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Exposure Factors Manual

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ABSTRACT: Assessing health risks associated with potential exposure to chemicals from petroleum or petrochemical operations requires the consideration of multiple exposure pathways. These pathways include ingestion of water, food, or soil, inhalation of vapors or airborne particulate, and dermal absorption from contaminated soil, water, or by direct skin contact. To estimate the exposures for each pathway, a number of variables related to exposure, that is, exposure factors, are needed. Some categories of exposure factors include physiologic factors (e.g., body weight), time-activity factors (e.g., time spent at home), and contact rate factors (e.g., soil ingestion rate). This manual is organized by exposure factor category and includes a description of selected exposure factors commonly used in risk assessments, a brief summary, and an evaluation of the current scientific data supporting a recommended point value for each factor, and available information on the known distributions. It is hoped that this information will promote consistency and quality among various risk assessment activities.

KEY WORDS: exposure factors, probability distributions, time activity patterns, contact rates.

I. INTRODUCTION

This document summarizes and evaluates the current scientific documentation and statistical data for various exposure factors used in risk assessments. Exposure factors are the variables used in the risk assessment calculations. They include contact rates with environmental media (e.g., ingestion rates of water, food, and soil), exposure frequency and duration (e.g., length of time in one residence, time spent indoors/outdoors/at work), body weight, averaging time, and chemical-specific factors (e.g., chemical transport through skin, lungs, and gut). These factors are used whenever risk assessments are performed, for example, when assessing the safety of products, when evaluating the emissions from manufacturing operations, and in efforts to assess and remediate waste sites. It is hoped that this information will promote consistency and quality among various risk assessment activities.

For each exposure factor, a rationale for use of a recommended point value is provided. This value is believed to represent the best single value for use in risk assessments. It is recognized that for each exposure factor, a distribution of values exist. Therefore, where available, information is included on the range of values in existence for the exposure factors presented, and a statistical treatment of the exposure factor distribution data is provided.

Use of recommended point values will minimize the severe overestimation of exposure that arises when exposure factors are chosen from the extreme end of distributions and subsequently chained together. However, use of point values results in an undefined, uncertain level of "acceptable" and "adequate" risk since the factors which affect exposure are dynamic, for example, household mobility, employment, and population age structure. High-quality assessments of risk and exposure provide information on the distributions of population risk; they do *not* manage risk. These assessments acknowledge that all members of a community differ in their daily activities, age, size, and the amount of time they live in the community. They provide the information on the variability in dose that individuals can experience. Some examples of how exposure factor distributions can be incorporated into risk assessments are provided in the manual.

Two lead organizations with expertise in exposure assessment technologies in the U.S., the U.S. Environmental Protection Agency (EPA) and the National Academy of Sciences (NAS), have recognized that many scientific gaps exist in currently used exposure assessment methodologies. These organizations, as well as academic groups, industry, and independent scientific groups, are actively engaged in research to improve existing exposure assessment methodologies. The scientific basis of the exposure factors commonly used in exposure/risk assessments (e.g., intake rates and time-activity patterns) are included in these research activities. In a recent conference on exposure assessment, numerous papers were devoted to this specific area (ATSDR/EPA/CDC, 1991). From these activities, it is reasonable to expect that improved information on exposure factors will be available in the near future.

II. PROBABILITY DISTRIBUTIONS

The purpose of describing an exposure factor as a set of possible values is to describe the range, variability, and uncertainty for each factor, and to calculate the range of possible risks or acceptable exposures. This is done by randomly choosing one possible value for each variable and calculating the risk or exposure. This is repeated many times, each time randomly selecting another possible value for each variable. The result is more than a single measure of risk or exposure. The result is a probability distribution with a most likely value, an average value, extreme values, and a shape that describes the variability and uncertainty around the calculated risk or exposure. The presentation of this information to environmental managers, regulators, and concerned community residents is intended to provide them with representative data on which they can make decisions.

A. Distribution Type

The probability distributions that are included in this manual for specific exposure factors are derived from the available scientific literature and reflect the quantity, quality, and variability of the data. They are described in terms that are used directly by the @RISK simulation software (Palisade, 1990), a tool that is used to randomly sample from the set of probable values for each factor when calculating outcomes, such as risk. @RISK is a Lotus 1-2-3 “add-in” and runs on IBM personal computers. A similar product, Crystal Ball (Decisioneering, 1993), is an Excel spreadsheet add-in.

Each exposure factor distribution is described by a specific term, such as lognormal, normal, cumulative, or triangular. This term describes the shape of the distribution. It is chosen based on the available data. The criteria for the most common distributions are listed as follows:

Normal — Normal “bell-shaped” curve described by a mean and standard deviation greater than 0. The @RISK standard entry is @NORMAL (mean, standard deviation).

Lognormal — Lognormal curve (no values less than 0) described by a mean and standard deviation greater than 0. The @RISK notation is @LOGNORM (mean, standard deviation).

Cumulative — Irregular probability distribution described by a minimum, maximum, and up to 25 points described by a point value, and point probability (greater than 0 and less than 1). The @RISK entry is @CUMUL (minimum, maximum, value_1, probability_1, value_2, probability_2 …, value_n, probability_n, n), where n is the total number of data pairs.

Histogram — Defined histogram distribution described by a minimum, maximum, and up to 25 equal-length classes, with each class being given a probability weight. The @RISK notation is @HISTOGRM (minimum, maximum, probability_1, probability_2,…, $\text{probability}_{n)}$.

Triangular — A triangular distribution described by three points: minimum, most likely, and maximum. The @RISK notation is @TRIANG (minimum, most likely, maximum).

Uniform — A uniform distribution described by two values: minimum, and maximum. The @RISK entry is @UNIFORM (minimum, maximum).

The distribution that utilizes the maximum amount of available information is chosen as the best descriptor. It is possible to have data for an exposure factor that describe the minimum, maximum, most likely (mode), mean, and have the data sorted into a frequency distribution. In this case, the cumulative or histogram distributions would use the maximum amount of information and would be the preferred choice. Normal or lognormal distributions are selected if there is confidence that the shapes of the curves are appropriate. Triangular and uniform distributions are least preferred and are used when only minimal information is available.

B. **Sampling Method**

Two methods for random sampling from probability distributions are available in simulation software: Monte Carlo and Latin hypercube.

Monte Carlo is the traditional technique for using random (or pseudorandom) numbers to sample from the input distribution. Samples are more likely to be drawn from values that have higher probabilities, for example, near the mode, and less likely to be drawn from values that have low probabilities, for example, near the "tails". Clustering of sampled values near the mode is a limitation if the tails are important to the calculated results (e.g., worst case). One way to overcome this limitation is to sample many, many times, that is, conduct many iterations. When combining distributions of multiple variables, Monte Carlo sampling is more likely to maintain unspecified correlations between variables because of the clustering effect.

Latin hypercube is a newer technique that uses random sampling within intervals of the input cumulative frequency distribution. This minimizes the number of samples necessary in order to sufficiently represent the distribution. The input distribution is divided into intervals equal to the number of samples (iterations). For example, if 100 samples are to be selected, the distribution is divided into 100 1% intervals. One sample is randomly selected within each interval. Latin hypercube sampling does not have the limitation of clustered sampling near the mode and is the preferred sampling technique when the less likely values are important to the outcome. When combining distributions of multiple variables, Latin hypercube sampling maintains complete independence of the variables. If any correlation between variables is intended, it must be specifically identified in the distribution descriptions, for example, one variable is defined as a function of a related variable. To maximize speed and minimize sampling iterations, Latin hypercube is the recommended method of sampling.

The @RISK software program used to develop the distributions in this manual provides, as output, an "expected value". This value is the distribution mean, which may not be the best representation of central tendency.

C. **Applications**

Typical applications for using exposure factor probability distributions are the calculation of health-based cleanup levels, lifetime dose, or risk. The following examples illustrate the calculation of health-based cleanup levels for a carcinogen and a noncarcinogen, for residential and industrial exposure areas.

A regulatory agency, the New Jersey Department of Environmental Protection and Energy (NJDEPE), proposed health-based soil cleanup levels based on single point values for various exposure factors (NJDEPE, 1992). A few point values represented the average value. However, most point values represented more extreme "worst-case" values. Using these single points, the NJDEPE calculated chemical-specific soil cleanup levels for two land-use areas: residential and nonresidential (industrial). However, it was not possible to determine the level of protection afforded by this combination of average and worst-case factors. In all cases, a level of safety was already incorporated by choosing health criteria with built-in safety (EPA reference doses and carcinogenicity slope factors) and through application of a conservative (1×10^{-6}) incremental risk level in the case of carcinogens.

Using Latin hypercube sampling from probability distributions of the exposure factors, distributions for soil cleanup levels were calculated (Figures 1–4). The NJDEPE calculated value was always at the extreme end of the distribution, more extreme than even the worst-case individual.

Benzene, a carcinogen, had an NJDEPE proposed soil cleanup level of 13 mg/kg for industrial areas and 3 mg/kg for residential areas. These levels were based on a 70-kg adult and 16-kg child, soil ingestion rates of 100 mg/d for adults and 200 mg/d for children, 25-year working lifetime with all soil ingested at work (or at home for children), and 70-year life spans. However, the cleanup levels were shown to inconsistently protect the exposed populations when distributions for body weight, soil ingestion rate, time at work, and length of residence time, as well as survey values for time at home, were considered. Figures 1 and 2 illustrate the distribution of benzene cleanup levels for industrial and residential land-use areas. The industrial standard of 13 mg/kg is very extreme and represents an unrealistic worst-case situation (99.2% of the cleanup values would be greater). The residential standard (3 mg/kg), on the other hand, is less extreme but still represents a worst-case scenario (89.5% of the cleanup values would be greater). The most likely values would cluster near the 50% values: 3920 mg/kg for industrial settings and 188 mg/kg for residential areas.

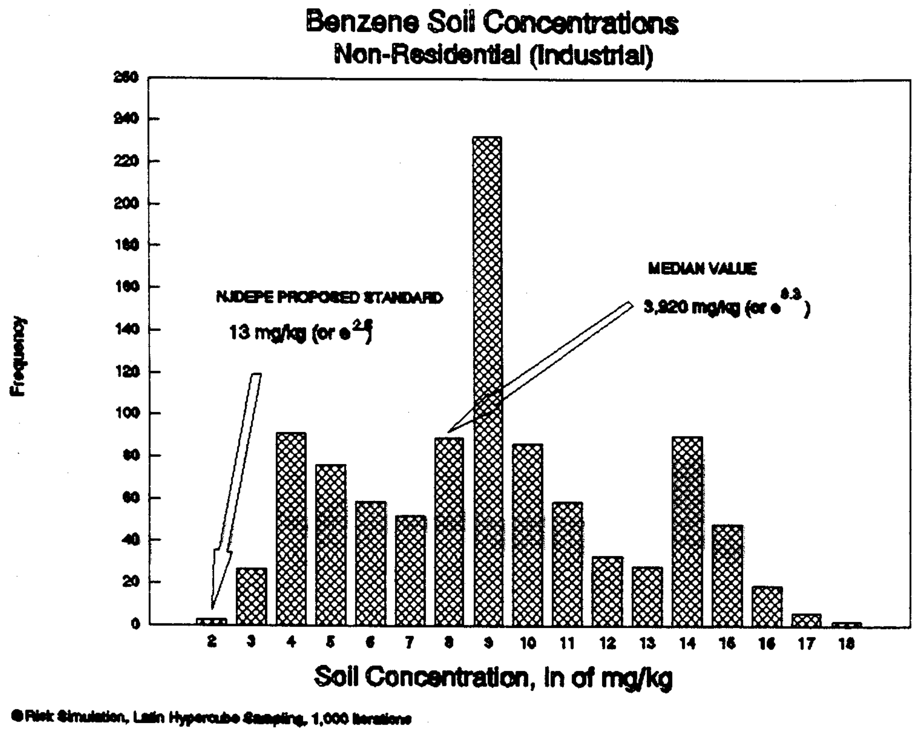

FIGURE 1. Benzene soil concentrations — nonresidential (mg/kg).

Percentile probabilities (chance of a result ≥ shown value):

13 mg/kg (or $e^{2.56}$), 99.2% NJDEPE proposed standard; 28.9 mg/kg (or $e^{3.36}$), 95%; 3920 mg/kg (or $e^{8.27}$), 50%.

Note: The NJDEPE proposed standard, 13 mg/kg, is 300 times less than the median distribution value (3920 mg/kg) and two times less than the upper 95th percentile value (28.9 mg/kg).

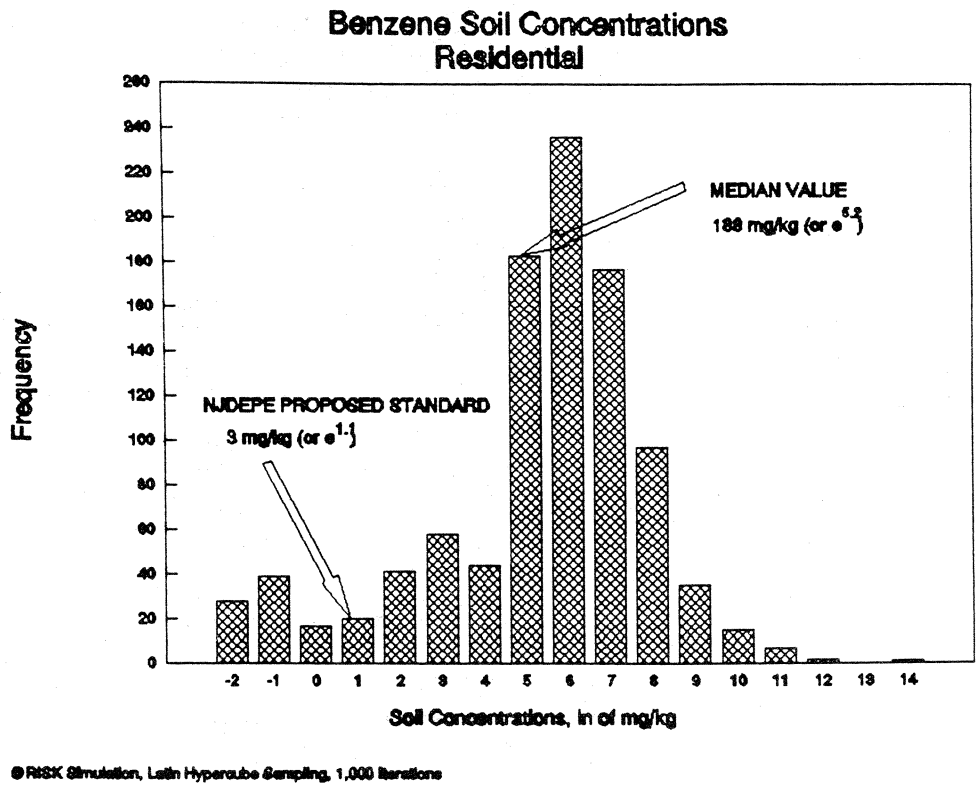

FIGURE 2. Benzene soil concentrations — residential (mg/kg).

Percentile probabilities (chance of a result ≥ shown value):

0.31 mg/kg (or $e^{-1.17}$), 95%; 3 mg/kg (or $e^{1.1}$), 89.5% NJDEPE proposed standard; 188 mg/kg (or $e^{5.24}$), 50%.

Note: The NJDEPE proposed standard, 3 mg/kg, is 63 times less than the median distribution value (188 mg/kg) and ten times greater than the upper 95th percentile value (0.31 mg/kg).

For naphthalene, a noncarcinogen, the NJDEPE-proposed standards represented extremely conservative situations. The 4200 mg/kg industrial standard is very rare; 99.9% of the possible cleanup values are greater. A value of 9500 mg/kg could still be considered a worst-case value; 95% of the possible values would be greater. For residential land use, NJDEPE-proposed 230 mg/kg, a value at the extreme tail of the distribution; 98% of the values are greater. Even a value ten times higher would represent 95% of the distribution. Figures 3 and 4 illustrate the distribution of naphthalene soil cleanup levels.

In situations such as these, safety factors to protect public health are incorporated into the health criteria employed. It is not recommended to add additional margins of safety by selecting extreme values from the tails of the cleanup level distribution. Rather, it is suggested that the median (50%) or mode (most frequent value) be selected. Use of average values is considered less favorable as they are unrepresentative of the central tendency in highly skewed distributions. A compilation of the recommended point values for use in risk assessments appears in Table 1. A summary of distribution data for selected factors appears in Table 2.

TABLE 1
Recommended vs. Default Point Value Exposure Factors

Exposure factor	Recommended point value[a]	Commonly used default value	Data quality
Adult body weight	72 kg	70 kg	High
Child body weight	13 kg	11 kg	High
Adult body surface area	1.8 m^2	2.0 m^2	Moderate
Weekly hours at work	23 h	40 h	Moderate
Working tenure	4 years	25 or 30 years	High
Weekly hours at home/away — adult	108 h home; 60 h away	168 h	Moderate
Weekly hours at home/away — child	138 h home; 30 h away	168 h	Moderate
Years at one residence	8.1 years	25 or 30 years	High
Weekly hours spent indoors/outdoors	156 h indoors; 12 h outdoors	168 h	High
Shower duration	7.6 m	12 m	Moderate
Adult soil ingestion	0.1 mg/d	100 mg/d	Low
Child soil ingestion	16 mg/d	200 mg/d	Moderate
Total dietary intake	1.6 kg/d	3.0 kg/d	Moderate
Consumption of home-grown fruits and vegetables — adult	28 g/d — fruit; 50 g/d — vegetables	40 g/d — fruit; 80 g/d — vegetables	Moderate
Consumption of fish and shellfish — adult	14 g/d (total) 6.5 g/d (nonmarine)	54 g/d	Moderate
Adult beef intake	88 g/d, 40 g/d as home-grown	75 g/d as home-grown	Moderate
Adult water intake	1.4 l/d	2 l/d	High
Adult inhalation rate	18 m^3/d	20–30 m^3/d	Moderate
Child inhalation rate	12 m^3/d	15–20 m^3/d	Moderate

[a] Recommended point values represent measures of central tendency (median, mode, or mean) from the best available source(s) of data. Data sources are cited in the text of this manual.

TABLE 2
Recommended Distribution Exposure Factors

Exposure factor	Recommended distribution	Unit	Source (see table footnote)
Adult body weight	@CUMUL (44,107,52.3,0.05,57.6,0.15,68.7,0.5, 84.4,0.85,97,0.95,5)	kg	1
Child body weight	@CUMUL (7,20,10.6,0.05,11.4,0.15,12.9,0.5, 14.7,0.85,16,0.95,5)	kg	1
Adult height — men	@NORMAL (69.12,2.85)	in.	2
Adult height — women	@NORMAL (63.68,2.60)	in.	2
Skin surface area — men	@CUMUL (1.5,2.3,1.66,0.05,1.53,0.15,1.69,0.5, 1.91,0.85,2.09,0.95,5)	m^2	1
Skin surface area — women	@CUMUL (1.4,2.1,1.45,0.05,1.53,0.15,1.69,0.5, 1.91,0.85,2.09,0.95,5)	m^2	1
Hours at work	@CUMUL (0,107,0.34,0.3,8.31,0.4,20.22,0.5,32-.08,0.6,37.68,0.7,41.33,0.8,46.88,0.9,7)	h/week	1
Years in one residence	@CUMUL (1,75,4,0.25,8,0.5,15,0.75,26,0.9,33, 0.95,47,0.99,6)	years	3
Adult soil ingestion	@CUMUL (0,216,0,0.17,0,0.33,0,0.5,17,0.67,14.8, 0.83,216,1,6)	mg/d	4
Child soil ingestion	@CUMUL (0,1391,0,0.05,0,0.10,16,0.5,67,0.9,1-10,0.95,5)	mg/d	5
Vegetable ingestion	@LOGNORM (62,1800)	g/d	6
Freshwater finfish ingestion	@CUMUL (0.4,15,0.4,0.02,1,0.13,1.6,0.36,2,0.49.3, 0.7,5,0.9,10,0.98,7)	mg/kg/d	7
Saltwater finfish ingestion	@CUMUL (0.2,10,0.2,0.03,0.8,0.25,1.4,0.53,2,0.74, 4,0.93,10,1,5)	mg/kg/d	7
Shellfish ingestion	@CUMUL (0.2,10,0.2,0.12,0.8,0.45,1.4,0.66,2,0.79, 4,0.96,5)	mg/kg/d	7
Beef ingestion	@NORMAL (75,56)	g/d	6
Water ingestion — adult	@CUMUL (0.4,2,0.4,0.192,0.96,0.396,1.28,0.6,1.7, 0.8,1.96,1,5)	l/d	1
Water ingestion — child	@CUMUL (0.6,3,0.676,0.025,1.046,0.25,1.316,0.5, 1.655,0.75,2.562,0.975,5)	l/d	8

[1] Exposure Factor Handbook.
[2] Brainard and Burmaster (1992).
[3] EPA-450/3-92-011.
[4] Calabrese *et al.* (1990).
[5] Calabrese *et al.* (1989b).
[6] Finley and Paustenbach (1992).
[7] EPA-503/8-89-002.
[8] Roseberry and Burmaster (1992).

