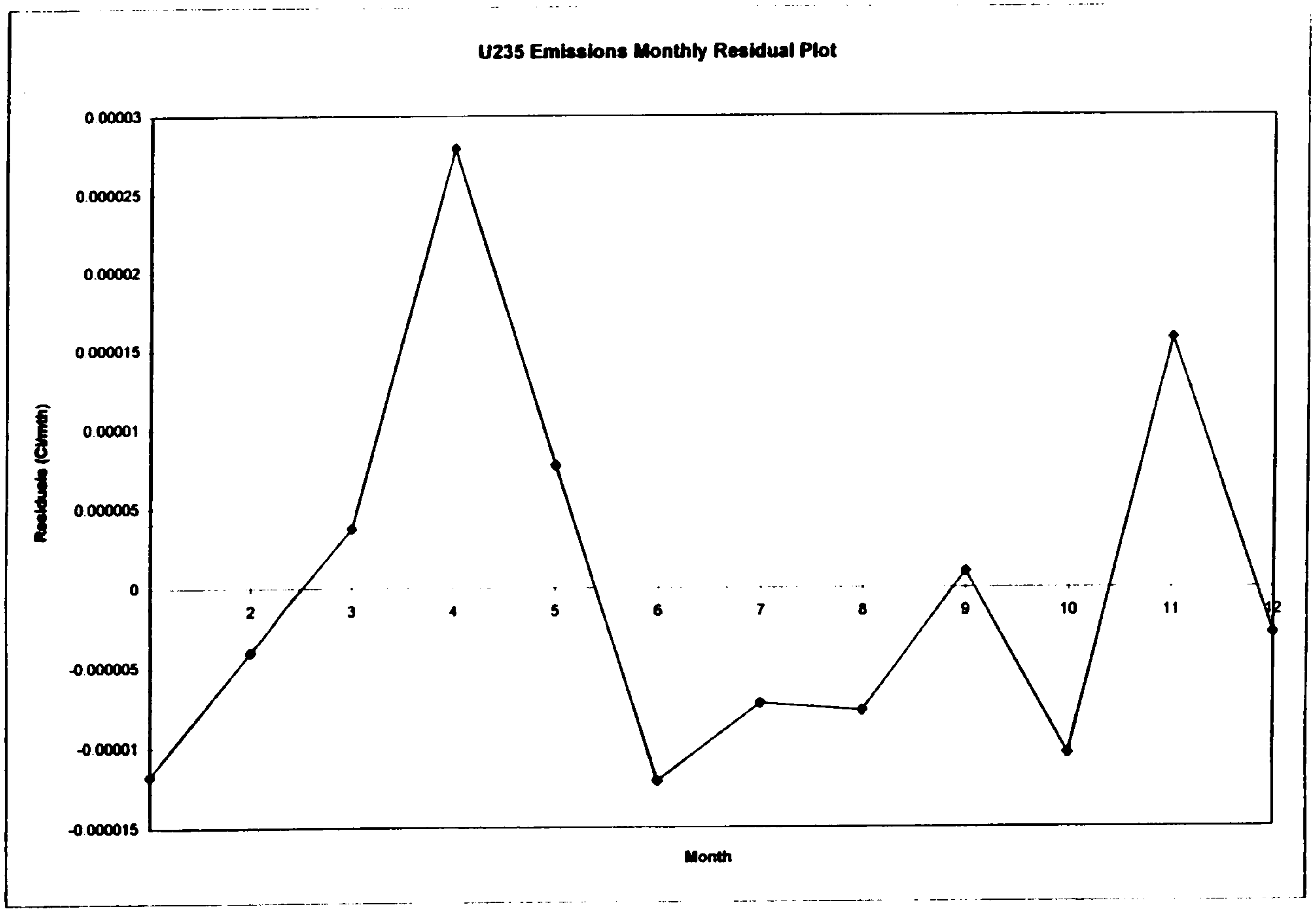


Figure E.2. Continued

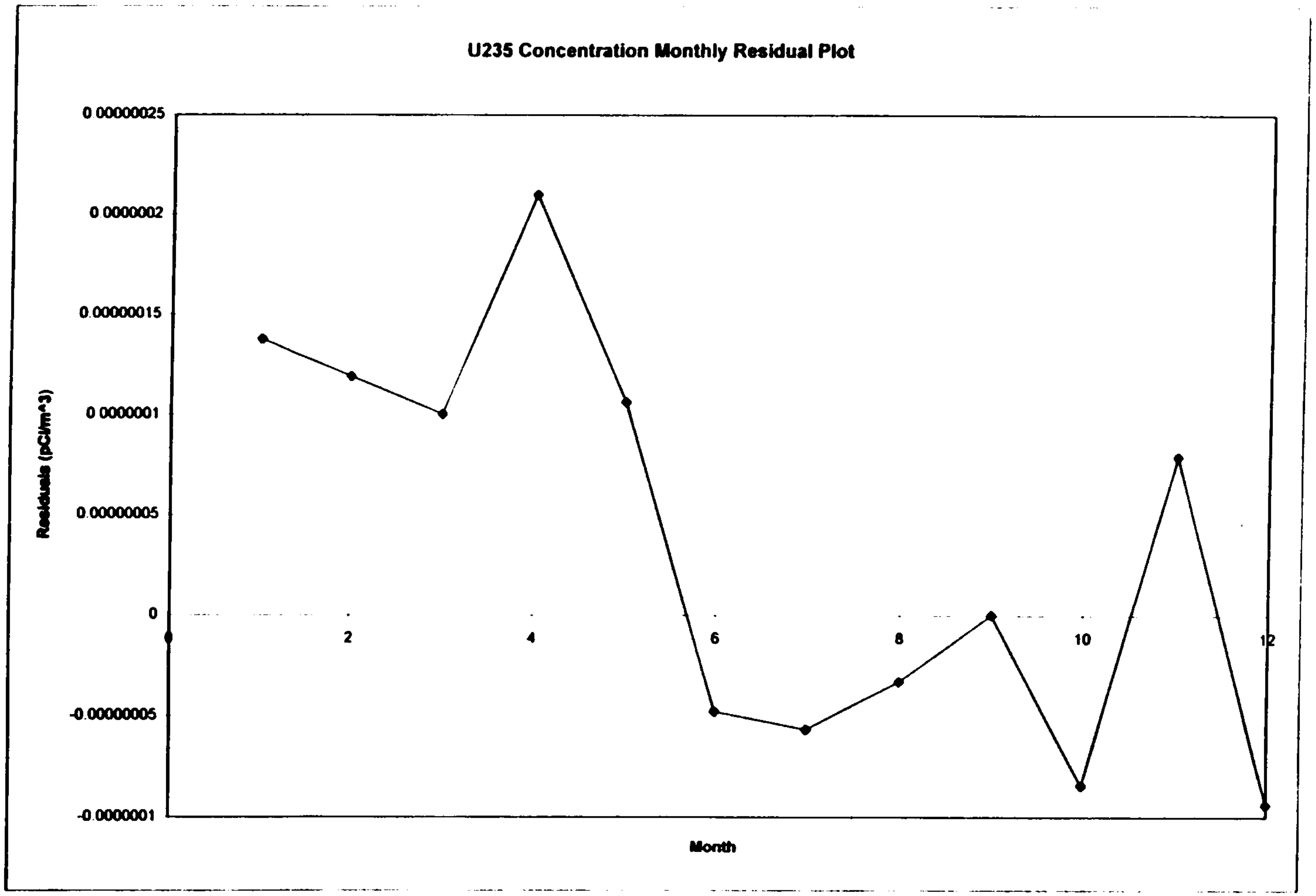


Figure E.2. Continued

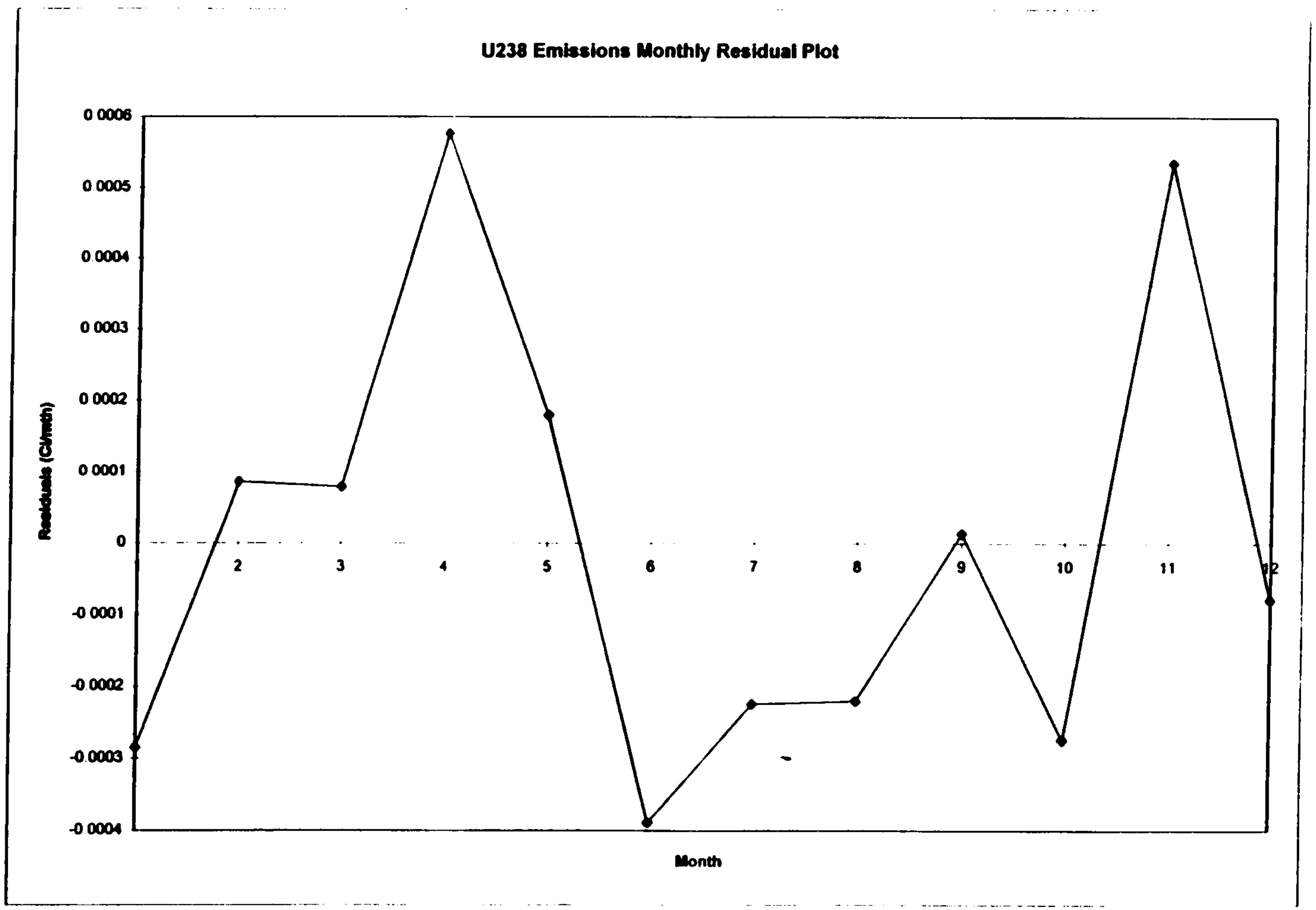


Figure E.2. Continued

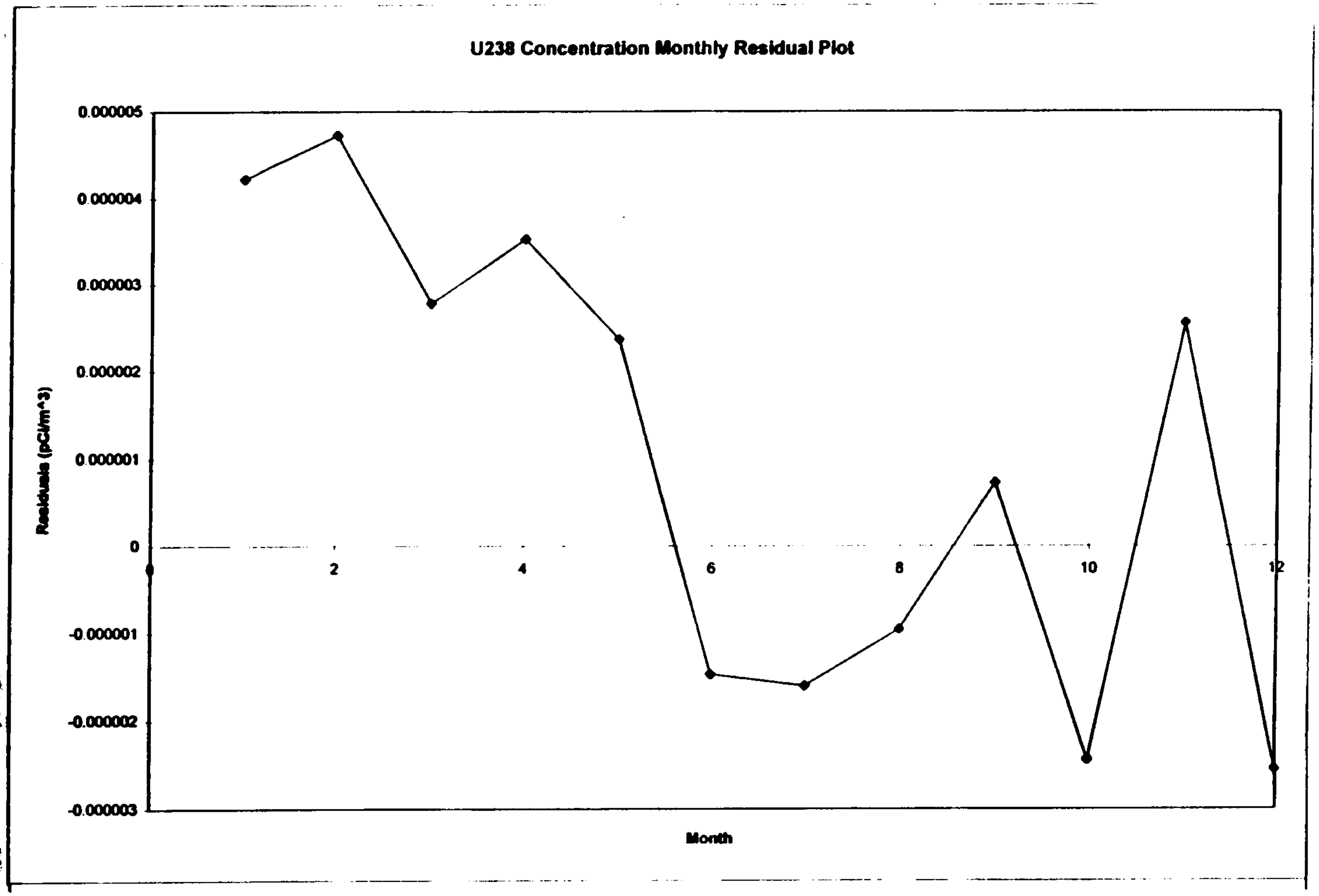


Figure E.2. Continued

APPENDIX F

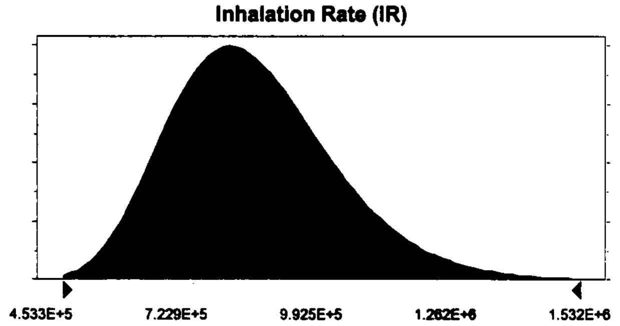
Parameter Probability Density Functions

Assumption: Inhalation Rate (IR)

Lognormal distribution with parameters:

Mean	8.506E+05
Standard Dev.	1.744E+05

Selected range is from 4.533E+5 to 1.532E+6
Mean value in simulation was 8.501E+5



Assumption: Exposure duration (ED)

Lognormal distribution with parameters:

