U.S. NUCLEAR REGULATORY COMMISSION

March 1976

REGULATORY GUIDE

OFFICE OF STANDARDS DEVELOPMENT

REGULATORY GUIDE 1.109

CALCULATION OF ANNUAL DOSES TO MAN FROM ROUTINE RELEASES OF REACTOR EFFLUENTS FOR THE PURPOSE OF EVALUATING COMPLIANCE WITH 10 CFR PART 50, APPENDIX I

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

LIST OF TABLES

A. INTRODUCTION

Section 20.106, "Radioactivity in Effluents to Unrestricted Areas," of the Nuclear Regulatory Commission's regulations in 10 CFR Part 20, "Standards for Protection Against Radiation," establishes limits on concentrations of radioactive material in effluents to unrestricted areas. Paragraph (c) of § 20.1, "Purpose," of 10 CFR Part 20 states that licensees should, in addition to complying with the limits set forth in that part, make every reasonable effort to maintain releases of radioactive materials in effluents to unrestricted areas as far below the limits specified as is reasonably achievable.

Sections 50.34a, "Design Objectives for Equipment to Control Releases of Radioactive Material in Effluents -- Nuclear Power Reactors," and 50.36a, "Technical Specifications on Effluents from Nuclear Power Reactors," of 10 CFR Part 50, "Licensing of Production and Utilization Facilities," set forth design objectives and technical specifications to control releases of radioactive effluents from light-water-cooled nuclear power reactors. Section 50.36a of 10 CFR Part 50 further provides that, in order to keep power reactor effluent releases as low as is reasonably achievable, each operating license will include technical specifications that (a) require compliance with the provisions of § 20.106 dealing with effluent discharge limits, (b) require that operating procedures for the control of effluents be established and followed and that equipment installed in the radioactive waste system be maintained and used, and (c) establish requirements for reporting measured releases of radionuclides to the environment.

Appendix I, "Numerical Guides for Design Objectives and Limiting Conditions for Operation to Meet the Criterion 'As Low As Is Reasonably Achievable' for Radioactive Material in Light-Water-Cooled Nuclear Power Reactor Effluents," to 10 CFR Part 50 provides numerical guidance for radioactive effluent design objectives and technical specification requirements for limiting conditions of operation for light-water-cooled nuclear power plants.

To implement Appendix I, the NRC staff has developed a series of guides that provide methods acceptable to the staff for the calculation of preoperational estimates of effluent releases, dispersion of the effluent in the atmosphere and different water bodies, and estimation of the associated radiation doses* to man. This guide describes basic features of these calculational models and suggests parameters for the estimation of radiation doses to man from effluent releases. The methods used herein are general approaches that the NRC staff has developed for application in lieu of specific parameters for individual sites. The use of site-specific values by the applicant is encouraged. However, the assumptions and methods used to obtain these parameters should be fully described and documented.

The procedures and models provided in this guide will be subject to continuing review by the staff with the aim of providing greater flexibility to the applicant in meeting the requirements of Appendix I. As a result of such reviews, it is expected that alternative acceptable methods for calculation will be made available to applicants and that calculational procedures found to be unnecessary will be eliminated.

This guide supersedes portions of Regulatory Guide 1.42, Revision 1, "Interim Licensing Policy on as Low as Practicable for Gaseous Radioiodine Releases from Light-Water-Cooled Nuclear Power Reactors," which is being withdrawn.

B. DISCUSSION

Appendix I to 10 CFR Part 50 provides guidance on the levels of exposure of the general public resulting from effluent releases that may be considered to be as low as is reasonably achievable. This guide describes basic features of the calculational models and assumptions in use by the NRC staff for the estimation of doses. These estimates can be used to implement Appendix I in lieu of site-specific phenomena actually affecting the estimation of radiation exposure.

*In this guide, the term "dose," when applied to individuals, is used instead of the more precise term "dose equivalent," as defined by the International Commission on Radiological Units and Measurements (ICRU).

Appendix A of this guide describes suggested methods for calculating the estimated doses to man from discharges to the hydrosphere. Appendix B of this guide describes suggested models and assumptions for calculating submersion doses from radionuclides discharged to the atmosphere, and Appendix C gives equations for estimating doses from radioiodines and other radionuclides released to the atmosphere. Appendix D describes the models and assumptions for calculating population dose (man-rem and man-thyroid-rem) from radionuclide releases to the atmosphere and hydrosphere.

The models and assumptions described in Appendices A, B, C, and D of this guide are acceptable to the NRC staff for calculating doses to individuals and populations. If other models are selected, they should include the same exposure pathways and physical mechanisms as are used in the models described in this guide.