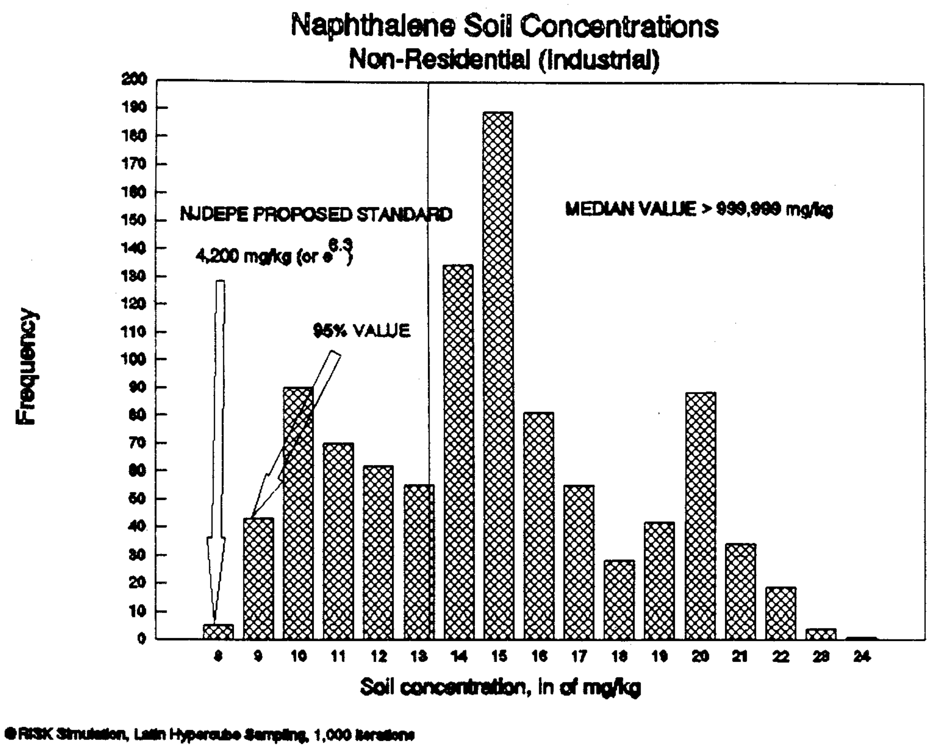

FIGURE 3. Naphthalene soil concentrations — nonresidential (mg/kg).

Percentile probabilities (chance of a result ≥ shown value):

4200 mg/kg (or $e^{8.34}$), >99.9% NJDEPE proposed standard; 9500 mg/kg (or $e^{9.16}$), 95%; >999,999 mg/kg (or $e^{13.8}$), 50%.

Note: The NJDEPE proposed standard, 4200 mg/kg, is more than 238 times less than the median distribution value (999,999 mg/kg) and two times less than the upper 95th percentile value (9500 mg/kg). Values >999,999 mg/kg represent 100% and indicate that pure product can be present because exposures are unlikely to occur.

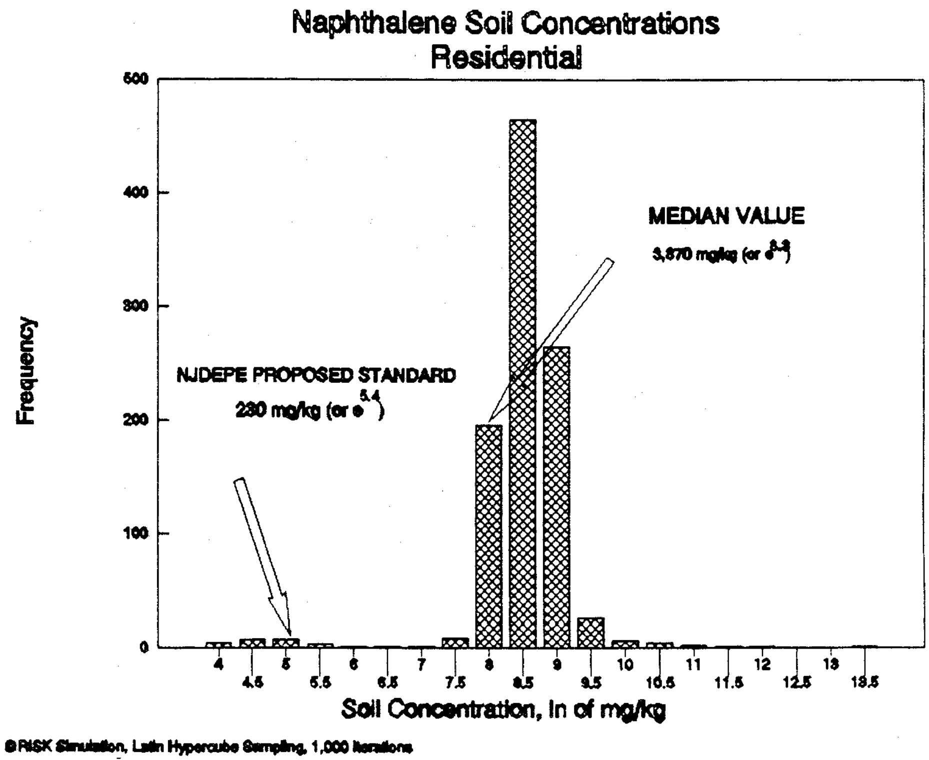

FIGURE 4. Naphthalene soil concentrations — residential (mg/kg).

Percentile probabilities (chance of a result ≥ shown value):

230 mg/kg (or $e^{5.44}$), 98% NJDEPE proposed standard; 2290 mg/kg (or $e^{7.74}$), 95%; 3870 mg/kg (or $e^{8.26}$), 50%.

Note: The NJDEPE proposed standard, 230 mg/kg, is 17 times less than the median distribution value (3870 mg/kg) and ten times less than the upper 95th percentile value (2290 mg/kg).

III. RECEPTOR PHYSIOLOGIC PARAMETERS

A. Adult Body Weight

1. Data Summary

The adult body weight recommended for use in risk assessments is 72 kg. This value is the average of the mean 50th percentile values for adults (men and women) across the age spectrum of 18 to 75 years listed in the EPA Exposure Factor Handbook (EPA, 1989a). Bivariate distributions for height and weight of men and women in the U.S. have been calculated based on data published in the U.S. Public Health Service (Brainard and Burmaster, 1992). As expected, height and weight were found to be correlated variables for both men and women.

Based on the distribution data, the commonly used default exposure factor value of 70 kg for human adult body weight is a reasonable value to use in risk assessments. Various distributions of adult body weight are presented below. Cumulative, normal, lognormal, and uniform distributions are represented. The normal, lognormal, and uniform distributions are extrapolations of data sets, where the actual data are not included in the publication. Use of cumulative distributions is most reasonable as all data are included. The uniform distribution is least useful as much of the actual data are compressed into two points, a maximum value and a minimum value. Using the simulated distribution of adult male and female (combined) body weights (ages 18 to 75) based on all the percentile data in the EPA Exposure Factor Handbook, the commonly used default value of 70 kg is near the mean of the distribution.

2. *Distributions (Figures 5 to 11)*

a. Distribution type, cumulative; @RISK formula, @CUMUL; (44,107,52.3,0.05,57.6, 0.15,68.7,0.5,84.4,0.85,97,0.95,5); Reference, EPA 5-42 and 5-43; Unit, kilograms; Note, both sexes; Median, 68.73 kg.

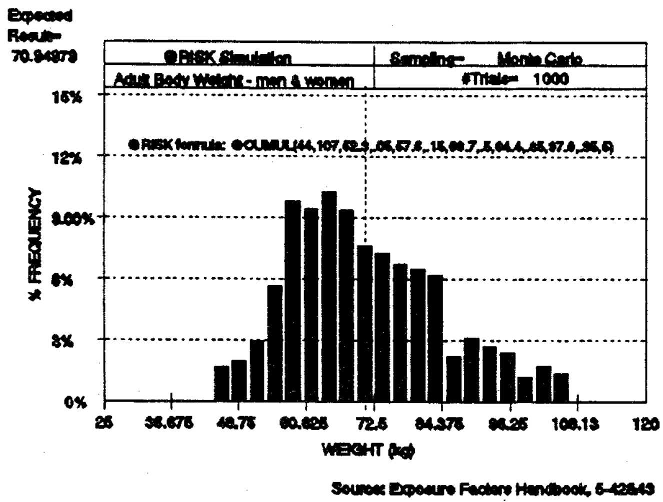

FIGURE 5. Adult body weight distribution (both sexes).

b. Distribution type, normal; @RISK formula, @NORMAL (75,3.536); Reference, RiskFocus, Versar, 1991; Unit, kilograms; Note, male; Median, 75.20 kg.

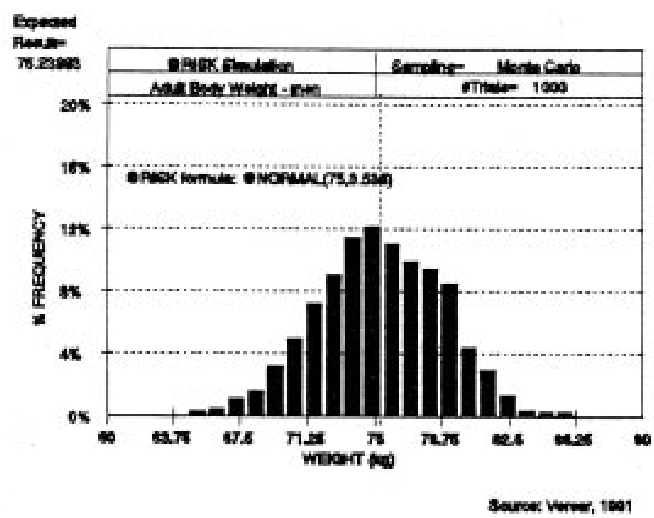

FIGURE 6. Adult body weight distribution — male.

c. Distribution type, normal; @RISK formula, @NORMAL (64.2,13.19); Reference, Finley and Paustenbach, 1992; Unit, kilograms; Note, both sexes; Median, 63.98 kg.

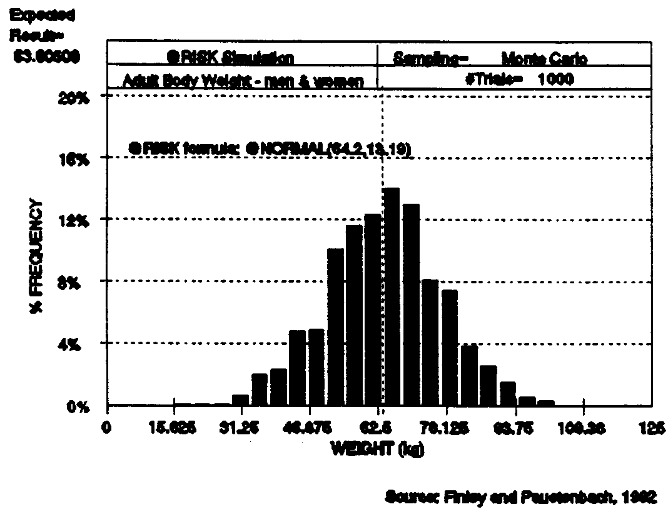

FIGURE 7. Adult body weight distribution (both sexes).

d. Distribution type, uniform; @RISK formula, @UNIFORM (46.8,101.7); Reference, Finley and Paustenbach, 1992; Unit, kilograms; Median, 74.115 kg.

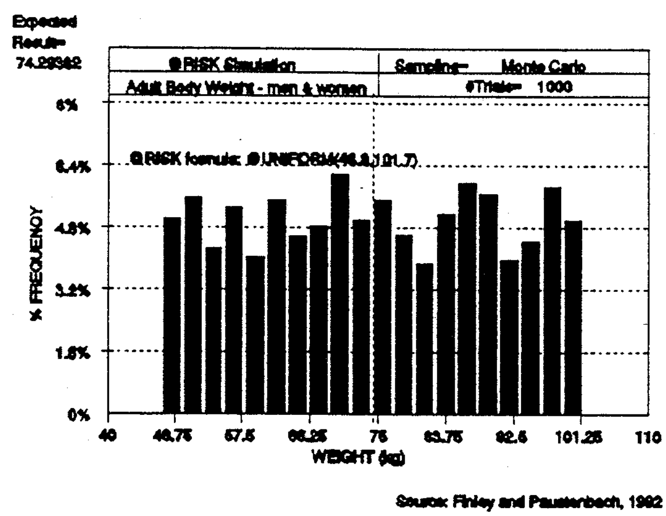

FIGURE 8. Adult body weight distribution.

e. Distribution type, normal; @RISK formula, @NORMAL (78.1,0.0016); Reference, Paustenbach *et al.*, 1991; Unit, kilograms; Note, both sexes; Median, 78.1 kg.

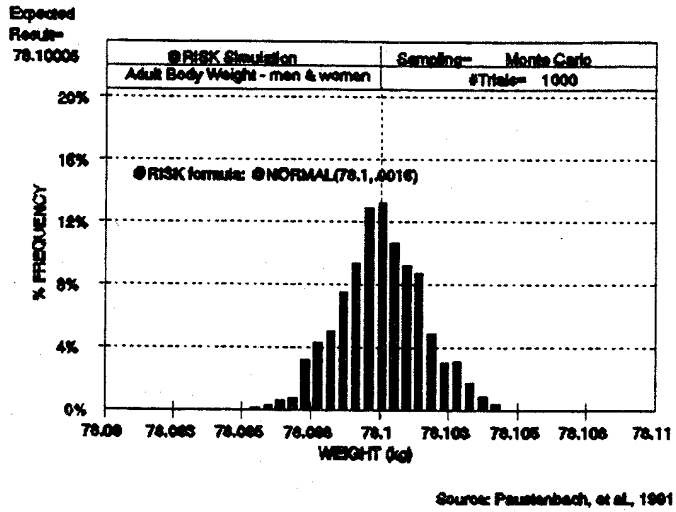

FIGURE 9. Adult body weight distribution (both sexes).

f. Distribution type, lognormal; @RISK formula, @LOGNORM (5.13,0.17); Reference, Brainard and Burmaster, 1992; Unit, ln (pound); Note, men; Median, 5.13 ln (lb).

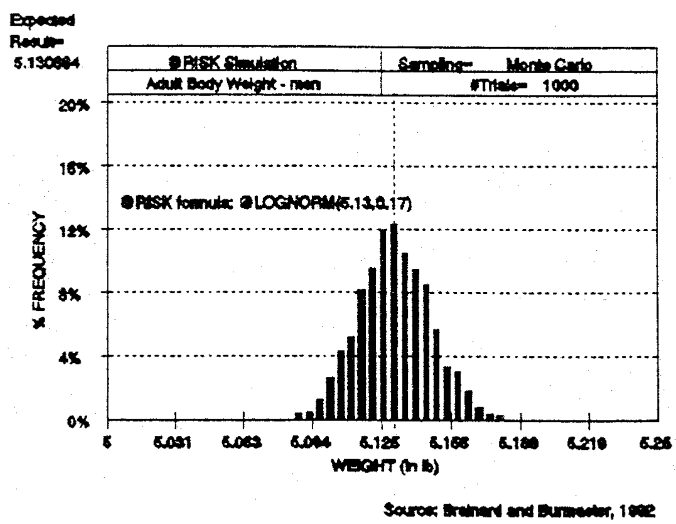

FIGURE 10. Adult body weight distribution — men.

g. Distribution type, lognormal; @RISK formula, @LOGNORM (4.96,0.20); Reference, Brainard and Burmaster, 1992; Unit, ln (pound); Note, women; Median, 4.95 ln (lb).

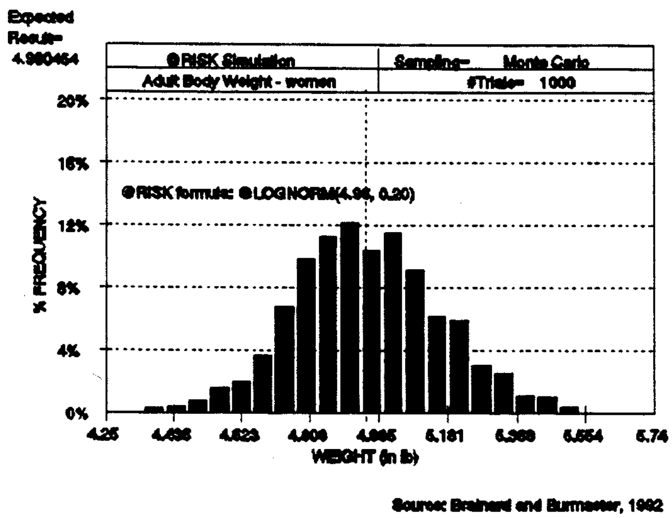

FIGURE 11. Adult body weight distribution — women.

B. Child Body Weight

1. Data Summary

Using available data in the literature, various organizations have selected different point values for child body weight (Table 3). The differences are primarily due to the assumed age range of the children. The point estimate body weight for children of age 1 to 4 years recommended for use in risk assessments is 13 kg. The 1 to 4 age range matches the age for which accurate soil ingestion data are available. The 13-kg value is the average of the mean 50th percentile values for boys and girls across the age spectrum of 1 to 4 years listed in the EPA Exposure Factor Handbook (EPA, 1989a).

Various distributions of child body weight are presented in Figures 12 to 14 and represented by both cumulative and normal distributions. The recommended distribution is the cumulative expression. Using the simulated distribution of child male and female (combined) body weights (ages 1 to 4) based on all the percentile data in the EPA Exposure Factor Handbook, the 13-kg value is very near the mean and median of the distribution. The value of 16 kg, which is the default value often used in regulatory-based risk assessments, is near the extreme upper end of the distribution. A value of 11 kg, also used in regulatory-based risk assessments, is near the opposite lower end of the distribution.

TABLE 3
Child Body Weight Point Values

Value	Unit	Notes	Ref.
11.3	kg	Noncarcinogens	NJDEPE
16	kg	Carcinogens	NJDEPE
14	kg	Preschool	Lioy *et al.*, 1992
30	kg	School age	Lioy *et al.*, 1992
13	kg	Canadian standard toddlers	Richardson *et al.*, 1992
6	kg	Canadian standard infants	Richardson *et al.*, 1992
15	kg		RAGS

2. ***Distributions***

a. Distribution type, cumulative; @RISK formula, @CUMUL; (7,20,10.6,0.05,11.4,0.15,12.9,0.5, 14.7,0.85,16,0.95,5); Reference, EPA 5-44 and 5-45; Unit, kilograms; Median, 12.83 kg.

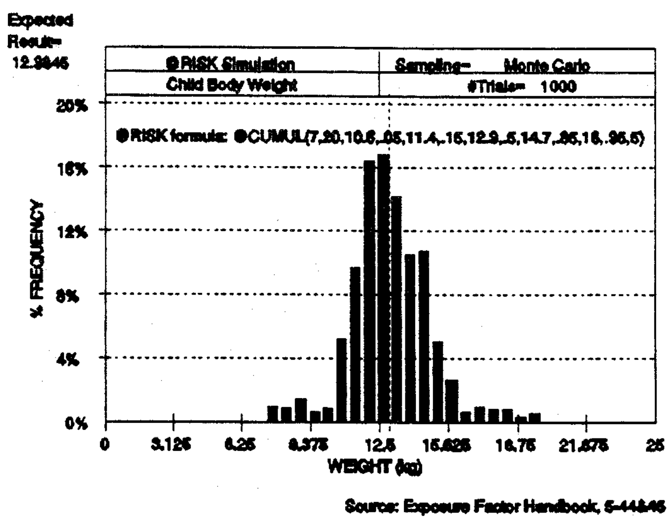

FIGURE 12. Child body weight distribution.

b. Distribution type, normal; @RISK formula, @NORMAL (12.6,0.949); Reference, RiskFocus, Versar, 1991; Unit, kilograms; Note, children 2 years old; Median, 12.64 kg.

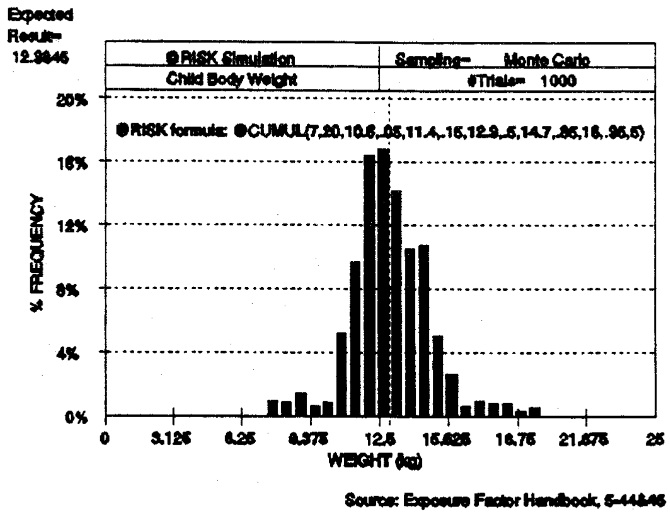

FIGURE 13. Child body weight distribution — 2 years old.

c. Distribution type, normal; @RISK formula, @NORMAL (47,8.3); Reference, Burmaster *et al.*, 1991; Unit, kilograms; Note, ages 8 to 18 years; Median, 47.02 kg.