Mean	10.79
Standard Dev.	7.13

Selected range is from 1.48 to 54.80
Mean value in simulation was 10.73

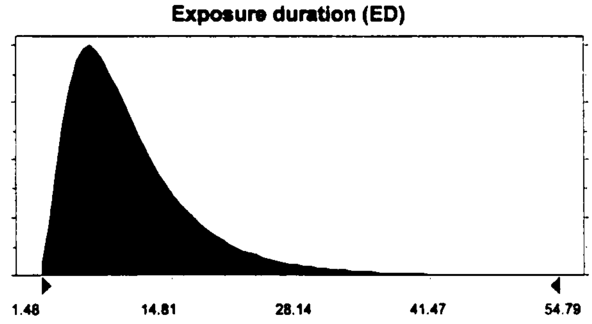


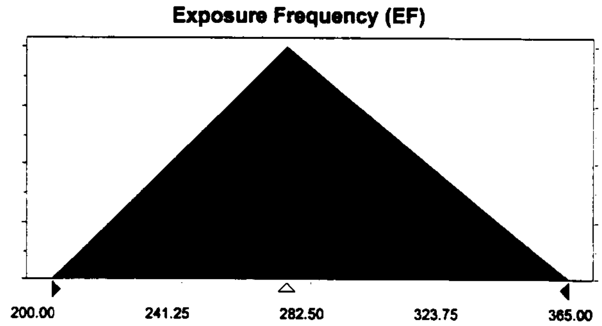
Figure F.1. Probability Density Functions for Assumption Parameters

Assumption: Exposure Frequency (EF)

Triangular distribution with parameters:

Minimum	200.00
Likeliest	275.00
Maximum	365.00

Selected range is from 200.00 to 365.00
Mean value in simulation was 280.01



Assumption: Dose Factor Cs-137

Triangular distribution with parameters:

Minimum	1.033E-05
Likeliest	3.099E-05
Maximum	9.300E-05

Selected range is from 1.033E-5 to 9.300E-5