As discussed in Section III.A.2 of Appendix I to 10 CFR Part 50, the applicant may take into account any real phenomena or actual exposure conditions that affect or modify the estimate of radiation exposure. Such conditions should include actual values for agricultural productivity, residence times, dose attenuation by structures, measured environmental transport factors (such as bioaccumulation factors), or similar values actually determined at a specific site. The applicant should provide enough information on the measurements or other methods used to derive these substitute values to enable the NRC staff to evaluate their validity.

C. REGULATORY POSITION

1. Radiation Doses from Liquid Effluent Pathways

The NRC staff will calculate radiation doses from potable water, aquatic food, shoreline deposits, and irrigated food pathways by using the following equations from Appendix A of this guide.

a. Potable Water

$$R_{apj} = 1100 \frac{M_p U_{ap}}{F} \sum_i^n Q_i' D_{aipj} \exp(-\lambda_i t_p) \quad (1)$$

b. Aquatic Foods

$$R_{apj} = 1100 \frac{U_{ap} M_p}{F} \sum_i^n Q_i' B_{ip} D_{aipj} \exp(-\lambda_i t_p) \quad (2)$$

c. Shoreline Deposits

$$R_{apj} = 110{,}000 \frac{U_{ap} M_p W}{F} \sum_i^n Q_i' T_i D_{aipj} [\exp(-\lambda_i t_p)][1 - \exp(-\lambda_i t)] \quad (3)$$

d. Irrigated Foods

For all radionuclides except tritium:

$$R_{apj} = U_{ap}^{veg} \sum_i^n d_i' \exp(-\lambda_i t_h) D_{aipj} \left[\frac{r[1 - \exp(-\lambda_{Ei} t_e)]}{Y_v \lambda_{Ei}} + \frac{B_{iv}[1 - \exp(-\lambda_i t_b)]}{P\lambda_i} \right]$$
$$+ U_{ap}^{animal} \sum_i^n S_{iA} D_{aipj} \left\{ Q_F d_i' \exp(-\lambda_i t_h) \left[\frac{r[1 - \exp(-\lambda_{Ei} t_e)]}{Y_v \lambda_{Ei}} + \frac{B_{iv}[1 - \exp(-\lambda_i t_b)]}{P\lambda_i} \right] + C_{iAw} Q_{Aw} \right\} \quad (4)$$

For tritium:

$$R_{apj} = U_{ap}^{veg} C_v D_{apj} + U_{ap}^{animal} D_{apj} \frac{kC_w}{\lambda_m} (w + Q_{Aw}) \quad (5)$$

where

B_{ip} is the equilibrium bioaccumulation factor for nuclide i in pathway p, expressed as the ratio of the concentration in biota (in pCi/kg) to the radionuclide concentration in water (in pCi/liter), in liters/kg;

B_{iv} is the concentration factor for uptake of radionuclide i from soil by edible parts of crops, in pCi/kg (wet weight) per pCi/kg dry soil;

C_{iAw} is the concentration of radionuclide i in water consumed by animals, assumed to be equal to C_{iw} (pCi/liter);

C_{iw} is the radionuclide concentration in water, in pCi/liter;

D_{aipj} is the dose factor, specific to a given radionuclide i, pathway p, organ j, and individual's age a, which can be used to calculate the radiation dose from an intake of a radionuclide, in mrem/pCi, or from exposure to a given concentration of a radionuclide in water, expressed as a ratio of the dose rate (in mrem/hr) and the radionuclide concentration in water (in pCi/liter);

d_i is the deposition rate of nuclide i, in pCi/m^2 per hr;

F is the flow rate of the liquid effluent, in ft^3/sec;

k is the reciprocal of the body water volume (0.0041 $liter^{-1}$ for beef cattle and 0.0028 $liter^{-1}$ for dairy cattle);

M_p is the mixing ratio (reciprocal of the dilution factor) at the point of exposure (or the point of withdrawal of drinking water or point of harvest of aquatic food) as described in Table A-1 (in Appendix A of this guide), dimensionless;

n is the number of radionuclides that are to be considered;

P is the effective "surface density" for soil, in kg(dry soil)/m^2. Assuming a uniform mixing of all radionuclides in a plow layer of 15 cm (6 in.) depth, P has a value of approximately 240 kg/m^2;

Q_{Aw} is the consumption rate of contaminated water by an animal, in liters/day;

Q_F is the consumption rate of contaminated feed or forage by an animal, in kg/day (net weight);

Q_i' is the release rate of nuclide i, in Ci/yr;

r is the fraction of deposited activity retained on crops (which is 0.25 for sprinkler irrigation, 0.2 for particulates, and 1.0 for airborne deposition of radionuclides), dimensionless;