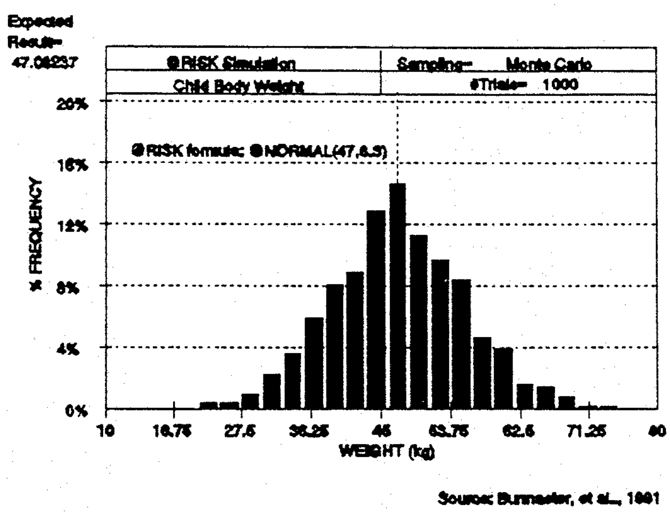

FIGURE 14. Child body weight distribution — ages 8 to 18.

C. **Adult Height**

1. Data Summary

The recommended adult height for use in risk assessments is 69 and 64 in. for men and women, respectively. These are the most likely values based on the distributions provided by Brainard and Burmaster (1992).

Simulated normal distributions of male and female height are listed below.

2. Distributions (Figures 15 and 16)

a. Distribution type, normal; @RISK formula, @NORMAL (69.12,2.85); Reference, Brainard and Burmaster, 1992; Unit, inches; Note, men; Median, 69.23 in.

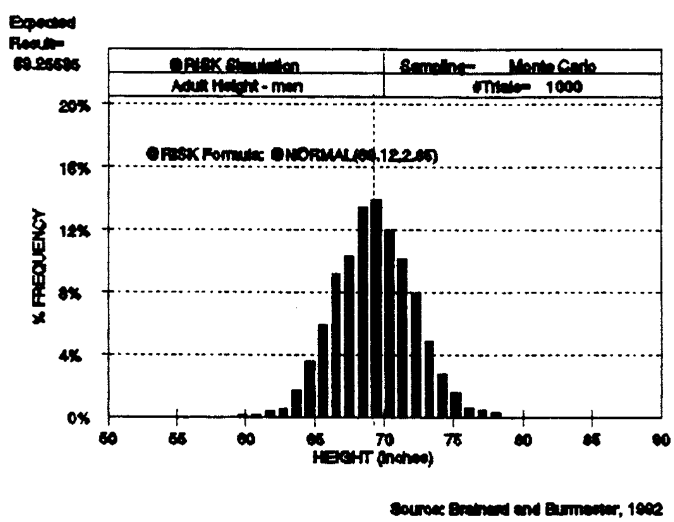

FIGURE 15. Adult height distribution — men.

b. Distribution type, normal; @RISK formula, @NORMAL (63.68,2.68); Reference, Brainard and Burmaster, 1992; Unit, inches; Note, women; Median, 63.69 in.

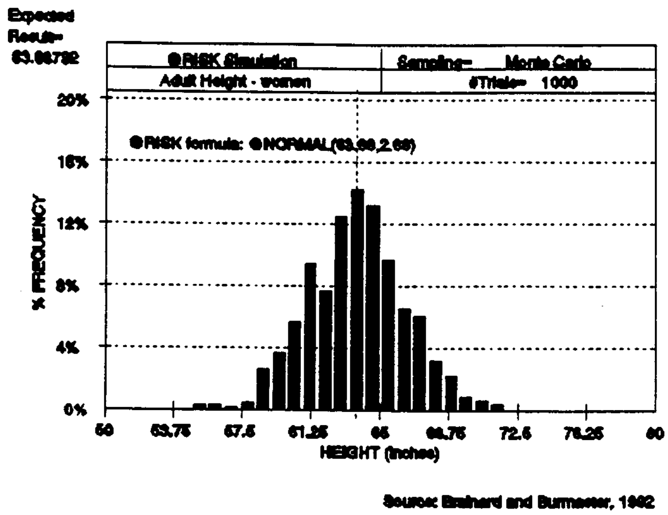

FIGURE 16. Adult height distribution — women.

D. **Skin Surface Area**

1. ***Data Summary***

The direct measurement of body surface area (e.g., by direct coating, triangulation, or surface area integration) is difficult and time consuming. Various formulas are available for estimating body surface area. In the Exposure Factor Handbook, the EPA used an estimation formula to estimate body surface area and analyzed data from direct measurements to obtain a standard error. The mean adult surface area obtained by EPA using this approach was 1.9 and 1.7 m^2 for men and women, respectively. Estimated values obtained from distribution data from other sources are presented below (Table 4A). These sources provide estimates of total body surface area that are similar to the EPA estimates. For purposes of a population-based risk assessment, a point value of 1.8 m^2 is recommended. Data for exposed body surface area and for specific body parts are presented in Table 4B.

Age- and sex-dependent values for total body surface are presented in Table 4C. The Exposure Factor Handbook presents cumulative distributions of skin surface area for children for the various age groups.

TABLE 4A
Literature Point Values — Skin Surface Area

Value	Unit	Notes	Ref.
1580	cm^2	Preschool children — exposed skin area	Lioy *et al.*, 1992
2700	cm^2	School-age children — exposed skin area	Lioy *et al.*, 1992
1980	cm^2	Adults — exposed skin area	Lioy *et al.*, 1992
3420	cm^2	Exposed skin area	Paustenbach *et al.*, 1991
5000 (0.5)	cm^2 (m^2)	Exposed skin area	McKone, 1990

TABLE 4B
Exposure Factor Handbook Body Part Specific Surface Area: Males (m^2)

Age (years)	Arms	Hands	Legs
3 < 4	0.096	0.040	0.18
6 < 7	0.110	0.041	0.24
9 < 10	0.130	0.057	0.31
Adult	0.230	0.082	0.55

TABLE 4C
Exposure Factor Handbook Total Body Surface Area Values: Age and Sex Dependent (m^2)

Age (years)	Male	Female
3 < 6	0.728	0.711
6 < 9	0.931	0.919
9 < 12	1.160	1.160
12 < 15	1.490	1.480
15 < 18	1.750	1.600
Adult	1.940	1.690

2. ***Distributions (Figures 17 to 23)***

a. Distribution type, cumulative; @RISK formula, @CUMUL; (1.5,2.3,1.66,0.05,1.76, 0.15,1.94,0.5,2.14,0.85,2.28,0.95,5); Reference, EPA 4-28; Unit, square meters; Note, surface area of adult men; Median, 1.93 m^2.

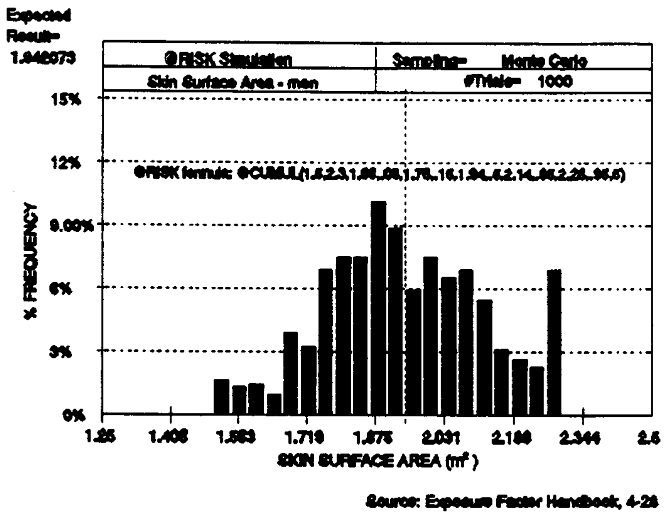

FIGURE 17. Skin surface area distribution — adult men.

b. Distribution type, cumulative; @RISK formula, @CUMUL; (1.4,2.1,1.45,0.05,1.53, 0.15,1.69,0.5,1.91,0.85,2.09,0.95,5); Reference, EPA 4-29; Unit, square meters; Note, surface area of adult women; Median, 1.69 m^2.

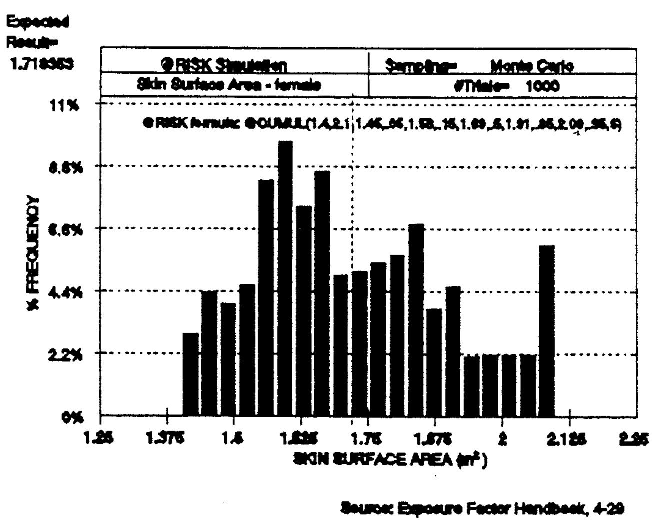

FIGURE 18. Skin surface area distribution — adult women.

c. Distribution type, normal; @RISK formula, @NORMAL (1.7,0.1); Reference, Finley and Paustenbach, 1992; Unit, square meters; Note, total body area; Median, 1.70 m^2.

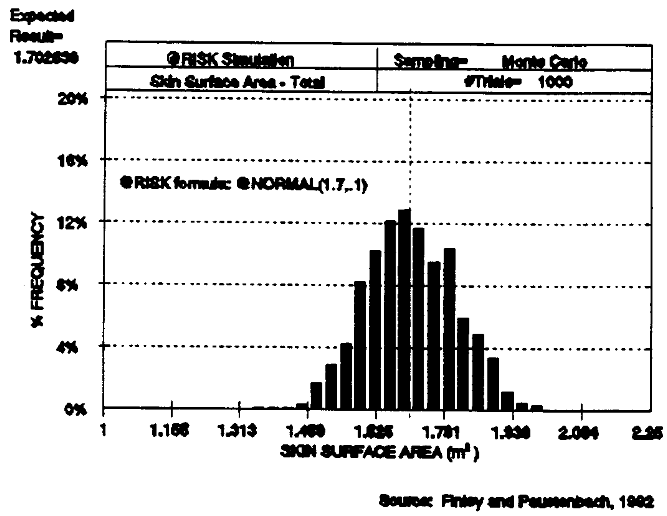

FIGURE 19. Distribution of total body area.

d. Distribution type, cumulative; @RISK formula, @CUMUL; Reference, EPA 4-30 and 4-31; Unit, square meters; Note, see EPA Exposure Factor Handbook for cumulative distributions of total body surface area of male and female children.

e. Distribution type, normal; @RISK formula, @NORMAL (1.4,0.17); Reference, Burmaster *et al.*, 1991; Unit, square meters; Note, total skin area of children ages 8 to 18; Median, 1.4 m^2.

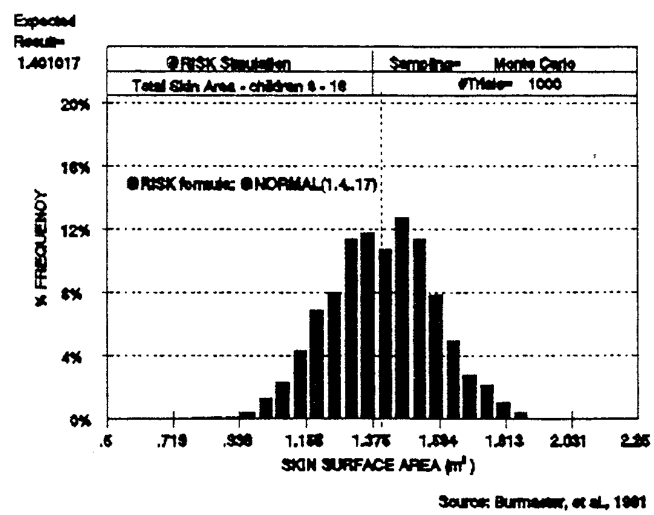

FIGURE 20. Distribution of total skin area (children ages 8 to 18).

f. Distribution type, triangular; @RISK formula, @TRIANG (0.1686, 0.3120, 0.4050); Reference, RiskFocus, Versar, 1991; Unit, square meters; Note, exposed skin area (hands and forearms); Median, 0.297 m^2.

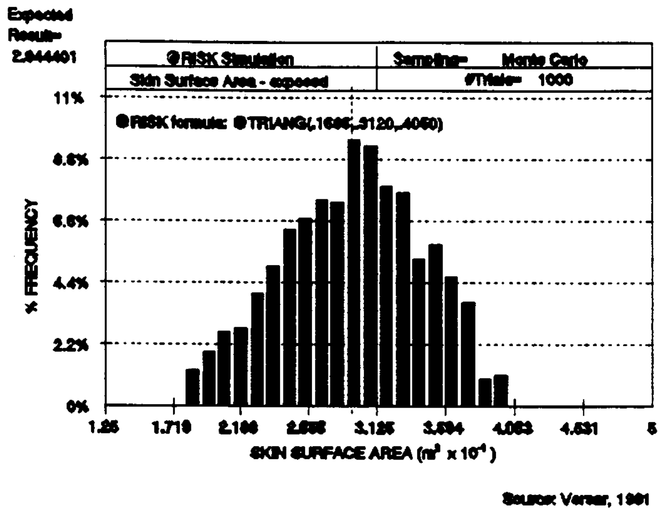

FIGURE 21. Distribution of exposed skin area (hands and forearms).

g. Distribution type, truncated normal; @RISK formula, @TNORMAL (0.118,0.016, 0.09,0.161); Reference, EPA, 1989, pp. 4–10; Unit, square meters; Note, surface area of the head; Median, 0.119 m^2.

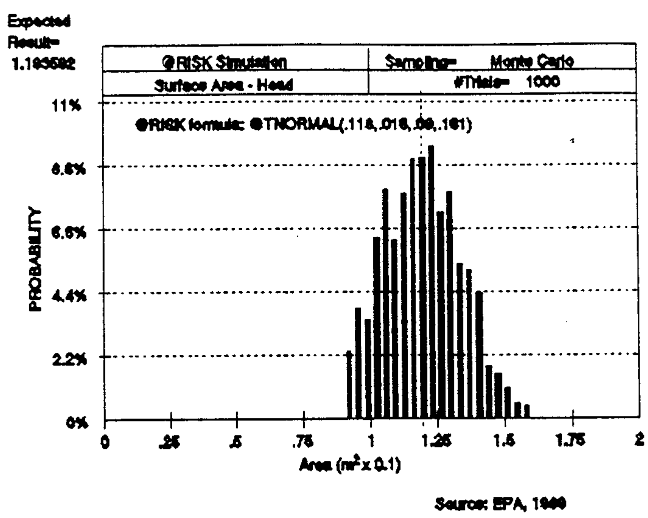

FIGURE 22. Surface area distribution — head.

h. Distribution type, truncated normal; @RISK formula, @TNORMAL (0.319,0.0461, 0.169,0.429); Reference, EPA, 1989, pp. 4–10; Unit, square meters; Note, surface area of the upper body; Median, 0.316 m^2.

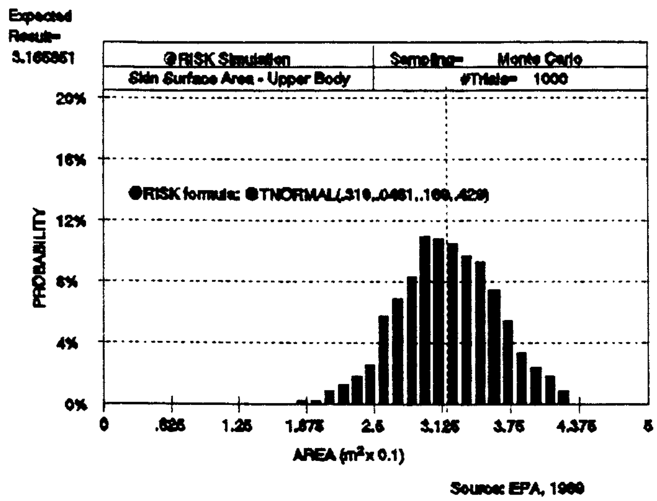

FIGURE 23. Surface area distribution — upper body.

IV. TIME-ACTIVITY PATTERNS

Time-activity patterns are integral to assessing risk because exposure is a function of the time a person spends, for example, near a contaminated area or in an area where exposures can occur. A number of factors influence time-activity patterns, including age, sex, marital status, and geographical location of residence.

A number of time-activity studies have been conducted. The University of Michigan Institute for Social Research has compiled information for three national time-activity studies. The most complete of these studies was conducted in 1975–1976 (Robinson, 1977). The entire noninstitutional U.S. population 18 years of age and older served as a sampling base for this study. A time-use diary was used to collect the information. Respondents were interviewed twice in 1975 and three times during February, May, and September of 1976. The total number of respondents who completed four time diaries with proper distribution between weekdays and weekend days was 975. A number of additional time-activity studies have been conducted since 1976, and methods to improve and expand time-activity data is an active area of investigation. A number of these studies are cited below.

Data on time-activity patterns indicate that default assumptions often used in regulatory-based risk assessments overestimate exposures. For example, the assumption that children spend all of their time at home in the outdoors or that adults are at work the entire work week are not valid. Information on a number of time-activity patterns commonly included as default factors are presented below.

A. Years in One Residence

1. *Data Summary*

In regulatory-based exposure/risk assessments, it is often assumed that an individual spends 25 to 30 or even 70 years at the same residence. For example, to calculate residential building interior cleanup standards and soil cleanup levels for residential areas, it is often assumed that the first 30 years of life are spent in the same residence. Data from the U.S. Department of Commerce Bureau of Census (1988) indicate that the average value of current residence time (time since moving into current residence) for all U.S. households is 10.6 years. In exposure assessments, the average value of the current residence time is often used as an estimate of the average total residence time (time between moving into and out of a residence). However, total residence time and current residence time do not generally share the same distribution and, therefore, their averages are different. Because survey data of total residence time do not exist, two different methods have been developed recently to model or simulate the desired distribution from available data. Both of these studies used different data sources as their basis: one started from current residence time data, while the second simulated a distribution of residential occupancy period (ROP) values (the number of years between the date the person moves into a new residence and the date that the person either moves out of the residence or dies) using individual mobility and mortality data.

Current residence time data were used to develop a "moving behavior model" in order to calculate current and total residence time distributions (Israeli and Nelson, 1992). The average total residence time calculated for all U.S. households was 4.7 years, or less than half the average current residence time. Only about 5% of all households were expected to stay in the same residence for over 23 years, whereas half of all households were expected to stay at the same residence for less than 1.5 years. An insignificant fraction was anticipated to stay at the same residence for a whole expected life span.

In the Israeli and Nelson study (1992), the expected total residence time depended strongly on the housing category. Values for householders and renters were 11.3 and 2.4 years, respectively. Small but significant differences were also found between different regions (from about 7.4 years in the northeast to about 3.5 years in the west). Urban and rural differences were also noted. Values for urban and rural areas were reported as 4.2 and 7.8 years, respectively.

A simulated distribution of residence time based on the data in this study is illustrated in Figure 24. The mean for years in one residence is 4.7 years and the median is 1.5 years. The often used default value of 30 years is at the extreme end of the distribution. In order to suggest that either the mean or median value of this distribution be used for the point value in risk assessments, one must assume that it is very unlikely that individuals would move from, for example, another contaminated site where they would receive exposure to the very same contaminants. Cumulative distributions for various residence types (e.g., renters, owners, rural, urban, and geographic regions) are listed below Figure 24 in distributions (b) through h (j).

A similar study was performed by an EPA contractor, International Technology Air Quality Services (ITAQS) (EPA, 1992). A methodology was developed that used a Monte Carlo technique to simulate a distribution of residential occupancy periods (ROPs) for a given population using mobility, mortality, and population data. The population simulated was the U.S. population as of July 1987. The year 1987 was chosen because it was the most recent year for which all three data sets were available. By randomly determining a person's age and sex from the distribution of ages and the male/female breakdown in 1987, respectively, a population of 500,000 was simulated. For each person simulated, the elapsed time already spend in his/her current residence was determined according to average mobility data for the person's age and sex, and the future time spend in his/her residence was calculated using both mobility and mortality data, and a similar technique. These two values were then added to arrive at an ROP value for each of the 500,000 simulated individuals.