Mean value in simulation was 4.477E-5

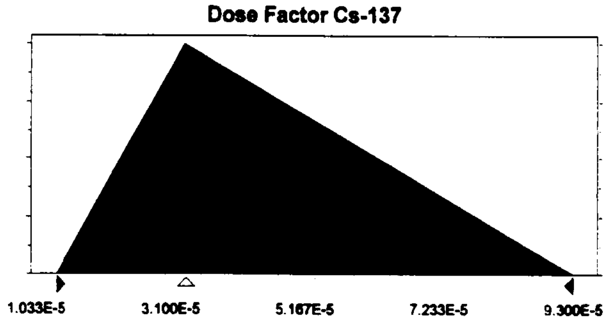


Figure F.1. Continued

Assumption: Risk Factor (RF)

Triangular distribution with parameters:

Minimum	1.50E-02
Likeliest	6.00E-02
Maximum	2.40E-01

Selected range is from 1.50E-2 to 2.40E-1
Mean value in simulation was 1.05E-1

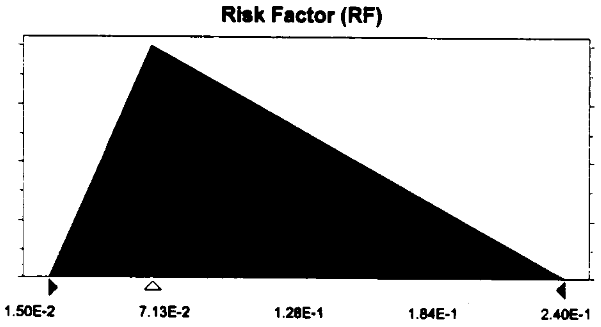


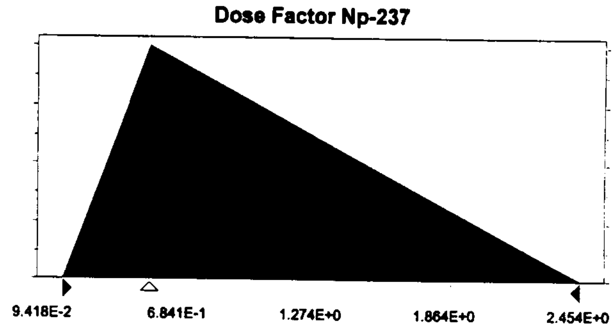
Figure F.1. Continued

Assumption: Dose Factor Np-237

Triangular distribution with parameters:

Minimum	9.418E-02
Likeliest	4.907E-01
Maximum	2.454E+00

Selected range is from 9.418E-2 to 2.454E+0
Mean value in simulation was 1.013E+0