The results of the ROP distribution for the simulated U.S. population are presented below in graphical form in Figures 25 through 29. The mean ROP for the entire population of 1987 is estimated at 11 years and the median is 8.1 years. In this distribution, the commonly used default value of 30 years is at the 93.5th percentile. Because of the large variability of the ROP distribution with respect to age, distributions for various age ranges are also presented. In the ITAQS study (EPA, 1992), the ROP cumulative distributions were given for every 3-year age interval starting with ages 0 to 3, but each group of three ages did not have the same population (i.e., the population of simulated people ages 0 to 3 was not the same as people ages 3 to 6). Therefore, to present age ranges >3 years, the member distributions have been weighted by a population fraction and averaged to give an overall cumulative distribution for the desired age range.

The two approaches for estimating a distribution of the average total residence time, Israeli and Nelson (1992) and ITAQS (EPA, 1992), are fundamentally different in two significant areas. First, the Israeli and Nelson study took survey data to determine the desired distribution for households, while ITAQS centered their model around individuals. Second, their data sources and data manipulation differed greatly. Israeli and Nelson took current residence time data and performed rigorous probability calculations to determine a moving rate and then a total residence time, whereas ITAQS utilized available data on mobility to do simple calculations for probabilities of moving and then iteratively ran these probabilities through a simulation to arrive at their final distribution.

Because of the above differences and the fact that ITAQS used the more current data of the two, it is recommended that the median value of 8.1 years be used as the best point value for total residence time in risk assessments.

2. *Distributions (Figures 24 to 29)*

a. Distribution type, cumulative; @RISK formula, @CUMUL, (0,50,0.5,0.25,1.4,0.5,3.7, 0.75,12.9,0.9,23.1,0.95,5); Reference, Israeli and Nelson, 1992; Unit, years; Note, all households; Median, 1.52 years.

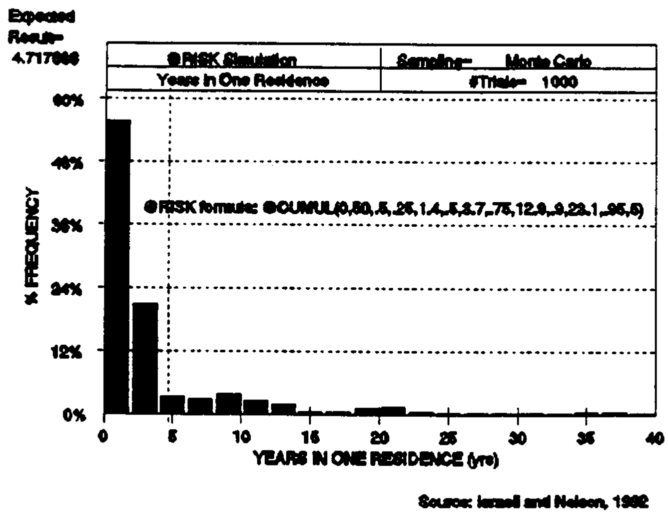

FIGURE 24. Distribution of years in one residence — all households.

b. Distribution type, cumulative; @RISK formula, @CUMUL (0,50,0.5,0.25,1.2,0.5,2.6, 0.75,5.2,0.9,8,0.95,5); Reference, Israeli and Nelson, 1992; Unit, years; Note, renters.
c. Distribution type, cumulative; @RISK formula, @CUMUL (0,50,1.4,0.25,5.2,0.5,17.1, 0.75,32,0.9,41.4,0.95,5); Reference, Israeli and Nelson, 1992; Unit, years; Note, owners.
d. Distribution type, cumulative; @RISK formula, @CUMUL (0,60,2.4,0.25,10,0.5,26.7, 0.75,48.3,0.9,58.4,0.95,5); Reference, Israeli and Nelson, 1992; Unit, years; Note, farms.
e. Distribution type, cumulative; @RISK formula, @CUMUL (0,30,0.5,0.25,1.4,0.5,3.4, 0.75,10.9,0.9,21.7,0.95,5); Reference, Israeli and Nelson, 1992; Unit, years; Note, urban.
f. Distribution type, cumulative; @RISK formula, @CUMUL (0,50,1.2,0.25,3.3,0.5,9.1, 0.75,21.7,0.9,32.2,0.95,5); Reference, Israeli and Nelson, 1992; Unit, years; Note, rural.
g. Distribution type, cumulative; @RISK formula, @CUMUL (0,50,1,0.25,2.8,0.5,7.5, 0.75,22.3,0.9,34.4,0.95,5); Reference, Israeli and Nelson, 1992; Unit, years; Note, Northeast region, U.S.
h. Distribution type, cumulative; @RISK formula, @CUMUL (0,50,0.6,0.25,1.6,0.5,4.3, 0.75,15.0,0.9,25.7,0.95,5); Reference, Israeli and Nelson, 1992; Unit, years; Note, Midwest region, U.S.

i. Distribution type, cumulative; @RISK formula, @CUMUL (0,50,0.4,0.25,1.2,0.5,3.0, 0.75,10.8,0.9,20.7,0.95,5); Reference, Israeli and Nelson, 1992; Unit, years; Note, southern region, U.S.
j. Distribution type, cumulative; @RISK formula, @CUMUL (0,50,0.4,0.25,1.2,0.5,2.9, 0.75,8.9,0.9,17.1,0.95,5); Reference, Israeli and Nelson, 1992; Unit, years; Note, western region, U.S.
k. Distribution type, cumulative; @RISK formula, @CUMUL (1,75,4,0.25,8,0.5,15, 0.75,26,0.9,33,0.95,47,0.99,6); Reference, EPA-450/3-92-011; Unit, years; Note, simulated total U.S. population; Median, 8.1 years.

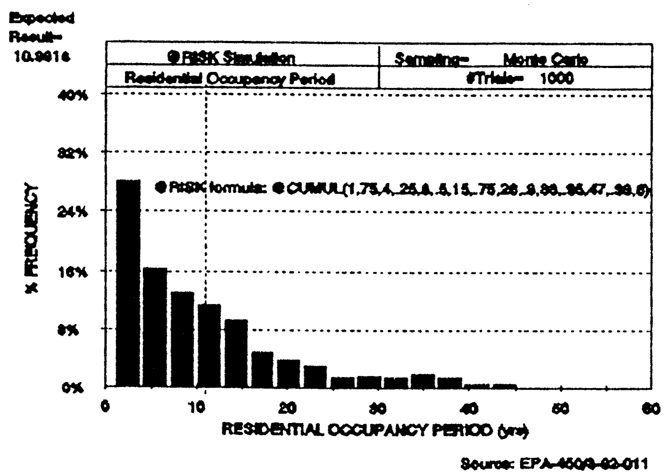

FIGURE 25. Residential occupancy period (ROP) simulated.

l. Distribution type, cumulative; @RISK formula, ((@CUMUL (1,30,3,0.25,5,0.5,8, 0.75,13,0.9,17,0.95,22,0.99,6), *1.146) + (@CUMUL (1,30,4,0.25,7,0.5,10, 0.75,15,0.9,18,0.95,22,0.99,6), *0.854))/2; Reference, EPA-450/3-92-011; Unit, years; Note, simulated children ≤ 6 years old; Median, 6.4 years.

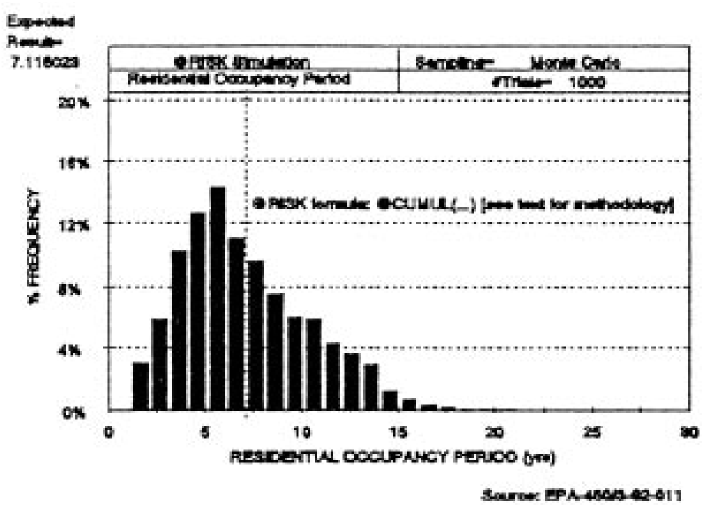

FIGURE 26. Distribution of ROP — simulated children ≤ 6 years old.

m. Distribution type, cumulative; @RISK formula, ((@CUMUL (1.30,4,0.25,7,0.5,1,0, 0.75,15,0.9,18,0.95,22,0.99,6), *1.042) + (@CUMUL (1,30,5,0.25,8,0.5,12, 0.75,16,0.9,18,0.95,22,0.99,6), *0.983) (@CUMUL (1,30,5,0.25,9,0.5,13, 0.75,16,0.9,18,0.95,23,0.99,6), *0.955) + (@CUMUL (1,30,5,0.25,8,0.5,12, 0.75,16,0.9,18,0.95,23,0.99,6), *0.955) + (@CUMUL (1,30,4,0.25,7,0.5,11, 0.75,16,0.9,18,0.95,23,0.99,6), *1.065))/5; Reference, EPA-450/3-92-011; Unit, years; Note, simulated children 6 ≤ age ≤ 18 years old; Median, 7.9 years.

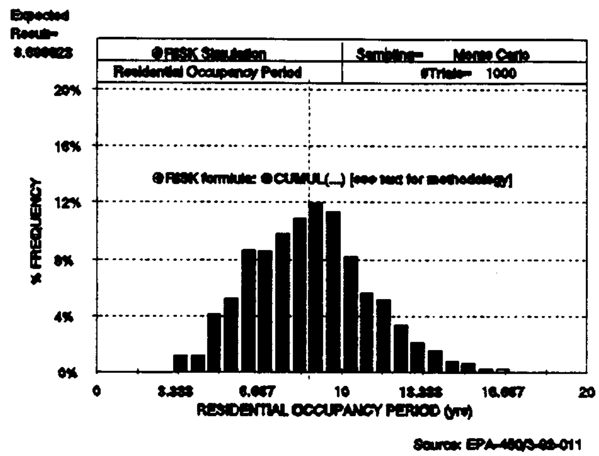

FIGURE 27. Distribution of ROP — simulated children 6 ≤ age ≤ 18 years old.

n. Distribution type, cumulative; @RISK formula, ((@CUMUL (1.30,4,0.25,7,0.5,11, 0.75,16,0.9,18,0.95,22,0.99,6), *0.906) + (@CUMUL (1,45,2,0.25,4,0.5,7, 0.75,12,0.9,16,0.95,23,0.99,6), *0.920) + (@CUMUL (1,45,2,0.25,4,0.5,6, 0.75,11,0.9,14,0.95,25,0.99,6), *1.017) + (@CUMUL (1,45,3,0.25,5,0.5,8, 0.75,13,0.9,17,0.95,30,0.99,6), *1.080) + (@CUMUL (1,45,3,0.25,6,0.5,10, 0.75,15,0.9,21,0.95,36,0.99,6), *1.080))/5; Reference, EPA-450/3-92-011; Unit, years; Note, simulated persons 18 ≤ age ≤ 30 years old; Median, 5.2 years.

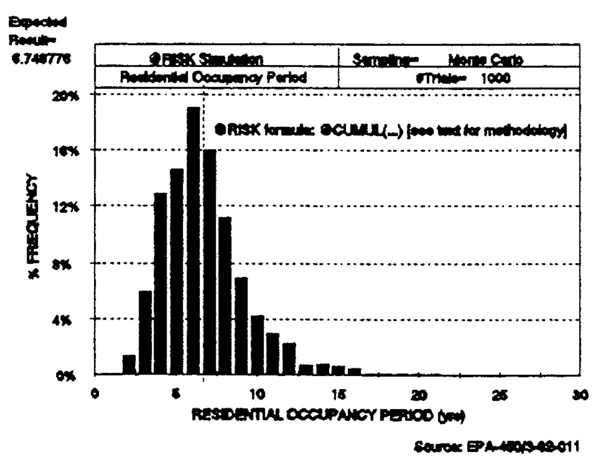

FIGURE 28. Distribution of ROP — simulated persons 18 ≤ age ≤ 30 years old.

o. Distribution type, cumulative; @RISK formula, ((@CUMUL (1,45,3,0.25,6,0.5,10, 0.75,15,0.9,21,0.95,36,0.99,6), *1.183) + (@CUMUL (1,55,4,0.25,7,0.5,12, 0.75,19,0.9,25,0.95,44,0.99,6), *1.134) + (@CUMUL (1,55,5,0.25,9,0.5,14, 0.75,23,0.9,31,0.95,49,0.99,6), *1.060) + (@CUMUL (1,55,6,0.25,10,0.5,17, 0.75,26,0.9,34,0.95,49,0.99,6), *0.986) + (@CUMUL (1,55,7,0.25,12,0.5,19, 0.75,29,0.9,37,0.95,50,0.99,6), *0.864) + (@CUMUL (1,55,8,0.25,13,0.5,21, 0.75,32,0.9,40,0.95,54,0.99,6), *0.773))/6; Reference, EPA-450/3-92-011; Unit, years; Note, simulated persons 30 ≤ age ≤ 45 years old; Median, 11.1 years.

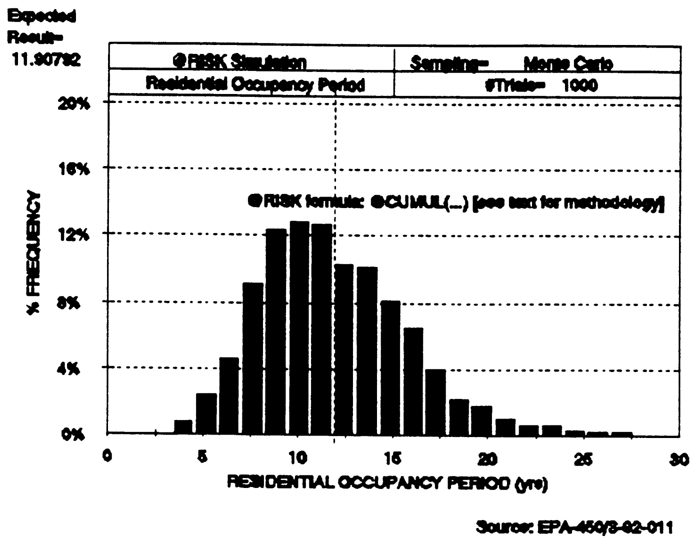

FIGURE 29. Distribution of ROP — simulated persons 30 ≤ age ≤ 45 years old.

p. Distribution type, cumulative; @RISK formula, ((@CUMUL (1,65,8,0.25,13,0.5,21, 0.75,32,0.9,40,0.95,54,0.99,6), *1.358) + (@CUMUL (1,65,9,0.25,15,0.5,23, 0.75,34,0.9,42,0.95,54,0.99,6), *1.139) + (@CUMUL (1,65,9,0.25,16,0.5,24, 0.75,35,0.9,41,0.95,52,0.99,6), *1.066) + (@CUMUL (1,65,9,0.25,16,0.5,24, 0.75,35,0.9,41,0.95,52,0.99,6), *1.025) + (@CUMUL (1,65,10,0.25,18,0.5,27, 0.75,37,0.9,42,0.95,54,0.99,6), *1,034); (@CUMUL (1,65,11,0.25,19,0.5,28, 0.75,36,0.9,41,0.95,54,0.99,6), *1.050) + (@CUMUL (1,65,12,0.25,20,0.5,29, 0.75,37,0.9,41,0.95,54,0.99,6), *1.036) + (@CUMUL (1,65,13,0.25,21,0.5,29, 0.75,37,0.9,43,0.95,51,0.99,6), *0.972) + (@CUMUL (1,65,13,0.25,21,0.5,30, 0.75,38,0.9,43,0.95,53,0.99,6), *0.885) + (@CUMUL (1,75,13,0.25,21,0.5,30, 0.75,39,0.9,45,0.95,55,0.99,6), *0.770) + (@CUMUL (1,75,13,0.25,20,0.5,29, 0.75,39,0.9,44,0.95,54,0.99,6), *0.660))/11; Reference, EPA-450/3-92-011; Unit, years; Note, simulated persons 45 ≤ age ≤ 75 years old; Median, 18.2 years.

B. **Time Spent Indoors/Outdoors**

1. Data Summary

A number of investigators have attempted to determine the amount of time spent indoors vs. the amount of time spent outdoors. Using the time-activity data from the studies conducted by Chapin (1974) and Szalai (1972), the EPA (1989a) classified activities as outdoor, transit, or 50% indoor/outdoor. Mean time values were added and the percent of daily time in each location was calculated for the amount of time spent outdoors and in transit. All remaining time was assumed to be spent indoors. The percent of daily time spent outdoors, in transit, or indoors was 3, 6, and 91% for men, 2, 5, and 93% for women, and 2, 5, and 93% for women and men combined, respectively. Therefore, for purposes of conducting population-based risk assessments, the recommended percentage of time spent indoors/outdoors is 93%/7%, corresponding to weekly indoor/outdoor values of 156 h/12 h.

Constant time-activity values, differentiated by smoking vs. nonsmoking microenvironments, for the southern California region are presented below (Table 5A). Time spent outdoors and in transit in the Southern California region are presented in Table 5B.

C. **Weekly Hours at Home/Away from Home — Adult**

1. Data Summary

The time spent at home or away from home by adults varies by age and sex. Part of this variation is attributed to the difference in time spent at work (see Section IV.E.1 below).

The time-activity data collected by the University of Michigan (Robinson, 1977) were arranged into ten broad categories: (1) market work, (2) house/yard work, (3) child care, (4) services/shopping, (5) personal care, (6) education, (7) organizations, (8) social entertainment, (9) active leisure, and (10) passive leisure. These categories were further broken down into specific activity types. Using these data, the EPA (1989a) assigned various activity types as home, away from home, or mixed (50% home/50% away from home). Using this approach and taking the mean time values, the weighted mean hours per week at home/away from home were calculated as 98/70 for men, 116/52 for women, and 108/60 for men and women combined. Therefore, for purposes of conducting population-based risk assessments, the weekly hours at home/away from home is recommended as 108/60, that is, the time spent at home/away from home is approximately 64%/36%.

TABLE 5A
Time Spent Indoors: Smoking and Nonsmoking Microenvironments, Southern California Data

Min/d	Notes
1175	Children: nonsmoking environment
1128	Adolescents: nonsmoking environment
1098	Adults, nonsmokers: nonsmoking environment
983	Adults, smokers: non smoking environment
68	Children: passive smoke
145	Adolescents: passive smoke
164	Adults, nonsmokers: passive smoke
211	Adults, smokers: passive smoke

Source: Lurmann *et al.* (1991).

TABLE 5B
Time Spent Outdoors and in Transit: Southern California Data

Min/d	Notes
64	Children: in transit
90	Adolescents: in transit
108	Adults, nonsmokers: in transit
74	Adults, smokers: in transit
132	Children: outdoors
73	Adolescents: outdoors
67	Adults, nonsmokers: outdoors
37	Adults, smokers: outdoors
1	Children: gas stations
3	Adolescents: gas stations
3	Adults (all): gas stations

Source: Lurmann *et al.* (1991).

2. ***Distributions (Figure 30)***

a. Distribution type, uniform; @RISK formula, @UNIFORM (8,20); Reference, McKone and Bogen, 1991; Unit, hours per day; Note, adult; Median, 13.76 h/d.

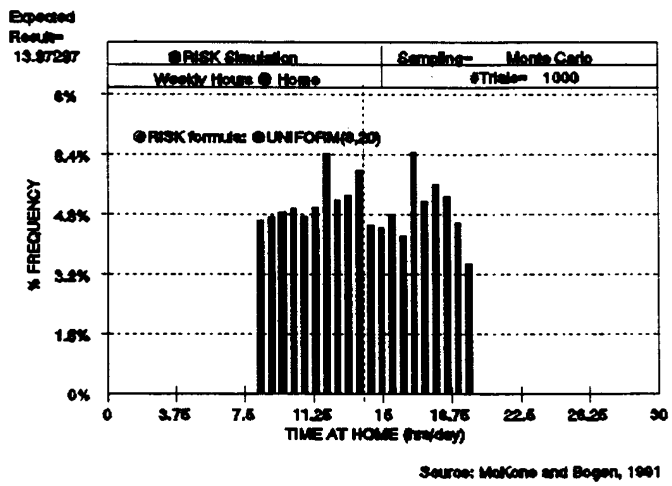

FIGURE 30. Weekly hours at home distribution (adult).

D. **Weekly Hours at Home/Away from Home — Child**

1. ***Data Summary***

In regulatory-based risk assessments, for example, in calculating residential surface soil cleanup standards, an accounting for time spent away from home is often not made. Activity pattern data for preschool children are presented in the EPA Exposure Factor Handbook. While such data are limited, they suggest that, on the average, children spend approximately 30 h/week (18% of the time) away from home, engaged in activities such as shopping, church, preschool, and visiting. Thus, a weekly "time away from home/time at home" adjustment factor of 138 h/168 h could be included in certain exposure assessments. Further refinement of the data, differentiated by age group, results in values of 27 h/week away from home for children ages 3 to 11 and 35 h/week away from home for children ages 12 to 17 (boys and girls combined).

E. **Weekly Hours at Work (Adult)**

1. Data Summary

In performing risk assessments, for example, in efforts to calculate nonresidential surface soil cleanup standards, an adjustment for hours spent at work is often excluded. However, on the average, 18- to 24-year-old women and men spend 18 and 27 h/week, respectively, at work (EPA, 1989a). For 20- to 44-year-old women and men, the time spent at work averages 18 and 41 h/week for women and men, respectively. The values drop to 17 and 28 h/week for 45- to 64-year-old women and men, respectively. The mean of all these values is 25 h/week.

A simulated distribution of the time adults (males and females, ages 18 to 64) spend at work per week based on the data presented in the EPA Exposure Factor Handbook is illustrated below. The 50th percentile value for this exposure factor is 22.5 h/week (includes lunchtime, breaks, travel). Failure to incorporate this time-activity factor is essentially equivalent to assuming that adult workers spend 100% of the work week (day and night) at work. Therefore, a time-at-work adjustment factor of 23/168 (hours at work/total hours in a week) could be included in certain exposure assessments.

2. Distributions (Figure 31)

a. Distribution type, cumulative; @RISK formula, @CUMUL (0,107,0.34,0.3,8.3,0.4, 20.2,0.5,32.1,0.6,37.7,0.7,41.3,0.8,46.9,0.9,7); Reference, EPA 5-64; Unit, hours per week; Note, men and women combined, ages 18 to 64; Median, 20.22 h/week.

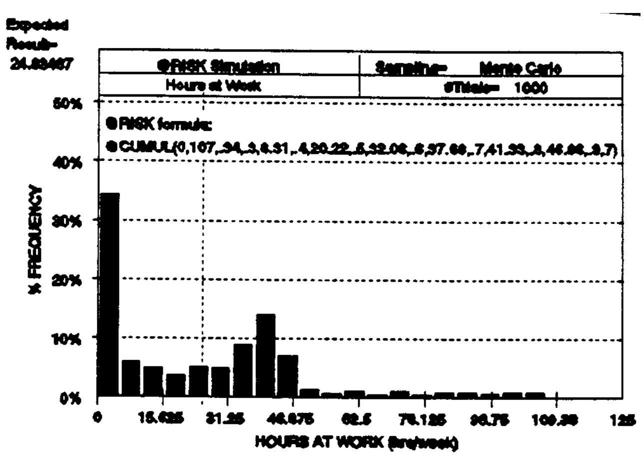

FIGURE 31. Distribution of weekly hours at normal work (men and women combined, ages 18 to 64).

F. **Working Tenure**

1. Data Summary

In regulatory-based risk assessments, for example, in calculating proposed nonresidential cleanup standards, exposure is assumed to occur for a working lifetime of 25 years. For example, in calculating interior building surface cleanup standards, the total number of days worked may be presented as 9125 (25 years × 365 d/year). According to data from the Bureau of Labor Statistics (1987), 25 years is the upper 95th percentile of the distribution for number of years spent at a specific job (working tenure). For purposes of performing environmental risk assessments, use of the 50th percentile value of 4 years is recommended. This value assumes that it is unlikely that a worker would move from one job to another job where he would be exposed to the same environmental (nonworkplace) contaminant(s).

For calculating building surface cleanup standards, adjustment for weekends and vacations (e.g., 3 weeks/year) could be incorporated. Therefore, for the building surface cleanup standard described above, the total number of days worked would be 984 (246 d/year × 4 years).

G. **Shower Duration**

1. Data Summary

The amount of time individuals spend showering is an important factor in calculating exposure via dermal absorption of chemicals in water supplies as well as by inhalation of volatile organic compounds that are released into the air when heating shower water. A study was conducted in Australia by James and Knuiman (1987) using diary records of 2500 households. The resulting distribution is presented below. The median value for shower duration is 7.6 min. Shower flow rates have been estimated as ranging from 5 to 15 gal (18.9 to 56.8 l/min) but data on their distributions are not available. The median value of 7.6 min per shower is recommended for use in risk assessments. This value is approximately 60% of the commonly used default value of 12 min.

2. *Distributions (Figure 32)*

a. Distribution type, cumulative; @RISK formula, @CUMUL (1,20,2,0.008,4,0.1,5,0.23,7, 0.53,9,0.73,12,0.9,15,0.96,19,0.99,8); Reference, James and Knuiman, 1987; Unit, minutes; Note, Australian population; Median, 7.6 min.

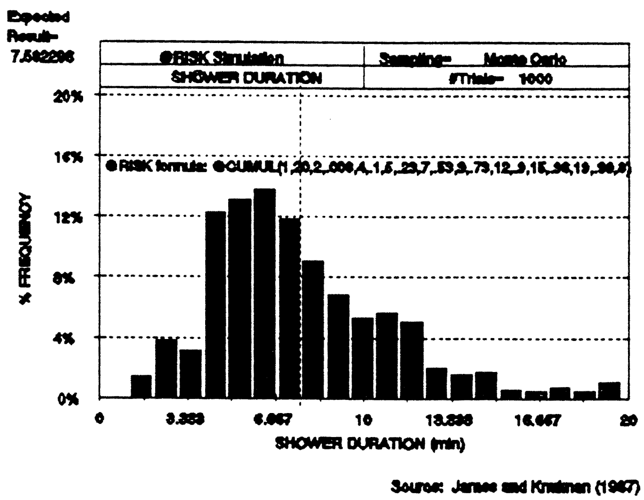

FIGURE 32. Distribution of shower duration in Australia.

V. RECEPTOR CONTACT RATES

A. Adult Soil Ingestion

1. *Data Summary*

Many regulatory-based exposure assessments use an adult soil ingestion rate of 100 mg/d. This value is the highest default value listed in the 1989 EPA Exposure

Factor Handbook. At the time the EPA recommendation was made, there were no actual quantitative measurements of soil ingestion in adults (EPA Exposure Factor Handbook, pp. 2–57). Since 1989, a pilot soil ingestion study in adult using a mass balance soil tracer approach was conducted (Calabrese *et al.*, 1990). Results of this study are discussed below.

Study participants in a pilot soil ingestion study consisted of six healthy adults, three males and three females, 25 to 41 years old (Calabrese *et al.*, 1990). The study was conducted over 3 weeks. Each participant ingested one capsule at breakfast and one capsule at dinner on Monday, Tuesday, and Wednesday of each week. During the first week, the capsules ingested were empty. During the second week, each capsule contained 50 mg of sterilized soil. During the third week, each capsule contained 250 mg of sterilized soil. Duplicate meal samples, food and beverage, were collected from breakfast on Monday through the evening meal on Wednesday for each subject in each week. All medications were included in the samples. Total excretory output, feces and urine, were collected from Monday noon through Friday noon of each week. Laboratory analyses estimated on a daily basis the total amount of eight tracers — aluminum (Al), barium (Ba), manganese (Mn), silicon (Si), titanium (Ti), vanadium (V), yttrium (Y), and zirconium (Zr) — ingested from food, from capsule doses, and in the fecal and urine output. The results were used to form a single estimate for each week and element of daily intake from food, soil, and total (fecal and urine output).

On the basis of sample percentage recovery values, it was reported that Al, Si, Y, and Zr were considered the most valid tracers. The median daily soil ingestion values of these tracers were Al, 57 mg; Si, 1 mg; Y, 65 mg; and Zr, –5 mg. The mean daily soil ingestion values were Al, 77 mg; Si, 5 mg; Y, 53 mg; and Zr, 22 mg. The average of the four median tracer values was 30 mg/d. The average of the four mean tracer values was 40 mg/d. The median of the four median tracer values was approximately 60 mg/d. The median of the four mean tracer values was 65 mg/d.

Since this study was conducted, Calabrese *et al.* have evaluated the detection limits used in soil ingestion studies. The conclusion from this evaluation was that none of the tracers used in the study described above (which is the only quantitative soil ingestion study for adults) demonstrated adequate detection limits for assessing soil ingestion in adults.

In order to provide some estimate of soil ingestion in adults, a simulated distribution of the data using zirconium, which has been demonstrated to be the most reliable soil tracer, was prepared. This distribution indicates that the commonly used default adult soil ingestion rate of 100 mg/d is toward the end of the distribution. The median adult soil ingestion rate from this distribution is far less than 1 mg/d. However, values above the 50% probability increase abruptly. For purposes of risk assessments, a point value in the range of 1 to 10 mg/d is likely to be a very conservative estimate of soil ingestion rate in adults.

2. *Distributions (Figures 33 and 34)*

a. Distribution type, cumulative; @RISK formula, @CUMUL (0,216,0,0.17,0,0.33,0,0.5, 17,0.67,148,0.83,216,1,6); Reference, Calabrese *et al.,* 1990; Unit, milligrams per day; Note, Zr tracer; Median, 0.094 mg/d.

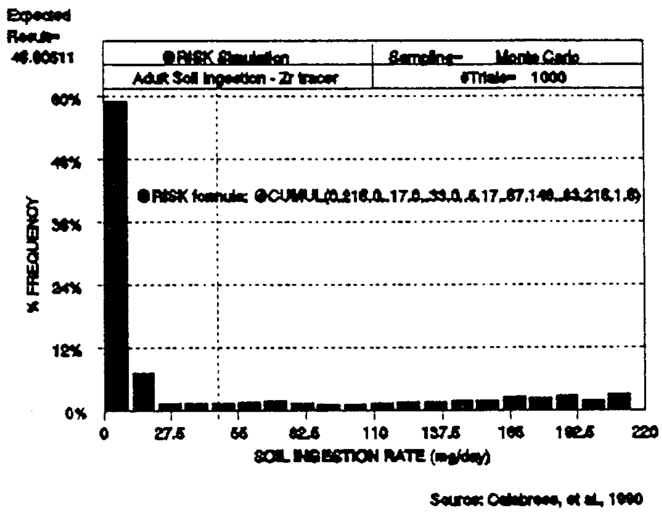

FIGURE 33. Distribution of adult soil ingestion — Zr tracer.

b. Distribution type, cumulative; @RISK formula, @CUMUL (0,216,1,0.375,27,0.55, 148,0.92,3); Reference, Calabrese *et al.,* 1990; Unit, milligrams per day; Note, four tracers: Al, Si, Y, Zr; Median, 31.67 mg/d.

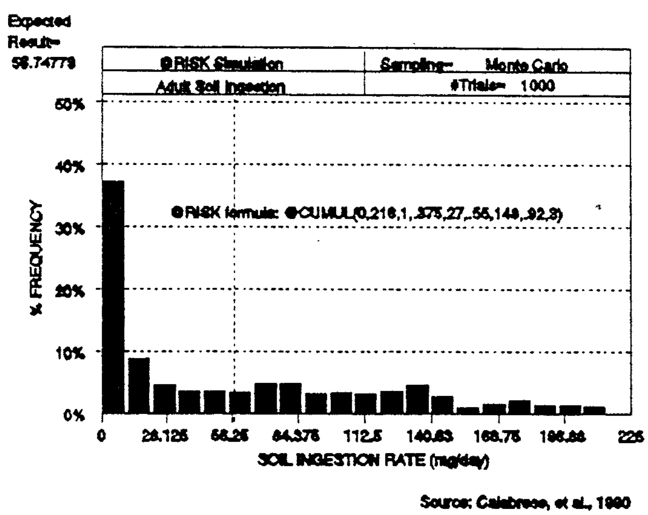

FIGURE 34. Adult soil ingestion distribution (four tracer).

B. **Child Soil Ingestion**

1. Data Summary

Many regulatory-based exposure assessment schemes use a soil ingestion rate of 200 mg/d for children. This value is the default value listed in the 1989 EPA Exposure Factor Handbook. The EPA default value was derived from data by Binder (1986) and a pilot soil ingestion study by Clausing *et al.* (1987). The more recent studies by Calabrese *et al.* (1989a,b), Davis *et al.* (1990), and Van Wijnen *et al.* (1990) were not available at the time the 200 mg/d value was recommended by the EPA.

Four investigators have attempted to determine soil ingestion rates in children using soil tracer methodologies (Davis *et al.,* 1990; Van Wijnen *et al.,* 1990; Calabrese *et al.,* 1989a,b; Binder, 1986). Recently, a model has been developed to estimate minimum soil ingestion detection levels from soil ingestion studies that use mass-balance methods (Calabrese *et al.,* 1989a,b). The validity of the estimates of soil ingestion from the four studies has been reviewed using the model. In addition, the strengths and weaknesses/limitations of the studies have been reviewed. The review indicates that the studies by Binder (1986) and Van Wijnen *et al.* (1990) have significant limitations in study design and therefore do not provide quantitative estimates of soil ingestion. While the study by Davis *et al.* (1990) provided a quantitative estimate of soil ingestion, low confidence was placed in the estimates due to the broad range of estimates near the median intake value. The reported intake rates predicted through use of six of the eight tracer elements used by Calabrese *et al.* (1989a,b) were far below their level of detection, as predicted by the soil ingestion model. However, in the study by Calabrese *et al.* (1989a,b), for the tracer element zirconium, quantifiable soil ingestion rates were obtained and variability near the median intake rate was minimal. Therefore, the soil ingestion rate by Calabrese *et al.* (1989a,b), where zirconium was used as the tracer element, provides the most scientifically reliable estimate of soil ingestion in children. The median soil ingestion value for children reported using zirconium as a tracer was 16 mg/d, with a 95% confidence interval of 8 to 24 mg/d for a sample size of 128.

Simulated distributions of the child soil ingestion rate based on the zirconium tracer in the Calabrese study (1989) and the Calabrese and Stanek study (1991) are illustrated below. The proposed regulatory default of 200 mg/d is at the extreme end of these distributions. For purposes of risk assessment, it is recommended that a value of 16 mg/d be used, which is the median of the distribution of the data for the Calabrese study (1989).

2. ***Distributions (Figures 35 to 39)***

a. Distribution type, cumulative; @RISK formula, @CUMUL (0,1391,0,0.05,0,0.10,16, 0.5,67,0.9,110,0.95,5); Reference, Calabrese *et al.*, 1989b; Unit, milligrams per day; Note, Zr tracer; Median, 15.98 mg/d.

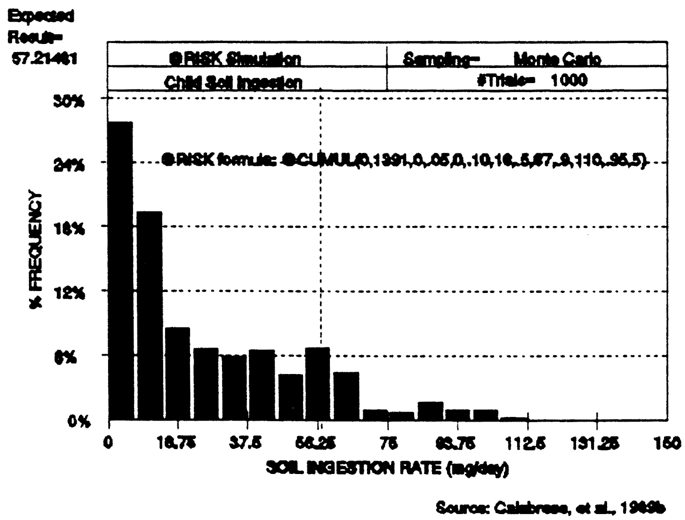

FIGURE 35. Child soil ingestion distribution (Zr tracer).

b. Distribution type, cumulative; @RISK formula, @CUMUL (0,1391,8,0.025,16, 0.5,24,0.975,3); Reference, Calabrese and Stanek, 1991; Unit, milligrams per day; Note, Zr tracer; Median, 15.98 mg/d.

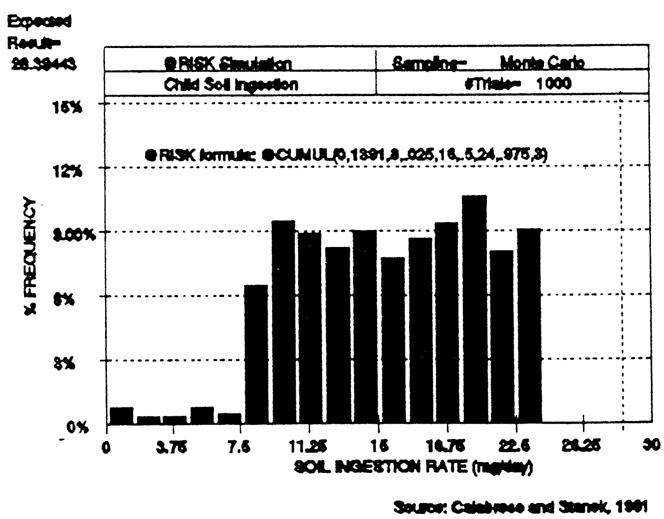

FIGURE 36. Child soil ingestion distribution (Zr tracer).

c. Distribution type, lognormal; @RISK formula, @LOGNORM (21,209); Reference, Calabrese *et al.*, 1989b; Unit, milligrams per day; Note, Zr tracer; Median, 2.22 mg/d.

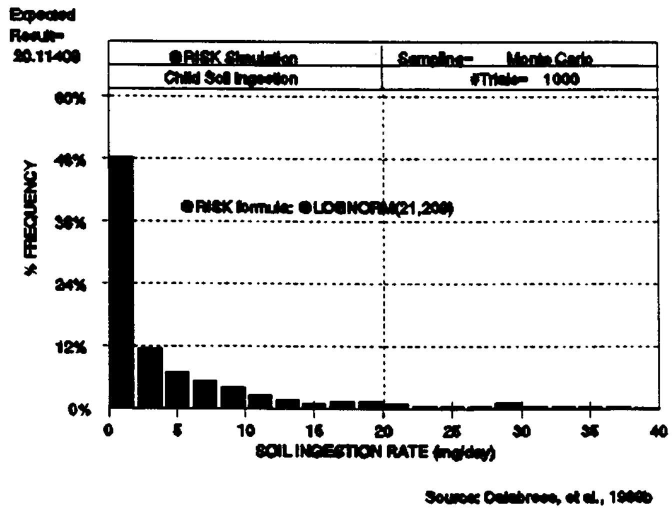

FIGURE 37. Child soil ingestion distribution (Zr tracer).

d. Distribution type, lognormal; @RISK formula, @LOGNORM (200,1.414); Reference, RiskFocus, Versar, 1991, p. 28; Unit, milligrams per day; Median, 199.92 mg/d.

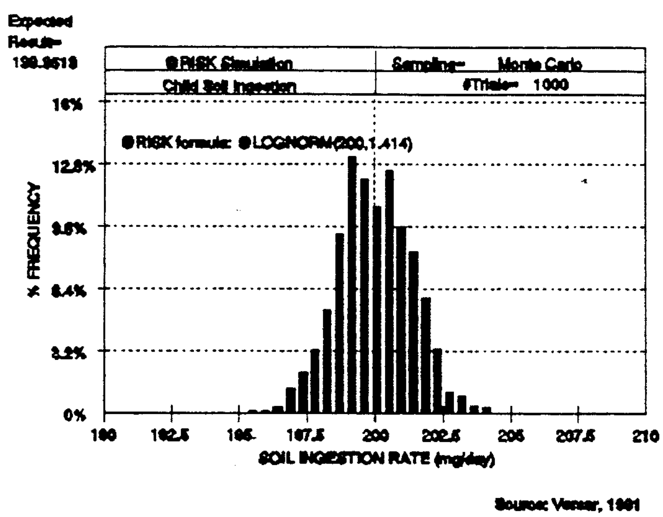

FIGURE 38. Child soil ingestion distribution

e. Distribution type, lognormal; @RISK formula, @LOGNORMAL (3.44,0.80); Reference, Burmaster *et al.,* 1991; Unit, milligrams per day; Median, 3.38 mg/d.