Assumption: Dose Factor Pa-234m

Triangular distribution with parameters:

Minimum	7.580E-10
Likeliest	3.792E-09
Maximum	1.896E-08

Selected range is from 7.580E-10 to 1.896E-8
Mean value in simulation was 7.837E-9

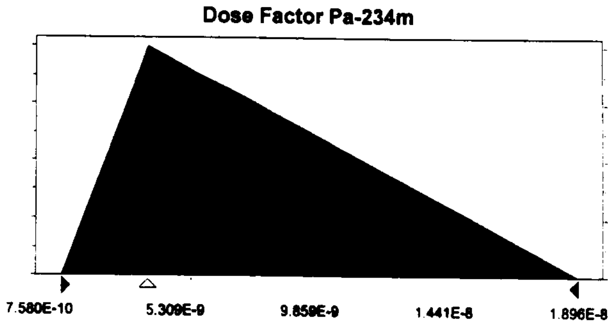


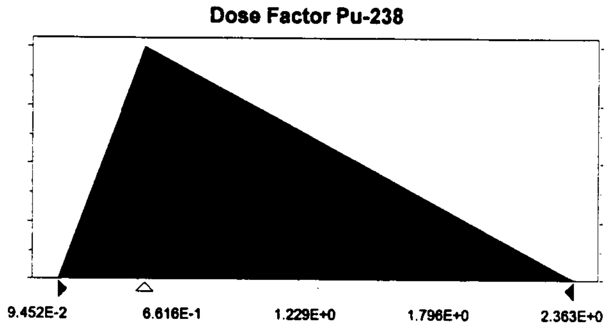
Figure F.1 Continued

Assumption: Dose Factor Pu-238

Triangular distribution with parameters:

Minimum	9.452E-02
Likeliest	4.726E-01
Maximum	2.363E+00

Selected range is from 9.452E-2 to 2.363E+0
Mean value in simulation was 9.768E-1



Assumption: Dose Factor Pu-239

Triangular distribution with parameters:

Minimum	1.056E-01
Likeliest	5.278E-01
Maximum	2.639E+00

Selected range is from 1.056E-1 to 2.639E+0
Mean value in simulation was 1.091E+0

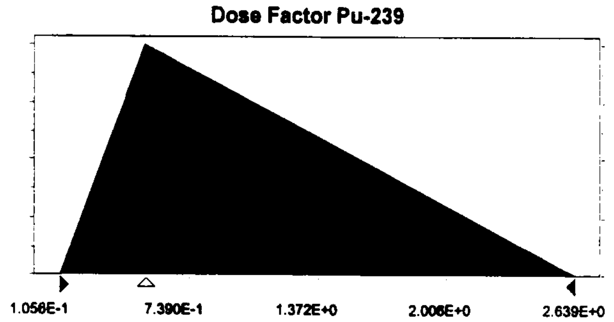


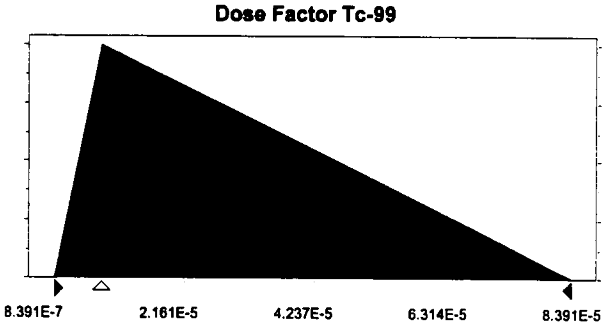
Figure F.1. Continued

Assumption: Dose Factor Tc-99

Triangular distribution with parameters:

Minimum	8.391E-07
Likeliest	8.391E-06
Maximum	8.391E-05

Selected range is from 8.391E-7 to 8.391E-5
Mean value in simulation was 3.105E-5



Assumption: Dose Factor Th-228

Triangular distribution with parameters:

Minimum	8.766E-02
Likeliest	4.383E-01
Maximum	2.192E+00

Selected range is from 8.766E-2 to 2.192E+0
Mean value in simulation was 9.060E-1

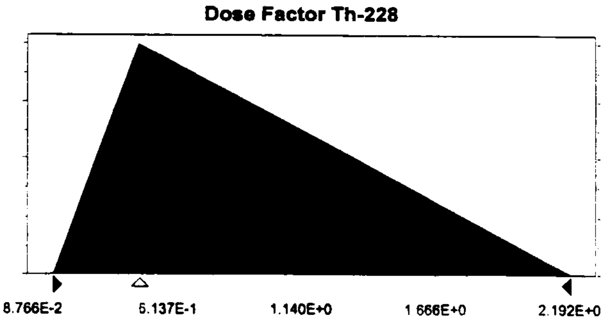


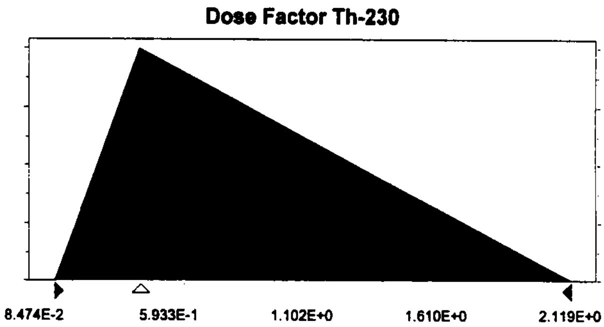
Figure F.1. Continued

Assumption: Dose Factor Th-230

Triangular distribution with parameters:

Minimum	8.474E-02
Likeliest	4.237E-01
Maximum	2.119E+00

Selected range is from 8.474E-2 to 2.119E+0
Mean value in simulation was 8.758E-1



Assumption: Dose Factor Th-232

Triangular distribution with parameters:

Minimum	1.236E-01
Likeliest	6.178E-01
Maximum	3.089E+00

Selected range is from 1.236E-1 to 3.089E+0
Mean value in simulation was 1.277E+0

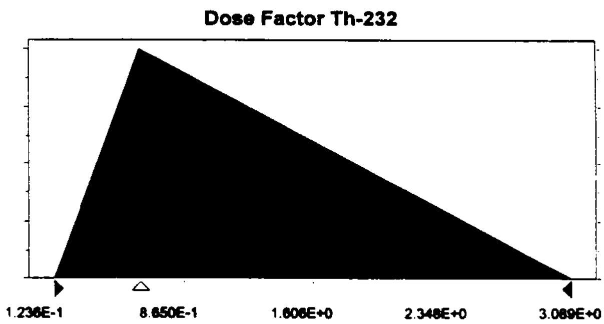


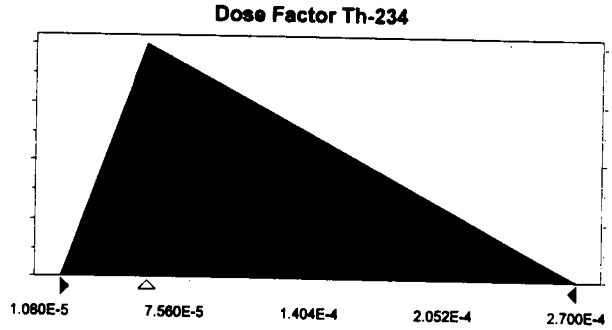
Figure F.1. Continued

Assumption: Dose Factor Th-234

Triangular distribution with parameters:

Minimum	1.080E-05
Likeliest	5.400E-05
Maximum	2.700E-04

Selected range is from 1.080E-5 to 2.700E-4
Mean value in simulation was 1.116E-4



Assumption: Dose Factor U-234

Triangular distribution with parameters:

Minimum	4.584E-02
Likeliest	2.292E-01
Maximum	1.146E+00

Selected range is from 4.584E-2 to 1.146E+0
Mean value in simulation was 4.737E-1

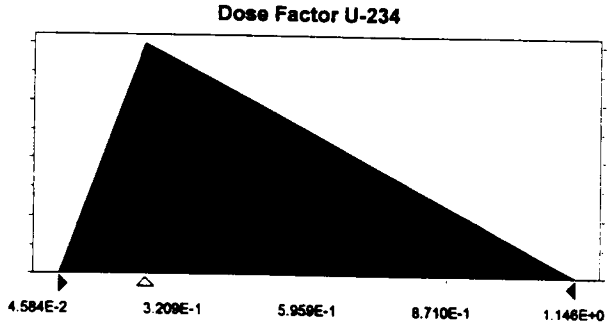


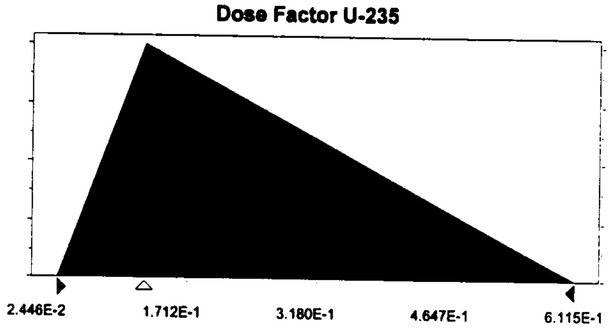
Figure F.1. Continued

Assumption: Dose Factor U-235

Triangular distribution with parameters:

Minimum	2.446E-02
Likeliest	1.223E-01
Maximum	6.115E-01

Selected range is from 2.446E-2 to 6.115E-1
Mean value in simulation was 2.527E-1



Assumption: Dose Factor U-238

Triangular distribution with parameters:

Minimum	4.078E-02
Likeliest	2.039E-01
Maximum	1.020E+00

Selected range is from 4.078E-2 to 1.020E+0
Mean value in simulation was 4.216E-1

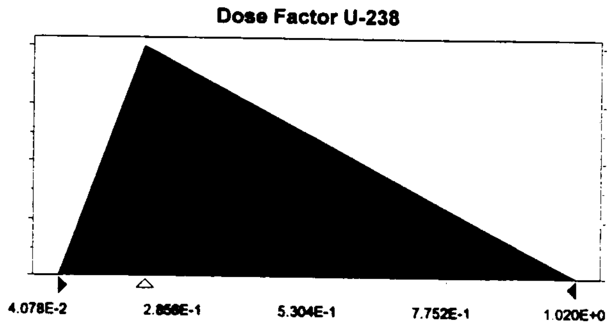


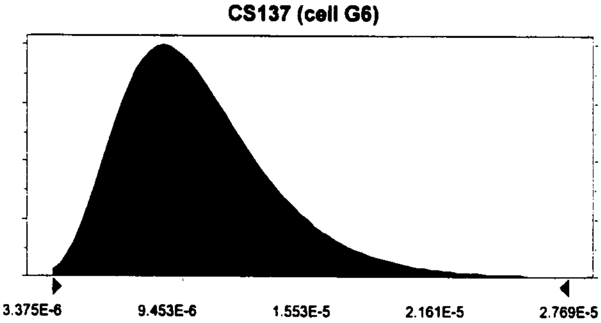
Figure F.1. Continued

Assumption: CS137 (cell G6)

Lognormal distribution with parameters:

Mean	1.028E-05
Standard Dev.	3.720E-06

Selected range is from 0.000E+0 to 2.769E-5
Mean value in simulation was 1.025E-5



Assumption: K40 (cell G8)

Lognormal distribution with parameters:

Mean	3.046E-04
Standard Dev.	4.933E-04

Selected range is from 0.000E+0 to 4.813E-3
Mean value in simulation was 2.955E-4

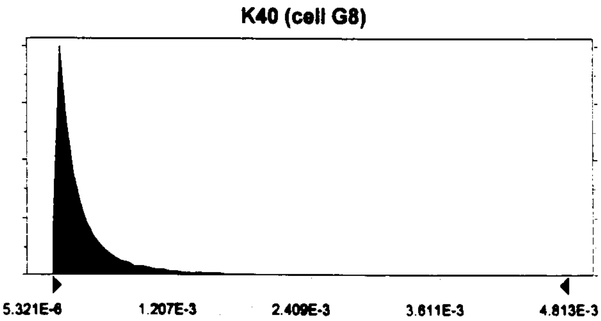


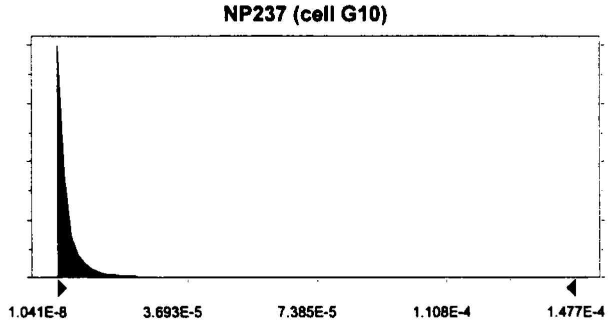
Figure ... Continued

Assumption: NP237 (cell G10)

Lognormal distribution with parameters:

Mean	4.412E-06
Standard Dev.	1.507E-05

Selected range is from 0.000E+0 to 1.477E-4
Mean value in simulation was 4.075E-6



Assumption: PU238 (cell G14)

Lognormal distribution with parameters:

Mean	2.591E-07
Standard Dev.	1.008E-06

Selected range is from 0.000E+0 to 9.603E-6
Mean value in simulation was 2.352E-7

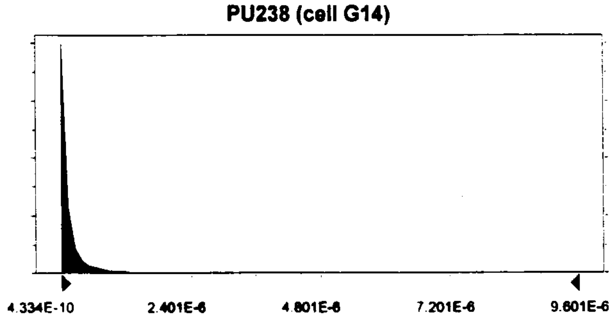


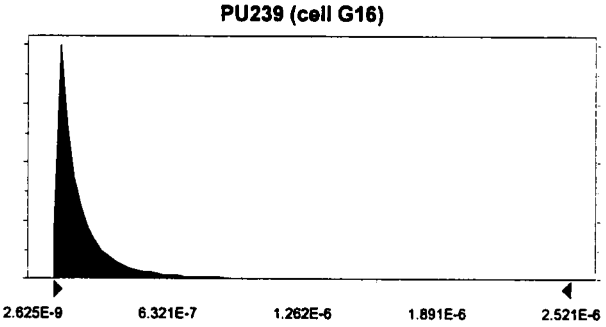
Figure F.1. Continued

Assumption: PU239 (cell G16)