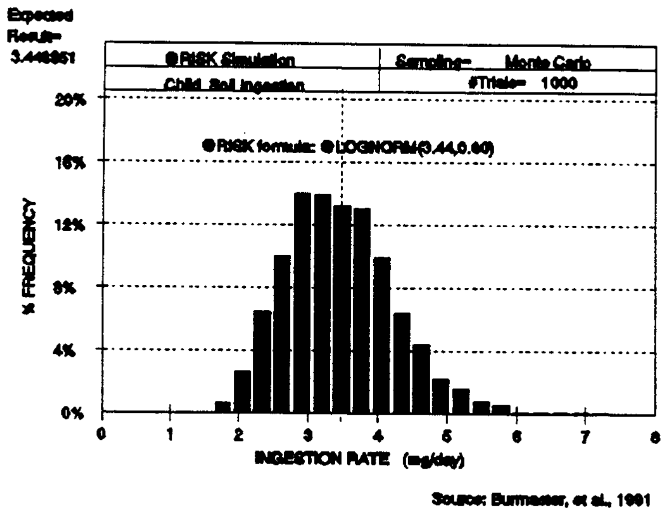

FIGURE 39. Child soil ingestion distribution.

f. Distribution type, cumulative; @RISK formula, @CUMUL (0,200,21,0.1,39,0.3,45,0.5,73, 0.7,197,0.9,5); Reference, Thompson and Burmaster, 1991; Unit, milligrams per day; Note, aluminum tracer (binder data corrected for actual fecal weight).
g. Distribution type, cumulative; @RISK formula, @CUMUL (0,200,19,0.1,36,0.3,60, 0.5,79,0.7,166,0.9,5); Reference, Thompson and Burmaster, 1991; Unit, milligrams per day; Note, silicon tracer (binder data corrected for actual fecal weight).
h. Distribution type, cumulative; @RISK formula, @CUMUL (0,2500,3,0.1,47,0.3,293, 0.5,724,0.7,2105,0.9,5); Reference, Thompson and Burmaster, 1991; Unit, milligrams per day; Note, titanium tracer (binder data corrected for actual fecal weight).
i. Distribution type, cumulative; @RISK formula, @CUMUL (0,200,22,0.1,43,0.3,59,0.5,92, 0.7,143,0.9,5); Reference, Thompson and Burmaster, 1991; Unit, milligrams per day; Note, average data (binder data corrected for actual fecal weight).
j. Distribution type, lognormal; @RISK formula, @LOGNORM (97,169); Reference, Thompson and Burmaster, 1991; Unit, milligrams per day; Note, aluminum data (binder data corrected for actual fecal weight).
k. Distribution type, lognormal; @RISK formula, @LOGNORM (85,95); Reference, Thompson and Burmaster, 1991; Unit, milligrams per day; Note, silicon data (binder data corrected for actual fecal weight).
l. Distribution type, lognormal; @RISK formula, @LOGNORM (91,126); Reference, Thompson and Burmaster, 1991; Unit, milligrams per day; Note, average data (binder data corrected for actual fecal weight).

C. **Adult Total Dietary Intake**

1. Data Summary

Total daily dietary food intake can be estimated in various ways. Family or household surveys are often used, but differences in intake based on age and the type of population studied make it difficult to relate these data to the average adult intake. Studies of the intake from mass balances of individuals are problematic due to the fact that it is unclear how these data apply to the broad population. Intakes based on food purchases have built-in conservativeness because such data do not account for food wasted.

Total dietary intake based on national and supranational household surveys range from 1.4 kg/d for the U.K. (based on food purchased minus 10% deducted for waste) to 1.6 kg/d for the U.S. (based on food purchased minus 15% for waste). A value of 1.42 kg/d for the European community was reported based on actual food consumption rates. Substantially different values may be apparent worldwide based on widely differing food availability.

In assessing the safety of indirect food additives, the U.S. Food and Drug Administration generally employs a food consumption value of 3 kg/d (FDA, 1988). Therefore, when performing risk assessments for purposes of submission to the FDA, a 3 kg/d value should be employed. However, this value is essentially twice the value reported in the household survey described above. For purposes of non-FDA risk assessments, a value of 1.6 kg/d is recommended.

D. **Consumption of Home-Grown Fruits and Vegetables by Adults**

1. Data Summary

Consumption rates of home-grown vegetables are influenced by a variety of factors, including the size of home gardening plots, yield, quality of produce (which in turn is influenced by a variety of factors), types of vegetables grown, length of the growing season, and climate. In 1987, it was estimated that 38% of U.S. households participated in vegetable gardening the previous year. The average size of the home vegetable garden in 1986 was 325 ft^2, which is less than the 1982 value of 600 ft^2. Vegetable gardening is more popular in the Midwest and South than in other parts of the country. Home-grown fruits and vegetables make up a larger portion of the average diet in rural areas as opposed to city and suburban areas. The percentage of a specific home-grown fruit or vegetable in the diet varies according to the difficulty involved in growing them.

After reviewing the available scientific information on ingestion of home-grown fruits and vegetables, the EPA concluded that no data are available that present actual annual consumption rates for home-grown fruits and vegetables by gardeners. Data concerning the total intake of fruits and vegetables ("all" and "bought") are available from a survey conducted in 1977–1978 by the USDA (USDA, 1983) and analyzed by a number of authors (Pao *et al.*, 1982; Yang and Nelson, 1985). These data indicate that the total average consumption rates of fruits and vegetables are 142 and 201 g/d, respectively. From these data, point value and distribution estimates of home-grown fruit and vegetable consumption rates were derived (EPA, 1989a).

In deriving home-grown fruit and vegetable estimates, it is assumed that the consumption behavior of home gardeners and their families follows the consumption rate frequencies of the U.S. population, which includes a majority of nongardeners. However, based on this information, an average home-grown percentage of 25% was derived for vegetable intake. Therefore, an estimated home-grown vegetable consumption rate is 50 g/d. Similarly, a home-grown fruit consumption rate of 28 g/d was derived from the total ingestion rate of 142 g/d, assuming a home-grown percentage of 20%. An additional source of uncertainty in the home-grown fruit estimate is that home gardeners prepare juice from fruit they grow. Another conservatism in the home-grown fruit and vegetable consumption estimates stems from the fact that in the USDA 3-d dietary recall survey, people who ate fruits and vegetables infrequently were underrepresented.

2. *Distributions (Figure 40)*

a. Distribution type, cumulative; @RISK formula, @CUMUL; Reference, EPA 2-19 to 2-21; Unit, grams per day; Note, see EPA Exposure Factor Handbook for cumulative distributions of ingestion rates for 32 different fruits or vegetables.
b. Distribution type, lognormal; @RISK formula, @LOGNORM (62,1800); Reference, Finley and Paustenbach, 1992; Unit, grams per day; Note, vegetables; Median, 20.5 g/d.

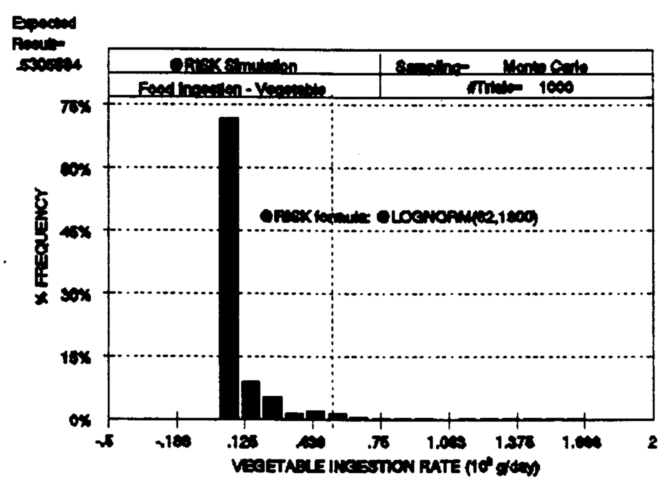

FIGURE 40. Distribution of adult food ingestion — vegetables.

c. Distribution type, lognormal; @RISK formula, unavailable, given limited information (alternate formula @TRIANG (9.1,56,309); Reference, RiskFocus, Versar, 1991; Unit, grams of food per day; Note, based on potato consumption.

E. Adult Fish and Shellfish Consumption Rates

1. Data Summary

A number of investigators have studied fish and shellfish consumption rates. These studies demonstrate that a number of factors influence fish and shellfish consumption rates, including ethnic background, location, sex, and climate. For example, Asian-Americans consume more fish than other groups. Males eat slightly more fish than females, and adults eat more fish than children. Higher fish consumption rates occur in the coastal states. A review of issues related to fish consumption rates has been presented by the EPA (1989b).

A value of 6.5 g/d is used commonly as an overall freshwater fish consumption rate for adults. This value is used by the EPA for setting ambient water quality criteria. The 6.5 g/d value is based on 1-year survey data collected during 1973 and 1974 by NPD Research, Inc. The overall fish consumption rate estimated from this survey was 14.3 g/d. Both of these values were estimated on a per capita basis and represent the average over the entire population, including fish eaters and non-fish eaters. A distinction between recreationally caught fish and purchased fish was not made. In addition, meals eaten away from home were included in the consumption compilations.

Using the data obtained by NPD Research, Inc., Javitz (1980) calculated means and 95th percentiles of monthly fish consumption for fish consumers in the U.S., assumed to be 94% of the population. The mean and 95th percentile consumption rates were 14.3 and 41.7 g/d, respectively.

In another study, information collected in the 1977–1978 USDA Nationwide Food Consumption Survey were used to obtain frequency distributions for consumption rates of various foods (Pao *et al.*, 1982). The USDA data were collected using 3-d diet records. The median and 95th percentile fish consumption rates for persons who included fish in their 3-d dietary intake were 37 and 128 g/d, respectively. Another investigator analyzed the USDA data and provided a mean fish ingestion rate of 17.5 g/d for adults. However, because only 24.5% of the population were reported to have eaten fish and shellfish in the last 3 d in the USDA study, these data cannot be used to derive distributions of annual consumption rates. In 1985, the USDA provided an average fish consumption value of 20 g/d (USDA, 1985) based on their 1977–1978 survey data.

A number of investigators have reported fish and shellfish consumption rates in sport fishing populations. Puffer (1981) reported 50th and 90th percentile consumption rates of 36.9 and 224.8 g/d, respectively. Pierce *et al.* (1981) reported 50th and 90th percentile rates of 23.0 and 54.0 g/d, respectively.

The 14 g/d value is considered the best point value for total daily fish consumption for adults for use in risk assessments where exposures to the general population are assessed. Where exposures to freshwater fish are considered, the 6.5 g/d value is recommended. These values are based on 1-year survey data, as opposed to the USDA data, which were based on 3-d survey data. As described above, the 14 and 6.5 g/d values should be viewed as conservative because consumption of fish from areas outside those considered in the risk assessment were included in the consumption values.

Distributions of fish consumption are presented below. These data were obtained from the EPA Guidance Manual *Assessing Human Health Risks from Chemically Contaminated Fish and Shellfish* (EPA-503/8-89-002). Consumption values are presented in units of grams of fish per kilogram of human body weight for any given day on which fish was consumed. Regional data on the number of days fish is consumed per year is necessary for completing the assessment. Values for the percent of the population that consumes fish are also given in the EPA document.

2. *Distributions (Figures 41 to 55)*

Distribution type, cumulative; Unit, grams of fish consumed per kilogram of human body weight on any given day fish are consumed (these units apply to distributions a through O)

a. @RISK formula, @CUMUL (0.4,15,0.4,0.02,1.0,0.13,1.6,0.36,2,0.49,3,0.7,5,0.9,10,0.98,7); Note, freshwater finfish; U.S. population, 48 states; Median, 2.0 g/kg.

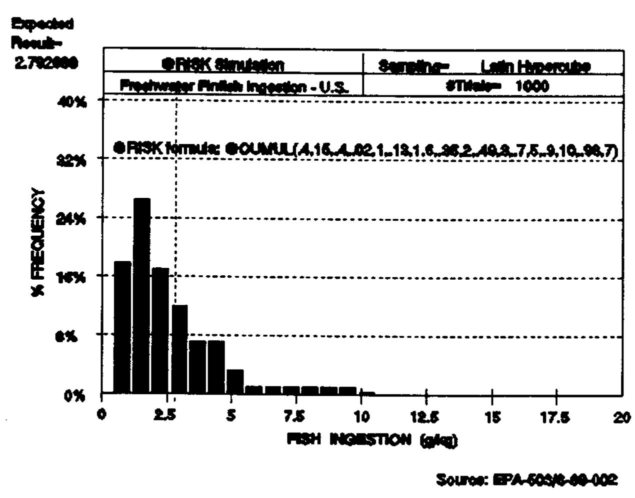

FIGURE 41. Distribution of freshwater finfish ingestion — U.S. population.

b. @RISK formula, @CUMUL (0.6,20,0.6,0.01,1,0.04,1.6,0.08,3,0.32,4,0.5,5,0.68, 10,0.92,15,0.97,8); Note, freshwater finfish; children 1 to 6 years old; Median, 3.99 g/kg.

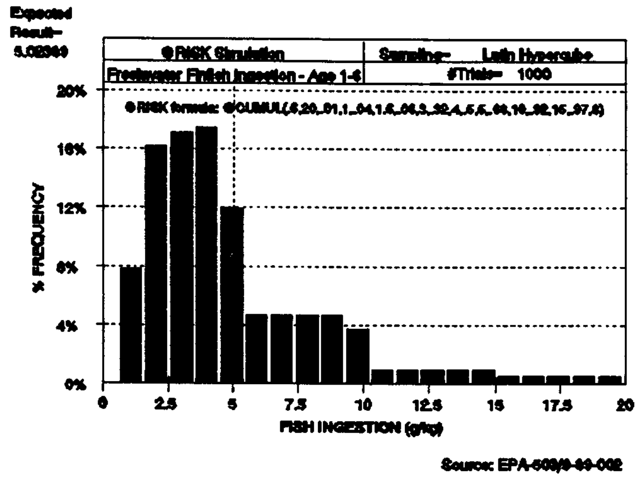

FIGURE 42. Distribution of freshwater finfish ingestion — children.

c. @RISK formula, @CUMUL (0.4,15,0.4,0.02,1,0.13,1.4,0.31,2,0.52,4,0.86,10,0.98,6); Note, freshwater finfish; females 13+ years old; Median, 1.91 g/kg.

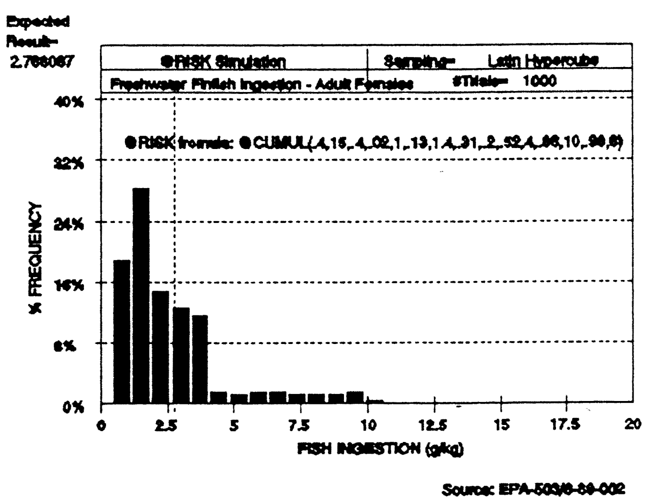

FIGURE 43. Distribution of freshwater finfish ingestion — adult females.

d. @RISK formula, @CUMUL (0.4,15,0.4,0.02,1.0,0.16,1.4,0.30,2,0.53,4,0.85,10,0.99,6); Note, freshwater finfish; males 13+ years old; Median, 1.95 g/kg.

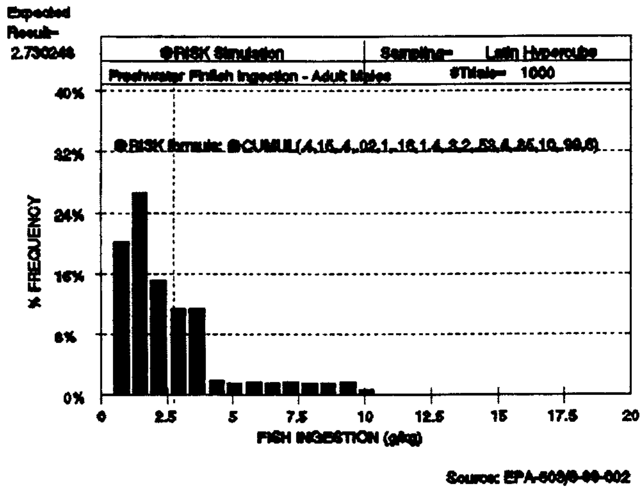

FIGURE 44. Distribution of freshwater finfish ingestion — adult males.

e. @RISK formula, @CUMUL (0.2,10,0.2,0.03,0.8,0.25,1.4,0.53,2,0.70,4,0.93,10,1,6); Note, saltwater finfish; U.S. population, 48 states; Median, 1.33 g/kg.

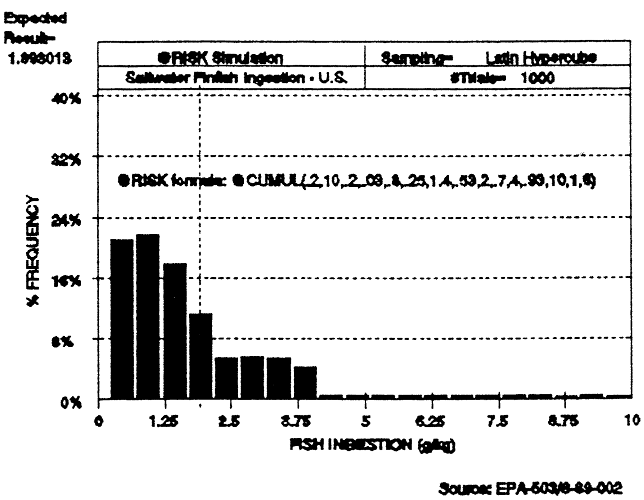

FIGURE 45. Distribution of saltwater finfish ingestion — U.S. population.

f. @RISK formula, @CUMUL (0.2,20,0.2,0.01,0.8,0.1,1.4,0.22,2,0.33,4,0.7,5,0.80,15,0.99,7); Note, saltwater finfish; children 1 to 6 years old; Median, 3.00 g/kg.

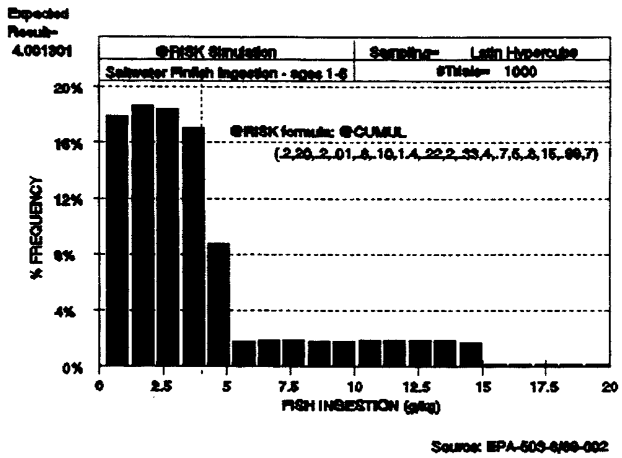

FIGURE 46. Distribution of saltwater finfish ingestion — children.

g. @RISK formula, @CUMUL (0.2,10,0.2,0.03,0.8,0.28,1.4,0.59,2,0.77,4,0.96,5); Note, saltwater finfish; females 13+ years old; Median, 1.25 g/kg.

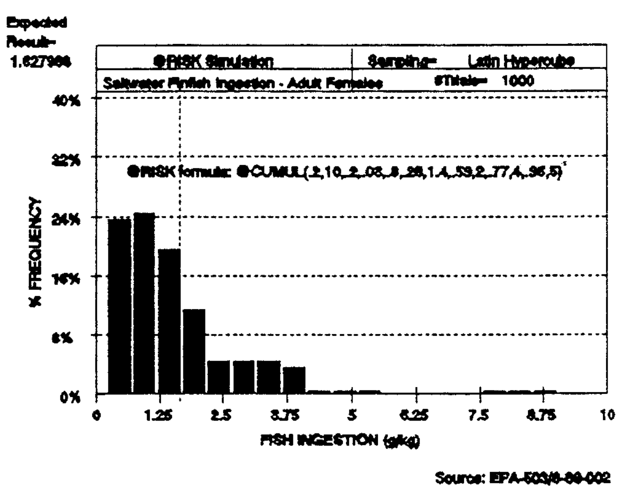

FIGURE 47. Distribution of saltwater finfish ingestion — adult females.

h. @RISK formula, @CUMUL (0.2,10,0.2,0.03,0.8,0.29,1.4,0.59,2,0.75,4,0.96,5); Note, saltwater finfish; males 13+ years old; Median, 1.08 g/kg.

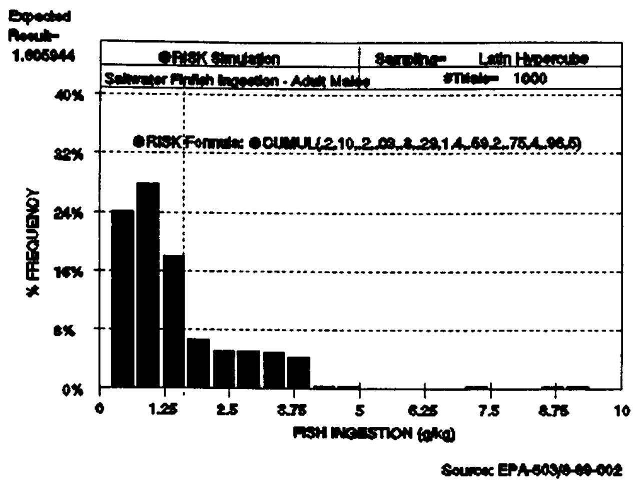

FIGURE 48. Distribution of saltwater finfish ingestion — adult males.

i. @RISK formula, @CUMUL (0.2,10,0.2,0.12,0.8,0.45,1.4,0.66,2,0.79,4,0.96,5); Note, shellfish; U.S. population, 48 states; Median, 1.05 g/kg.