Lognormal distribution with parameters:

Mean	1.566E-07
Standard Dev.	2.576E-07

Selected range is from 0.000E+0 to 2.520E-6
Mean value in simulation was 1.518E-7



Assumption: TC99 (cell G20)

Lognormal distribution with parameters:

Mean	6.178E-04
Standard Dev.	6.812E-04

Selected range is from 0.000E+0 to 6.029E-3
Mean value in simulation was 6.072E-4

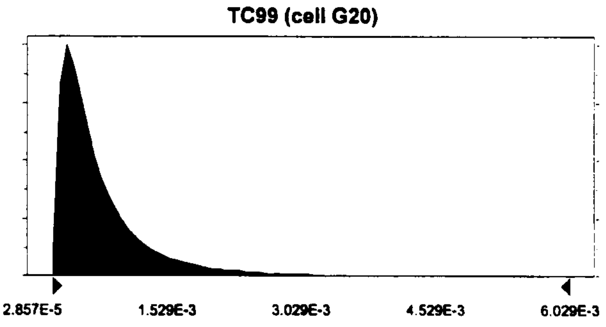


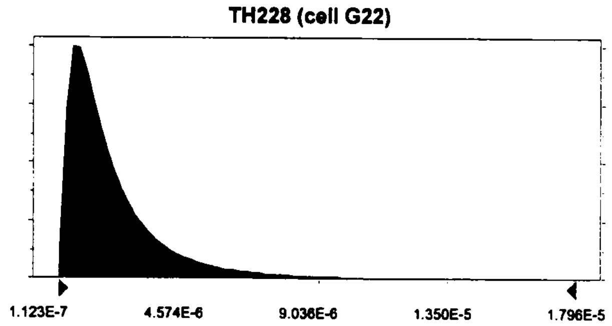
Figure F.1. Continued

Assumption: TH228 (cell G22)

Lognormal distribution with parameters:

Mean	2.031E-06
Standard Dev.	2.076E-06

Selected range is from 0.000E+0 to 1.796E-5
Mean value in simulation was 2.004E-6



Assumption: TH230 (cell G24)

Lognormal distribution with parameters:

Mean	9.809E-07
Standard Dev.	1.629E-06

Selected range is from 0.000E+0 to 1.597E-5
Mean value in simulation was 9.507E-7

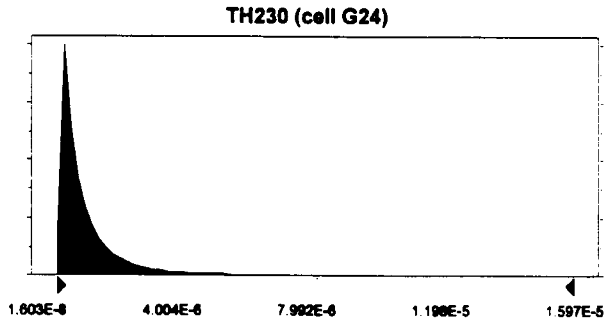


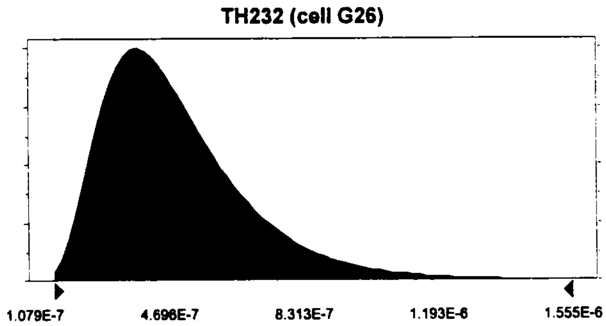
Figure F.1. Continued

Assumption: TH232 (cell G26)

Lognormal distribution with parameters:

Mean	4.521E-07
Standard Dev.	2.114E-07

Selected range is from 0.000E+0 to 1.555E-6
Mean value in simulation was 4.503E-7



Assumption: TH234 (cell G28)

Lognormal distribution with parameters:

Mean	1.571E-05
Standard Dev.	1.065E-05

Selected range is from 0.000E+0 to 8.231E-5
Mean value in simulation was 1.559E-5

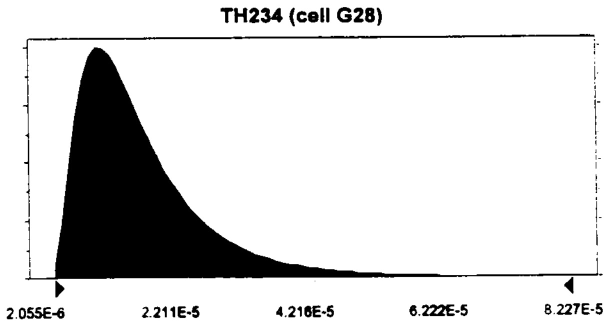


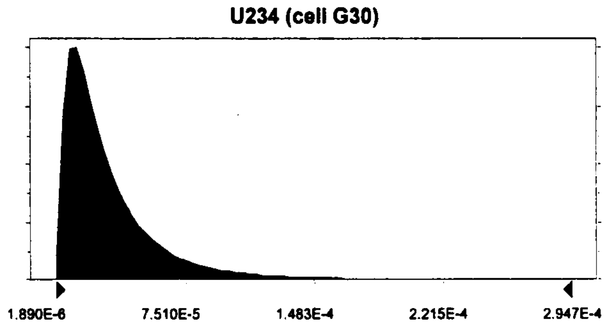
Figure F.1. Continued

Assumption: U234 (cell G30)

Lognormal distribution with parameters:

Mean	3.363E-05
Standard Dev.	3.414E-05

Selected range is from 0.000E+0 to 2.947E-4
Mean value in simulation was 3.319E-5



Assumption: U235 (cell G32)

Lognormal distribution with parameters:

Mean	1.284E-06
Standard Dev.	1.128E-06

Selected range is from 0.000E+0 to 9.325E-6
Mean value in simulation was 1.270E-6