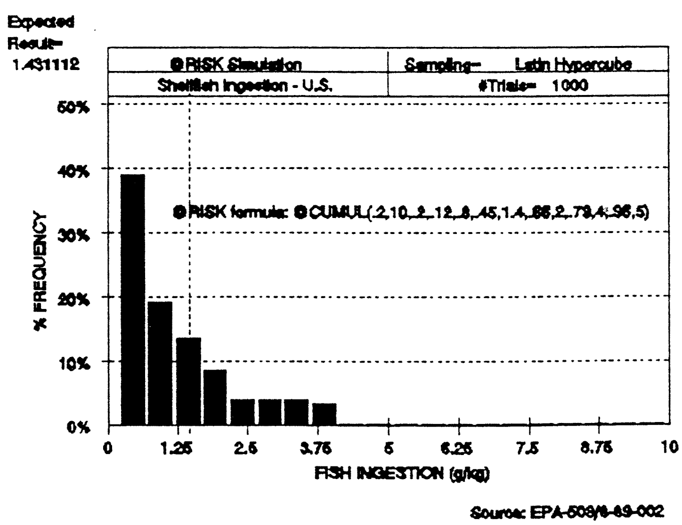

FIGURE 49. Distribution of shellfish ingestion — U.S. population.

j. @RISK formula, @CUMUL (0.2,15,0.2,0.1,0.8,0.36,1.4,0.45,2,0.57,4,0.87,10,0.99,6); Note, shellfish; children 1 to 6 years old; Median, 1.68 g/kg.

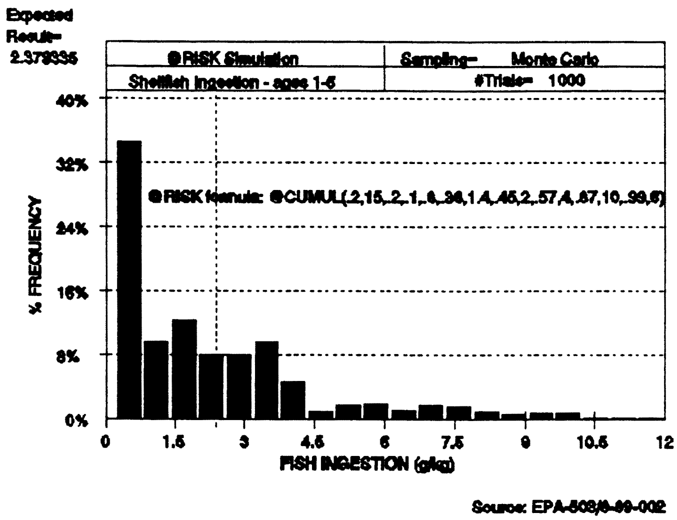

FIGURE 50. Distribution of shellfish ingestion — children, ages 1 to 6.

k. @RISK formula, @CUMUL (0.2,10,0.2,0.13,0.8,0.44,1.4,0.66,2,0.79,4,0.96,5); Note, shellfish; females 13+ years old; Median, 0.916 g/kg.

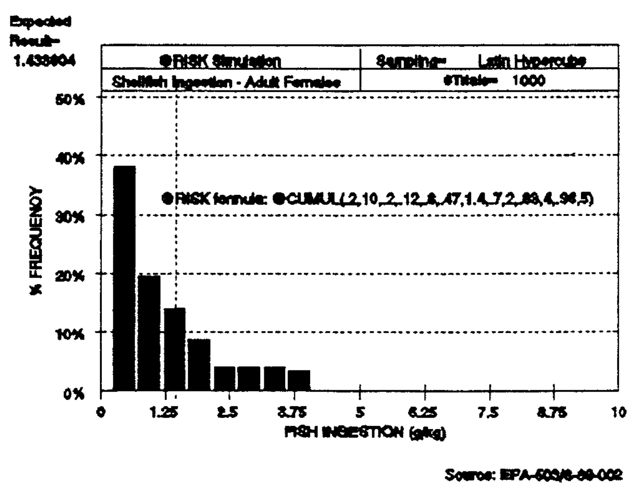

FIGURE 51. Distribution of shellfish ingestion — adult females, ages 13+.

l. @RISK formula, @CUMUL (0.2,10,0.2,0.12,0.8,0.47,1.4,0.70,2,0.83,4,0.96,5); Note, shellfish; males 13+ years old; Median, 0.84 g/kg.

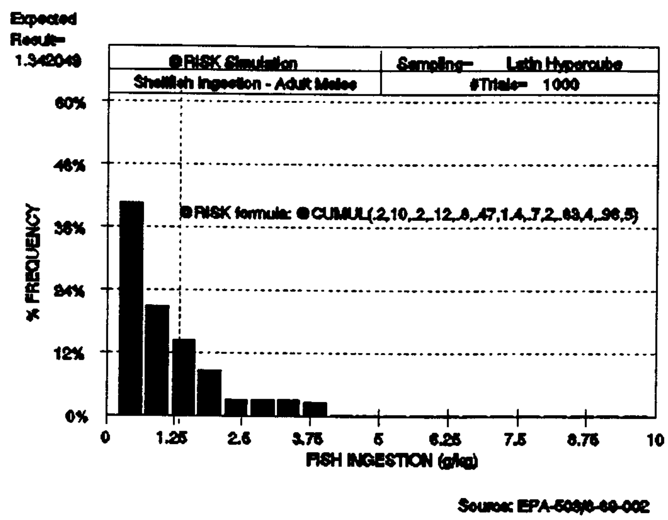

FIGURE 52. Distribution of shellfish ingestion — adult males, ages 13+.

m. @RISK formula, @CUMUL (0.4,5,0.4,0.04,0.8,0.31,1.4,0.44,2,0.72,4,0.95,5); Note, fish, unspecified; U.S. population, 48 states; Median, 1.5 g/kg.

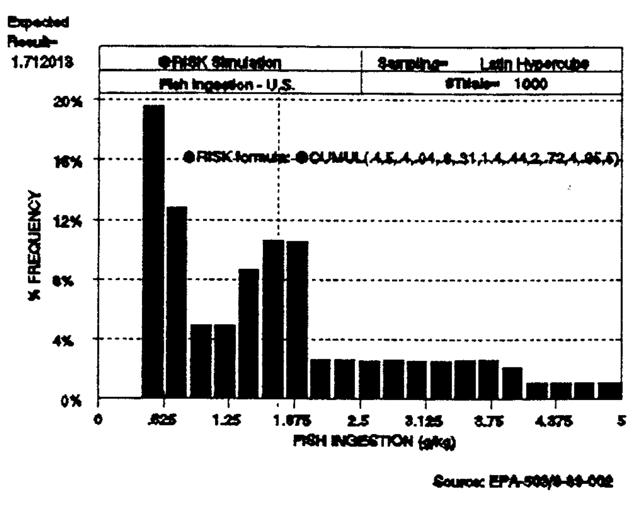

FIGURE 53. Distribution of fish (unspecified) ingestion — U.S. population.

n. @RISK formula, @CUMUL (0.8,4,0.8,0.21,1.4,0.21,2,0.57,3,0.88,4); Note, fish, unspecified; females 13+ years old; Median, 1.90 g/kg.

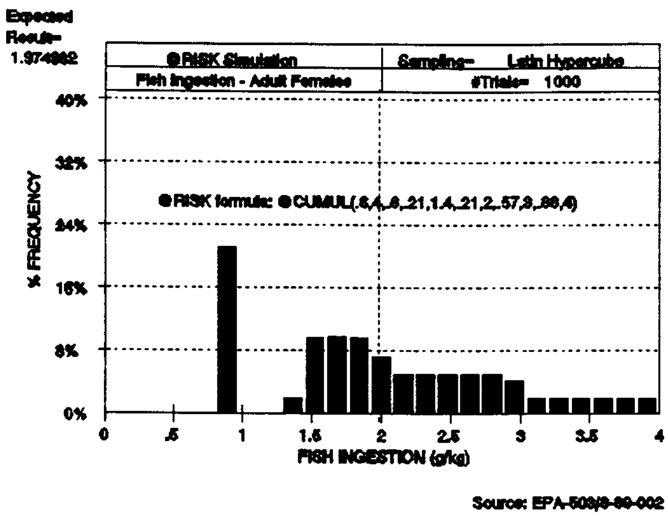

FIGURE 54. Distribution of fish (unspecified) ingestion — adult females.

o. @RISK formula, @CUMUL (0.4,2,0.4,0.08,0.8,0.46,1.4,0.74,1.8,0.93,4); Note, fish, unspecified; males 13+ years old; Median, 0.91 g/kg.

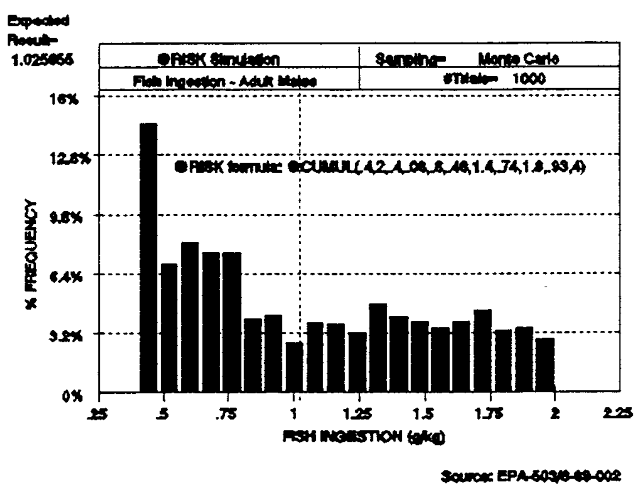

FIGURE 55. Distribution of fish (unspecified) ingestion — adult males.

F. Adult Meat and Beef Consumption

1. *Data Summary*

Various estimates of beef and meat consumption in the U.S. are available. The estimates performed by the EPA that appear in the Exposure Factor Handbook (EPA, 1989a) are based on the USDA Nationwide Food Consumption Survey conducted in 1977–1978. A more complete statistical analysis of these data was performed by Yang and Nelson (1986). As per other categories of food, consumption of meat varied by a number of factors, including geographical region and sex. Somewhat higher meat consumption rates were observed in the North, Central, and Southern regions than in the Northeast and Western regions. However, these differences were rather small (approximately 5%). Somewhat higher meat consumption was observed for males vs. females. However, after adjusting for body weight, these differences were also small (less than 10%). In the analysis of the USDA data performed by Yank and Nelson (1986), the mean meat and beef consumption across geographical regions was 172.2 and 87.6 g/d, respectively, with standard errors of ±1.6 and ±1.1 g/d, respectively.

Only a fraction of meat and beef consumption is from a home-grown source. For purposes of performing risk assessments, it may be important to differentiate between commercial and home-grown meat consumption. According to USDA studies, in farm households where beef is grown, the average annual consumption of beef that is home-grown is 44%. Applying this value to the above average consumptions yields home-grown meat and beef estimates of 75 and 40 g/d, respectively. The 40 g/d value for home-grown beef consumption contrasts with the commonly used default factor of 75 g/d (EPA, 1989a). This value represents a 90th percentile consumption value. It should be stressed that this exposure scenario should only be applied when there is a concern for ingesting home-grown beef and should not be applied to the general population.

2. ***Distributions (Figure 56)***

a. Distribution type, normal; @RISK formula, @NORMAL (75,56); Reference, Finley and Paustenbach, 1992 (Pao *et al.,* [1982]); Unit, grams per day; Note, based on beef consumption; Median, 70.54 g/d.

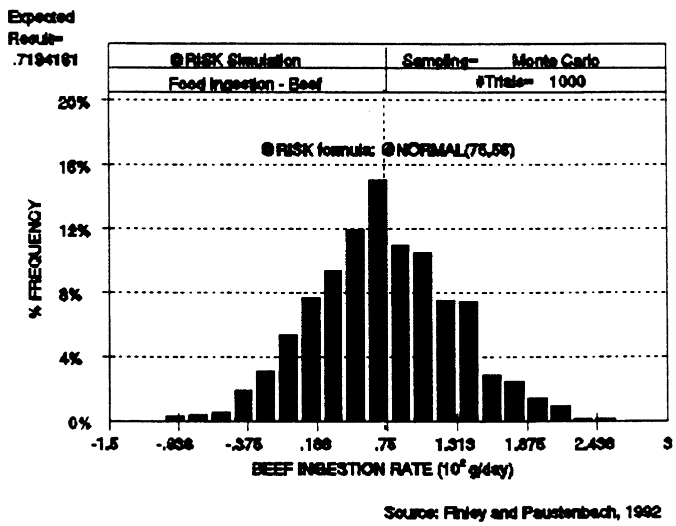

FIGURE 56. Distribution of adult food ingestion — beef.

G. **Adult Drinking Water Consumption Rate**

1. ***Data Summary***

To calculate the health-based drinking water criteria, many regulatory agencies employ the EPA default drinking water consumption rate of 2 l/d. As described in the EPA Exposure Factor Handbook, the 2 l/d drinking water intake default value "is a historical figure set by the U.S. Army in determining the amount of water needed for each person in the field" and "is an overestimate for most people" (EPA, 1989a). The 2 l/d value includes drinking water consumed in the form of juices and other beverages containing tapwater (e.g., coffee) (EPA, 1989a). Intake of these beverages during any normal daily activity for adults takes place at multiple locations, including work sites, restaurants, and a variety of nonhousehold locations. Therefore, using the 2 l/d value as a single source intake as commonly assumed in risk assessments (e.g., as the household water intake rate) is an overestimate. On the other hand, it is recognized that exposure to potable water contaminants occurs during showering and bathing as well as ingestion. The information needed to accurately quantify these noningestion routes of exposure is not currently available, and they are generally not considered in developing drinking water standards. It is not likely that intake through showering and bathing is more substantial than intake at nonhousehold sites.

Based on studies conducted by the National Academy of Sciences (1977), Cantor *et al.* (1987), Gullies and Patulin (1983), Pennington (1983), and the EPA (1984), the average adult drinking water consumption rate is 1.4 l/d and the reasonable worst-case value is 2.0 l/d. The 2.0 l/d value is approximately the 90th percentile value in the studies by Gullies and Patulin (1983) and Cantor *et al.* (1987). Therefore, the 1.4 l/d value is recommended for use in risk assessments.

2. *Distributions (Figures 57 to 67)*

a. Distribution type, normal; @RISK formula, @NORMAL (1.53,0.298); Reference, RiskFocus, Versar, 1991; Unit, liters per day; Median, 1.52 l/d.

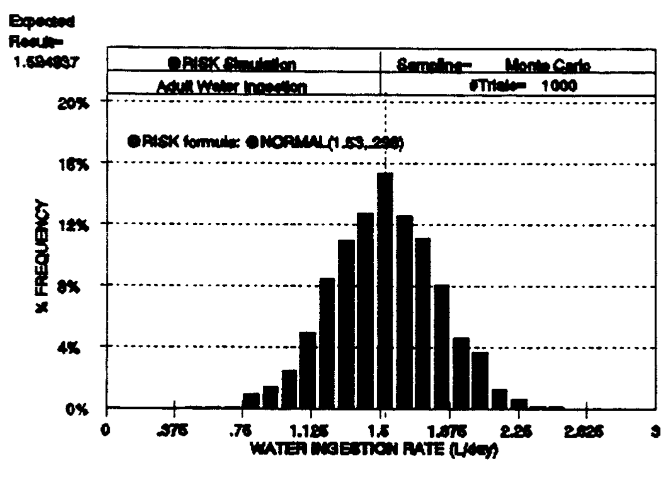

FIGURE 57. Adult water ingestion distribution.

b. Distribution type, uniform; @RISK formula, @UNIFORM (0.4,2.2); Reference, Finley and Paustenbach, 1992; Unit, liters per day; Median, 1.30 l/d.

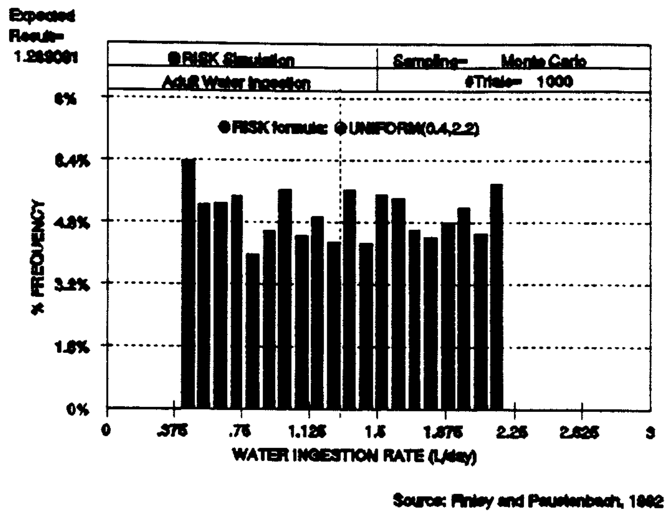

FIGURE 58. Adult water ingestion distribution.

c. Distribution type, cumulative; @RISK formula, @CUMUL (0.4,2,0.4,0.192,0.96,0.396, 1.28,0.6,1.7,0.8,1.96,1,5); Reference, EPA 2–5; Unit, liters per day; Median, 1.13 l/d.

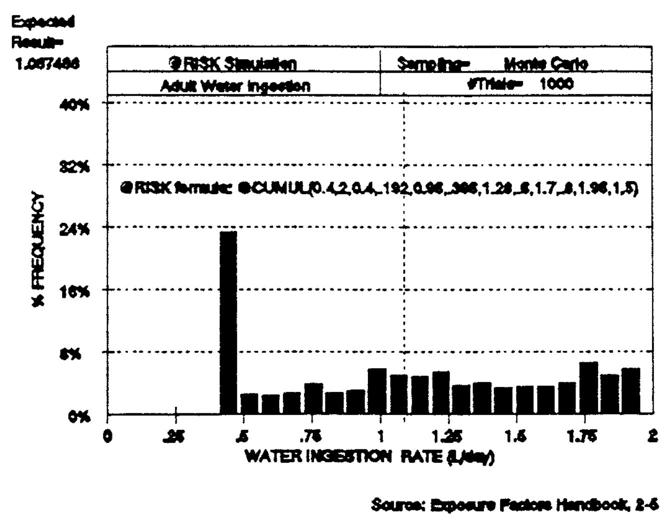

FIGURE 59. Adult water ingestion distribution.

d. Distribution type, cumulative; @RISK formula, @CUMUL (600,2000,607,0.025, 882,0.25,1074,0.5,1307,0.75,1900,0.975,5); Reference, Roseberry and Burmaster, 1992; Unit, milliliters per day; Note, total water intake; 0 < age < 1 year.
e. Distribution type, cumulative; @RISK formula, @CUMUL (600,3000,676,0.025, 1046,0.25,1316,0.5,1655,0.75,2562,0.975,5); Reference, Roseberry and Burmaster, 1992; Unit, milliliters per day; Note, total water intake; 1 < age < 11 years.
f. Distribution type, cumulative; @RISK formula, @CUMUL (800,4000,907,0.025, 1417,0.25,1790,0.5,2262,0.75,3534,0.975,5); Reference, Roseberry and Burmaster, 1992; Unit, milliliters per day; Note, total water intake; 11 < age < 20 years.
g. Distribution type, cumulative; @RISK formula, @CUMUL (800,4500,879,0.025,1470,0.25, 1926,0.5,2522,0.75,4218,0.975,5); Reference, Roseberry and Burmaster, 1992; Unit, milliliters per day; Note, total water intake; 20 < age < 65 years.
h. Distribution type, cumulative; @RISK formula, @CUMUL (800,4000,970,0.025,1541,0.25, 1965,0.5,2504,0.75,3978,0.975,5); Reference, Roseberry and Burmaster, 1992; Unit, milliliters per day; Note, total water intake; 65+ years.
i. Distribution type, cumulative; @RISK formula, @CUMUL (800,4000,807,0.025,1358,0.25, 1785,0.5,2345,0.75,3947,0.975,5); Reference, Roseberry and Burmaster, 1992; Unit, milliliters per day; Note, total water intake; all ages (all survey data); Median, 1782.07 ml/d.