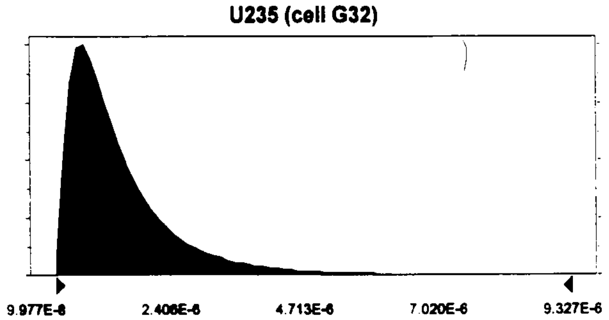


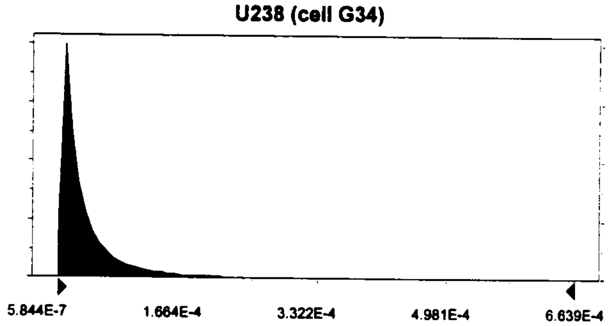
Figure F.1. Continued

Assumption: U238 (cell G34)

Lognormal distribution with parameters:

Mean	3.917E-05
Standard Dev.	6.733E-05

Selected range is from 0.000E+0 to 6.639E-4
Mean value in simulation was 3.789E-5



Assumption: Dose Factor K-40

Triangular distribution with parameters:

Minimum	4.260E-06
Likeliest	1.278E-05
Maximum	3.834E-05

Selected range is from 4.260E-6 to 3.834E-5
Mean value in simulation was 1.846E-5

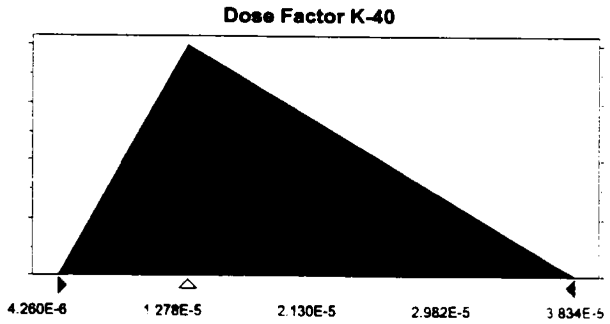


Figure F.1. Continued

APPENDIX G

Dose and Risk EXCEL Spreadsheet Layout

Table G.1. Dose and Risk EXCEL Spreadsheet Layout

i	PARAMETER	UF	REF *	UNITS	MINIMUM	LIKELIEST or MEDIAN	MAXIMUM or GSD	MEAN	STD DEV	MIN	MAX	PDF	EDEi	LRi
	UNCERTAINTY ANALYSIS OF TSCA EMISSIONS RISK (Radionuclides, Inhalation Pathway)													
1	Concentration Cs-137 (C1)		1	pCi/m^3		9.670E-06	1.420E+00	1.028E-05	3.720E-06	0.000E+00	2.769E-05	LN		
1	Dose Factor Cs-137	3	7	mrem/pCi	1.033E-05	3.099E-05	9.300E-05					T	1.648E-06	8.900E-12
2	Concentration K-40 (C2)			pCi/m^3		1.600E-04	3.110E+00	3.046E-04	4.933E-04	0.000E+00	4.813E-03	LN		
2	Dose Factor K-40	3	7	mrem/pCi	4.260E-06	1.278E-05	3.834E-05					T	8.716E-08	4.706E-13
3	Concentration Np-237 (C2)		1	pCi/m^3		1.240E-06	4.920E+00	4.412E-06	1.507E-05	0.000E+00	1.477E-04	LN		
3	Dose Factor Np-237	5	7	mrem/pCi	9.418E-02	4.907E-01	2.454E+00					T	3.346E-03	1.807E-08
4	Concentration Pa-234m (C4)		1	pCi/m^3		3.84E-08						PT		
4	Dose Factor Pa-234m	5	7	mrem/pCi	7.584E-10	3.792E-09	1.896E-08					T	8.008E-13	4.325E-18
5	Concentration Pu-238 (C5)		1	pCi/m^3		6.450E-08	5.300E+00	2.591E-07	1.008E-06	0.000E+00	9.603E-06	LN		
5	Dose Factor Pu-238	5	7	mrem/pCi	9.452E-02	4.726E-01	2.363E+00					T	1.676E-04	9.053E-10
6	Concentration Pu-239 (C6)		1	pCi/m^3		8.140E-08	3.140E+00	1.566E-07	2.576E-07	0.000E+00	2.520E-06	LN		
6	Dose Factor Pu-239	5	7	mrem/pCi	1.056E-01	5.278E-01	2.639E+00					T	2.363E-04	1.276E-09
7	Concentration Ru-106 (C7)			pCi/m^3		8.370E-05						PT		
7	Dose Factor Ru-106	5	7	mrem/pCi	9.554E-05	4.777E-04	1.433E-03					T	2.199E-04	1.187E-09
8	Concentration Tc-99 (C6)		1	pCi/m^3		4.150E-04	2.440E+00	6.178E-04	6.812E-04	0.000E+00	6.029E-03	LN		
8	Dose Factor Tc-99	10	7	mrem/pCi	8.391E-07	8.391E-06	8.391E-05					T	1.915E-05	1.034E-10
9	Concentration Th-228 (C7)		1	pCi/m^3		1.420E-06	2.330E+00	2.031E-06	2.076E-06	0.000E+00	1.796E-05	LN		
9	Dose Factor Th-228	5	7	mrem/pCi	8.766E-02	4.383E-01	2.192E+00					T	3.423E-03	1.848E-08
10	Concentration Th-230 (C8)		1	pCi/m^3		5.060E-07	3.160E+00	9.809E-07	1.629E-06	0.000E+00	1.597E-05	LN		
10	Dose Factor Th-230	5	7	mrem/pCi	8.474E-02	4.237E-01	2.119E+00					T	1.179E-03	6.367E-09
11	Concentration Th-232 (C9)		1	pCi/m^3		4.095E-07	1.560E+00	4.521E-07	2.114E-07	0.000E+00	1.555E-06	LN		
11	Dose Factor Th-232	5	7	mrem/pCi	1.236E-01	6.178E-01	3.089E+00					T	1.391E-03	7.513E-09
12	Concentration Th-234 (C10)		1	pCi/m^3		1.300E-05	1.850E+00	1.571E-05	1.065E-05	0.000E+00	8.231E-05	LN		
12	Dose Factor Th234	5	7	mrem/pCi	1.080E-05	5.400E-05	2.700E-04					T	3.861E-06	2.085E-11
13	Concentration U-234 (C11)		1	pCi/m^3		2.360E-05	2.320E+00	3.363E-05	3.414E-05	0.000E+00	2.947E-04	LN		
13	Dose Factor U-234	5	7	mrem/pCi	4.584E-02	2.292E-01	1.146E+00					T	2.975E-02	1.606E-07
14	Concentration U-235 (C12)		1	pCi/m^3		9.650E-07	2.130E+00	1.284E-06	1.128E-06	0.000E+00	9.325E-06	LN		
14	Dose Factor U-235	5	7	mrem/pCi	2.446E-02	1.223E-01	6.115E-01					T	6.491E-04	3.505E-09
15	Concentration U-238 (C13)		1	pCi/m^3		1.970E-05	3.230E+00	3.917E-05	6.733E-05	0.000E+00	6.639E-04	LN		
15	Dose Factor U-238	5	7	mrem/pCi	4.078E-02	2.039E-01	1.020E+00					T	2.209E-02	1.193E-07
	Inhalation Rate (IR)		3,8	cm^3/hr		8.333E+05	1.225E+00	8.506E+05	1.744E+05	4.533E+05	1.532E+06	LN		
	Exposure Duration (ED)		4,8	yr		9	1.826	1.079E+01	7.132E+00	1.478E+00	5.480E+01	LN		
	Exposure Frequency (EF)		5,8	d/yr		275	75					T		
	Risk Factor (RF)	4	6	.060/sv	0.015	6.00E-02	0.24					T		
	Conversion Factor (K1) for dose			2.40E-08		2.40E-05								
	Conversion Factor (K2) for risk			1.00E-05		1.00E-05								
							Total EDE						6.248E-02	
							Total LR						3.374E-07	

Notes:

Effective Dose Equivalent per radionuclide i (EDEi) = (C adjusted)i x IR x EF x DFi x K1 mrem/yr

EDE for all radionuclides = SUM for i = 1 to n (EDEi) mrem/yr

Lifetime Risk per radionuclide i (LRi) = EDEi x ED x RF x K2

Table G.1. Continued

LR for all radionuclides = [SUM for i=1 to n (LRi)]	
UF = Uncertainty Factor	
PDF = Probability Density Function (N=Normal, T=Triangular, LN=Lognormal, PT = Point Estimate)	
K1 = 24 hr/day x 1E-6 m^3/cm^3	
K2 = 1E-5 Sv/mrem	
pCi = pico Curie = Ci x 1E-12	
Median is the geometric mean	
GSD is the geometric standard deviation	
Mean is the mean of the lognormal distribution = exp[ln(median) + 0.5*ln(GSD)^2]	
Std Dev is the standard deviation of the lognormal distribution = SQRT[(mean^2)*(exp(ln(GSD)^2)-1)]	
* References for values, uncertainty factors and ranges:	
1. La71, An75	5. EPA91
2. Li79	6. NCRP93
3. EPA89a	7. EPA89c
4. EPA89b	8. DOE93b

APPENDIX H

Deterministic Risk Calculations

Table H.1. Deterministic Risk Calculation Using ICRP Factors

ICRP METHODOLOGY ANALYSIS OF TSCA EMISSIONS RISK			
(Radionuclides, Inhalation Pathway)			
RADIONUCLIDE	CONCENTRATION	DOSE	RISK
	MEAN VALUE	FACTOR	
	(pCi/m^3)	(mrem/pCi)	
Cs-137	1.696E-05	3.099E-05	6.622E-11
K-40	3.802E-04	1.278E-05	6.122E-10
Np-237	3.410E-06	4.907E-01	2.108E-07
Pa-234m	3.840E-08	3.792E-09	1.835E-17
Pu-238	3.648E-07	4.726E-01	2.172E-08
Pu-239	1.968E-07	5.278E-01	1.309E-08
Ru-106	8.370E-05	4.777E-04	5.038E-09
Tc-99	5.806E-04	8.391E-06	6.138E-10
Th-228	1.422E-05	4.383E-01	7.853E-07
Th-230	9.586E-07	4.237E-01	5.118E-08
Th-232	5.094E-07	6.178E-01	3.965E-08
Th-234	1.684E-04	5.400E-05	1.146E-09
U-234	2.744E-05	2.292E-01	7.924E-07
U-235	1.267E-06	1.223E-01	1.952E-08
U-238	3.349E-05	2.039E-01	8.604E-07
Total Risk=		Total Risk=	2.802E-06
(Sum of risk per nuclide)			
Where:			
Risk per Nuclide= Concentration x Dose Factor x IR x ED x EF			
	x Risk Conversion Factor x 1E-5 Sv/mrem		
Risk Conversion Factor=			0.06/Sv
Inhalation Rate (IR)=		20	m^3/d
Exposure Duration (ED)=		30	y
Exposure Frequency (EF)=		350	d/y

Table H.2. Deterministic Risk Calculation Using

EPA Slope Factors

EPA SLOPE FACTOR ANALYSIS OF TSCA EMISSIONS RISK			
(Radionuclides, Inhalation Pathway)			
RADIONUCLIDE	CONCENTRATION	SLOPE	RISK
	MEAN VALUE	FACTOR	
	(pCi/m^3)	(risk/pCi)	
Cs-137	1.696E-05	1.910E-11	6.803E-11
K-40	3.802E-04	7.460E-12	5.956E-10
Np-237	3.410E-06	3.450E-08	2.471E-08
Pa-234m	3.840E-08	6.270E-15	5.056E-17
Pu-238	3.648E-07	2.740E-08	2.099E-09
Pu-239	1.968E-07	2.780E-08	1.149E-09
Ru-106	8.370E-05	1.150E-10	2.021E-09
Tc-99	5.806E-04	2.890E-12	3.524E-10
Th-228	1.422E-05	9.450E-08	2.822E-07
Th-230	9.586E-07	1.720E-08	3.462E-09
Th-232	5.094E-07	1.930E-08	2.065E-09
Th-234	1.684E-04	1.900E-11	6.719E-10
U-234	2.744E-05	1.400E-08	8.067E-08
U-235	1.267E-06	1.300E-08	3.459E-09
U-238	3.349E-05	1.240E-08	8.721E-08
Total Risk=		Total Risk=	4.907E-07
(Sum of risk per nuclide)			
Where:			
Risk per Nuclide= Concentration x Slope Factor x IR x ED x EF			
Inhalation Rate (IR)=		20	m^3/d
Exposure Duration (ED)=		30	y
Exposure Frequency (EF)=		350	d/y

VITA

Teresa Lynn Cook Perry was born in Pikeville, Kentucky and at the age of three moved with her family to Knoxville, Tennessee. She graduated from Central High School and began attending the University of Tennessee. She has received the following degrees from the University of Tennessee in Knoxville: Bachelor of Arts with a double major in English and French, Bachelor of Science in Civil Engineering, and Master of Engineering with a concentration in structural engineering. In December, 1995, she received the Master of Science in Environmental Engineering.

She worked with the Tennessee Valley Authority (TVA) for 13 years in various positions as a manager, civil engineer, and programmer analyst. In 1990, she left TVA to pursue a growing interest in returning to engineering work and studying environmental engineering. She worked with Bechtel Environmental Inc. from 1990 to 1992 as a senior engineer. From 1992 and currently, she works with the U.S. Department of Energy as a program manager and environmental engineer in the Environmental Restoration Division in Oak Ridge, Tennessee.

Her academic and research interests are diverse and currently include uncertainty analysis in environmental engineering and other areas of engineering, transport and deposition modeling, risk analysis and risk management, and statistical and computer applications.