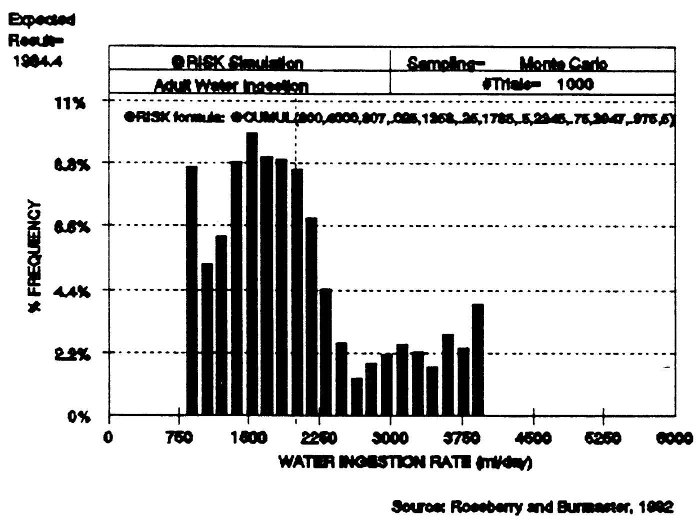

FIGURE 60. Adult total water intake distribution.

j. Distribution type, cumulative; @RISK formula, @CUMUL (800,4000,808,0.025,1363,0.25, 1794,0.5,2360,0.75,3983,0.975,5); Reference, Roseberry and Burmaster, 1992; Unit, milliliters per day; Note, total water intake; simulated balanced population; Median, 1836.92 ml/d.

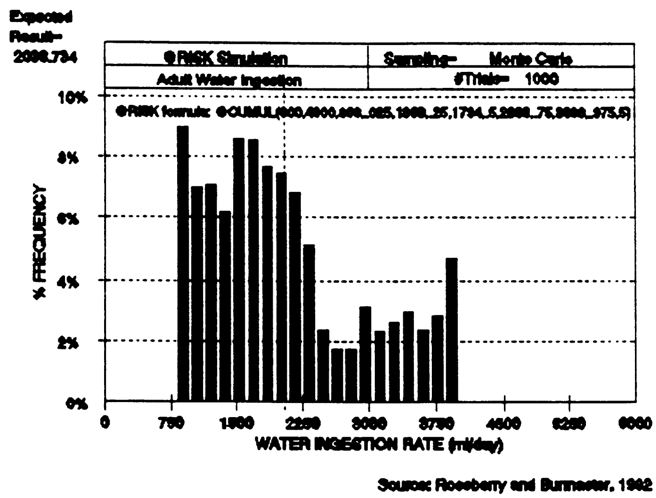

FIGURE 61. Adult total water intake distribution — simulated balanced.

k. Distribution type, cumulative; @RISK formula, @CUMUL (50,1000,80,0.025,176,0.25, 267,0.5,404,0.75,891,0.975,5); Reference, Roseberry and Burmaster, 1992; Unit, milliliters per day; Note, tap water intake; 0 < age < 1 year.
l. Distribution type, cumulative; @RISK formula, @CUMUL (200,2000,233,0.025,433,0.25, 620,0.5,867,0.75,1644,0.975,5); Reference, Roseberry and Burmaster, 1992; Unit, milliliters per day; Note, tapwater intake; 1 < age < 11 years.
m. Distribution type, cumulative; @RISK formula, @CUMUL (250,2500,275,0.025,548,0.25, 786,0.5,1128,0.75,2243,0.975,5); Reference, Roseberry and Burmaster, 1992; Unit, milliliters per day; Note, tapwater intake; 11 < age < 20 years.
n. Distribution type, cumulative; @RISK formula, @CUMUL (350,3000,430,0.025,807,0.25, 1122,0.5,1561,0.75,2926,0.975,5); Reference, Roseberry and Burmaster, 1992; Unit, milliliters per day; Note, tapwater intake; 20 < age < 65 years.
o. Distribution type, cumulative; @RISK formula, @CUMUL (400,3100,471,0.025,869,0.25, 1198,0.5,1651,0.75,3044,0.975,5); Reference, Roseberry and Burmaster, 1992; Unit, milliliters per day; Note, tapwater intake; 65+ years old.

p. Distribution type, cumulative; @RISK formula, @CUMUL (300,3000,341,0.025,674,0.25, 963,0.5,1377,0.75,2721,0.975,5); Reference, Roseberry and Burmaster, 1992; Unit, milliliters per day; Note, tapwater intake; all ages (all survey data); Median, 965.54 ml/d.

q. Distribution type, cumulative; @RISK formula, @CUMUL (300,3000,310,0.025,649,0.25, 957,0.5,1411,0.75,2954,0.975,5); Refrence, Roseberry and Burmaster, 1992; Unit, milliliters per day; Note, tapwater intake; simulated balanced population; Median, 943.96 ml/d.

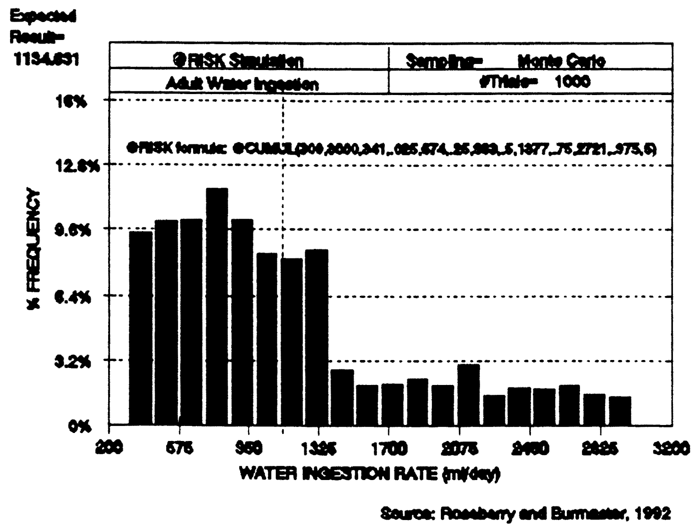

FIGURE 62. Distribution of adult tap water ingestion.

r. Distribution type, lognormal; @RISK formula, @LOGNORM (6.979,0.291); Reference, Roseberry and Burmaster, 1992; Unit, ln milliliters per day; Note, total water intake; infants <1 year old.

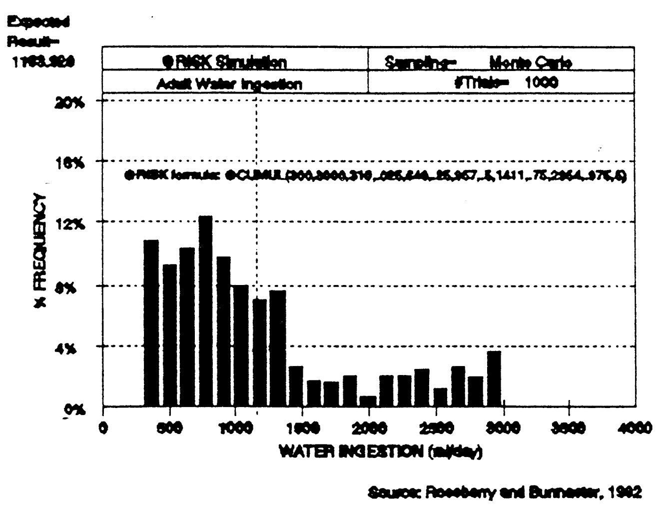

FIGURE 63. Distribution of adult tap water intake — simulated balanced.

s. Distribution type, lognormal; @RISK formula, @LOGNORM (7.182,0.340); Reference, Roseberry and Burmaster, 1992; Unit, ln milliliters per day; Note, total water intake; 1 < age < 11 years.
t. Distribution type, lognormal; @RISK formula, @LOGNORM (7.490,0.347); Reference, Roseberry and Burmaster, 1992; Unit, ln milliliters per day; Note, total water intake; 11 < age < 20 years.
u. Distribution type, lognormal; @RISK formula, @LOGNORM (7.563,0.400); Reference, Roseberry and Burmaster, 1992; Unit, ln milliliters per day; Note, total water intake; 20 < age < 65 years.
v. Distribution type, lognormal; @RISK formula, @LOGNORM (7.583,0.360); Reference, Roseberry and Burmaster, 1992; Unit, ln milliliters per day; Note, total water intake; 65+ years.
w. Distribution type, lognormal; @RISK formula, @LOGNORM (7.487,0.405); Reference, Roseberry and Burmaster, 1992; Unit, ln milliliters per day; Note, total water intake; all ages (all survey data); Median, 7.46 ml/d.

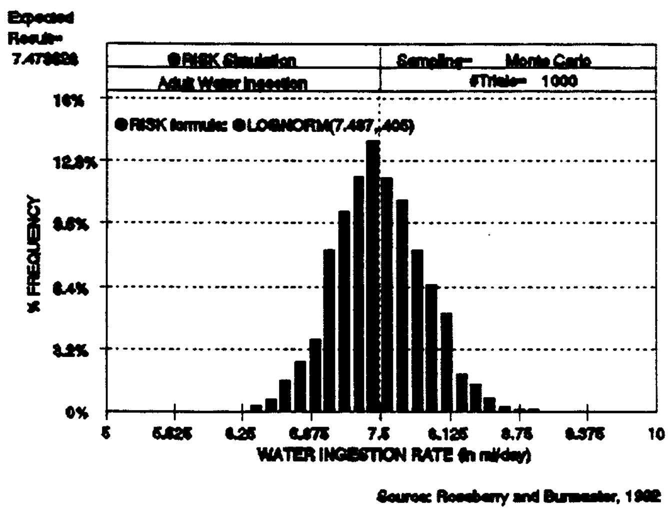

FIGURE 64. Adult total water ingestion distribution.

x. Distribution type, lognormal; @RISK formula, @LOGNORM (7.492,0.407); Reference, Roseberry and Burmaster, 1992; Unit, ln milliliters per day; Note, total water intake; simulated balanced population; Median, 7.45 ml/d.

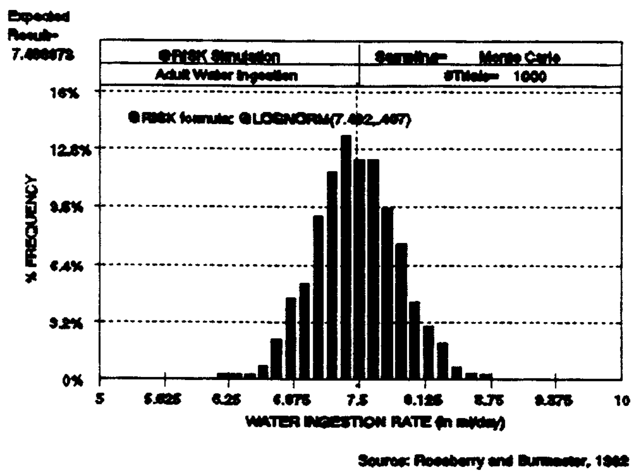

FIGURE 65. Adult total water intake distribution — simulated balanced.

y. Distribution type, lognormal; @RISK formula, @LOGNORM (5.587,0.615); Reference, Roseberry and Burmaster, 1992; Unit, ln milliliters per day; Note, tapwater intake; 0 < age < 1 year.

z. Distribution type, lognormal; @RISK formula, @LOGNORM (6.429,0.498); Reference, Roseberry and Burmaster, 1992; Unit, ln milliliters per day; Note, tapwater intake; 1 < age < 11 years.

aa. Distribution type, lognormal; @RISK formula, @LOGNORM (6.667,0.535); Reference, Roseberry and Burmaster, 1992; Unit, ln milliliters per day; Note, tapwater intake; 11 < age < 20 years.

bb. Distribution type, lognormal; @RISK formula, @LOGNORM (7.023,0.489); Reference, Roseberry and Burmaster, 1992; Unit, ln milliliters per day; Note, tapwater intake; 20 < age < 65 years.

cc. Distribution type, lognormal; @RISK formula, @LOGNORM (7.088,0.476); Reference, Roseberry and Burmaster, 1992; Unit, ln milliliters per day; Note, tapwater intake; 65+ years.

dd. Distribution type, lognormal; @RISK formula, @LOGNORM (6.870,0.530); Reference, Roseberry and Burmaster, 1992; Unit, ln milliliters per day; Note, tapwater intake; all ages (all survey data); Median, 6.85 ml/d.

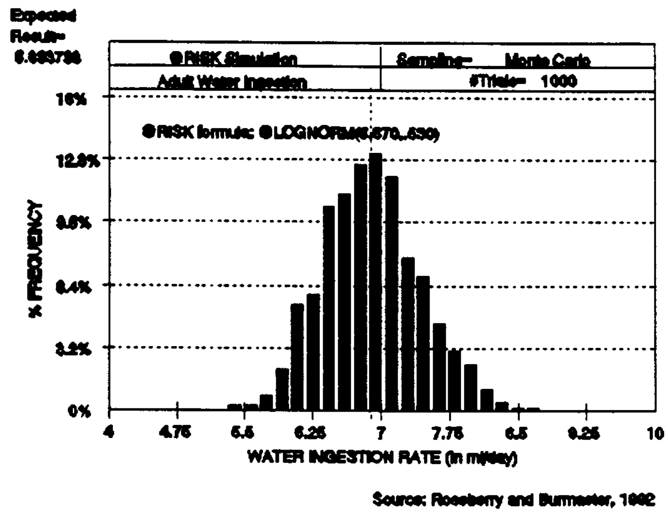

FIGURE 66. Distribution of adult tap water intake.

ee. Distribution type, lognormal; @RISK formula, @LOGNORM (6.864,0.575); Reference, Roseberry and Burmaster, 1992; Unit, ln milliliters per day; Note, tapwater intake; simulated balanced population; Median, 6.81 ml/d.

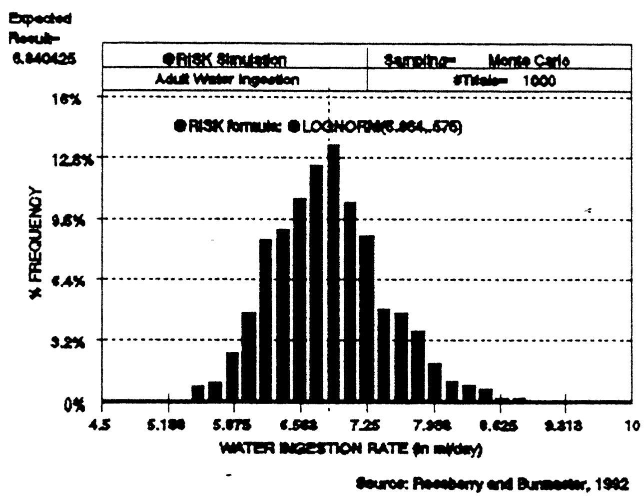

FIGURE 67. Distribution of adult tap water ingestion — simulated balanced.

H. **Daily Inhalation Rate for Adults**

1. Data Summary (Tables 6 and 7)

The daily inhalation rate for adults recommended for use in risk assessments is 18 m^3/d. This value was calculated based on the combined average adult inhalation rates for men and women listed in the EPA Exposure Factor Handbook (EPA, 1989a) and assuming the following daily activity pattern: 12 h rest (including sleeping, watching television, and reading), 10 h light activity (including domestic work, attending to personal needs and care, hobbies, and conducting light work activities and home improvements), 1 h moderate activity (including strenuous work activities and climbing stairs), and 1 h heavy activity (including vigorous physical exercise).

In certain cases, the volume of air inhaled for purposes of performing a risk assessment may be less than the total daily inhalation rate. For example, the volume of contaminated air inhaled daily by an adult living adjacent to a waste site recommended for use in risk assessments may be less than 18 m^3. In this case, a value of 11 m^3/d is calculated by adjusting the total daily inhalation rate of 18 m^3/d for an adult by the mean at home/away from home activity patterns for men and women (Section IV.C.1). Men and women spend an average of 58% (98 h) and 69% (116 h) of their time at home per week, respectively. Therefore, the volume of contaminated air inhaled by an adult = $107/168 \times 18$ m^3/d = 11.5 m^3/d.

The 11 m^3/d value may be adjusted when considering certain modifications of the above exposure scenario (living near a waste site). For example, if the waste site is proposed for use as parkland, an additional 1 h/d of exposure can be added to account for exposure associated with combined residential living and parkland usage.

TABLE 6A
Point Value Estimates of Adult Air Intake Rate

Value	Unit	Notes	Ref.
20	m^3/d	Canadian standard	Richardson *et al.*
20	m^3/d	Outdoor residential and agricultural; industrial	RAGS
15	m^3/d	Indoor residential and agricultural	RAGS
0.6	m^3/h	Showering	RAGS

TABLE 6B
Exposure Factor Handbook:
Inhalation as a Function of Activity

	Resting	Light	Moderate	Heavy
Male	0.7	0.8	2.5	4.8
Female	0.3	0.5	1.6	2.9
Average	0.5	0.6	2.1	3.9

Note: See EPA Exposure Factor Handbook for description of activity levels. Unit of measure is cubic meters per hour.

Source: EPA 3-4.

TABLE 7
Exposure Factor Handbook:
Inhalation as a Function of Activity

	Resting	Light	Moderate	Heavy
Child, age 6	0.4	0.8	2.0	2.4
Child, age 10	0.4	1.0	3.2	4.2

Note: See EPA Exposure Factor Handbook for description of activity levels. Unit of measure is cubic meters per hour.

Source: EPA 3-4.

2. ***Distributions (Figures 68 and 69)***

a. Distribution type, uniform; @RISK formula, @UNIFORM (0.21,0.74); Reference, Finley and Paustenbach, 1992; Unit, cubic meters per hour; Median, 0.471 m^3/h.

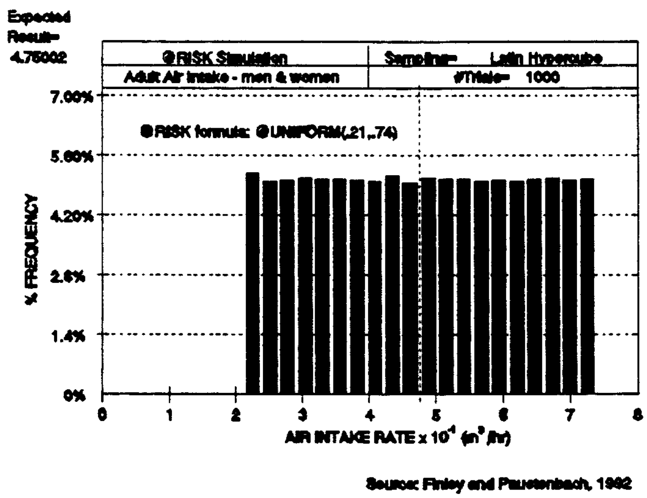

FIGURE 68. Distribution of adult inhalation rate — men and women.

b. Distribution type, cumulative; @RISK formula, @CUMUL (0.7,4.8,0.7,0.28,0.8,0.56, 2.5,0.93,4.8,1,4); Reference, EPA, 1989, pp. 3–8; Unit, cubic meters per hour; Note, physical labor, outdoors; Median, 0.78 m^3/h.

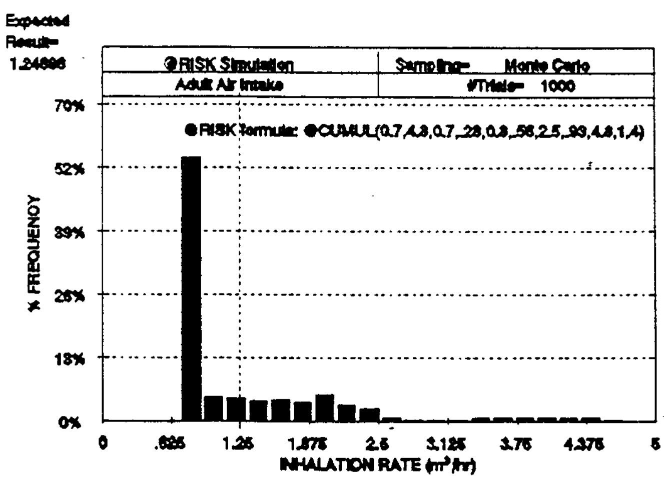

FIGURE 69. Adult inhalation rate distribution.

I. Daily Inhalation Rate for Children

1. Data Summary

The daily inhalation rate recommended for use in risk assessment for children ages 1 to 4 is 12 m^3/d. This value is based on the value for 6-year-old children listed in the EPA Exposure Factor Handbook and assuming the following activity pattern: 12 h rest (including sleeping, watching television, and reading), 10 h light activity (including light play activities), and 2 h moderate activity (inducing moderately vigorous play activities). The value for 1 to 4 years olds was estimated by adjusting the value for 6 year olds by a factor of 0.75. A value for children aged 1 to 4 was used because the most reliable soil ingestion data are for children of this age range.

As for adults, for certain exposure assessments the volume of air inhaled may be less than the total daily value. For example, for assessments concerning inhalation of air near a waste site, a value of less than the total daily rate is recommended. In this case, a value of 10 m^3/d, calculated by adjusting the total daily inhalation rate for a child by the fraction of exposure duration at the site, could be used. The total daily exposure duration at the site was estimated by evaluating activity pattern data for children (Section IV.D.1). Such data are limited. However, they suggest that, on the average, children spend approximately 30 h/week (18%) away from home, engaged in activities such as shopping, church, preschool, and visiting. Thus, the volume per day of contaminated air inhaled by children = $138/168 \times 12$ m^3/d = 10 m^3/d.

Distributions of child air intake have been derived from data presented in the Exposure Factor Handbook. As stated in the previous section, effort should be made to ensure that inconsistent representations of the data do not occur due to conflicts in time-activity patterns and breathing rate.

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