R_{apj} is the total annual dose to organ j of individuals of age a from all of the nuclides i in pathway p, in mrem/yr;

S_i is the transfer coefficient for radionuclide i which relates the daily intake rate by an animal to the concentration in an edible portion of animal product, in pCi/liter (milk) per pCi/day or pCi/kg (animal product) per pCi/day;

t is the period of time for which sediment is exposed to the contaminated water, nominally taken to be the mid-point of the operating lifetime of the facility, in hours;

t_b is the mid-point of the soil exposure time (15 years for a typical power reactor), in hours;

t_e is the time period that crops are exposed to contamination during the growing season, in hours;

t_h is a holdup time that represents the time interval between harvest and consumption of the food, in hours;

T_i is the radioactive half life of nuclide i, in days;

t_p is the average transit time required for nuclides to reach the point of exposure. For internal dose, t_p is the total time elapsed between release of the nuclides and ingestion of food or water, in hours;

U_{ap} is a usage factor that specifies the exposure time or intake rate for an individual of age a associated with pathway p, in hr/yr or kg/yr (as appropriate);

w is the water intake rate via fresh forage (28 liters/day for beef cattle and 38 liters/day for dairy cattle);

W is the shoreline width factor, dimensionless;

Y_v is the agricultural productivity (yield), in kg(wet weight)/m^2;

λ_{Ei} is the effective removal rate constant for radionuclide i from crops, in hr^{-1}, provided that $\lambda_{Ei} = \lambda_i + \lambda_w$, where λ_i is the radioactive decay constant, in $(hr)^{-1}$, and λ_w is the removal rate constant for physical loss by weathering (λ_w = 0.0021 hr^{-1}, which corresponds to a removal half-life of 14 days);

λ_i is the radioactive decay constant of nuclide i, in hr^{-1};

λ_m is the water elimination rate constant (0.32/day for beef cattle and 0.28/day for dairy cattle);

1100 is the factor to convert from (Ci/yr)/(ft^3/sec) to pCi/liter; and

110,000 is the factor to convert from (Ci/yr)/(ft^3/sec) to pCi/liter and to account for the proportionality constant used in the sediment radioactivity model.

These equations yield the dose rate to various organs of an individual from the exposure pathways mentioned above. Appendix I of 10 CFR Part 50 requires that the annual doses or dose commitments to the total body or any organ of an individual from the sum of the exposure pathways from liquid effluents associated with each reactor should not exceed 3 mrem and 10 mrem, respectively.

2. Gamma and Beta Doses from Gaseous Effluents

The NRC staff will calculate radiation doses from gaseous effluents using the following equations from Appendix B of this guide. The definitions of elevated and ground-level releases are found in Regulatory Guide 1.111, "Methods for Estimating Atmospheric Transport and Dispersion for Gaseous Effluents on Routine Releases from Light-Water-Cooled Reactors," and Appendix B to this guide.

a. Gamma Air Dose Rates for Elevated Releases

$$D^{\gamma}(r,\Theta) = \frac{260}{r(\Delta\Theta)} \sum_n \frac{1}{u_n} \sum_s f_{ns} \sum_k \mu_a(E_k)\, E_k I(H,u,s,\sigma_z,E_k) \sum_i Q'^{D}_{ni} A_{ki} \qquad (6)$$

where

A_{ki} is the photon yield for gamma-ray photons in energy group k from the decay of radionuclide i, in photons/disintegration;

$D^{\gamma}(r,\Theta)$ is the annual total gamma air dose at a distance r in the sector at angle Θ, in mrad/yr;

E_k is the energy of the kth photon energy group, in MeV/photon;

f_{ns} is the fraction of the time that stability class s and wind speed n occur for sector Θ, dimensionless;

$I(H,u,s,\sigma_z,E_k)$ is the result of the numerical integration accounting for the distribution of radioactivity according to meteorological conditions of wind speed (u) and atmospheric stability (s) which in part determine the effective stack height (H) and the vertical plume standard deviation (σ_z). In addition, I is a function of the photon energy E_k and is $\overline{I} = \overline{I}_1 + k\overline{I}_2$ as formulated in Slade (see Reference 1 in Appendix B of this guide);

$Q_{ni}^{'D}$ is the release rate of radionuclide i, corrected for decay during transit to the distance r under wind speed u_n, in Ci/yr;

r is the distance from the release point to the receptor, in meters;

u_n is the mean wind speed of wind speed class n, in m/sec;

ΔΘ is the sector width over which atmospheric conditions are averaged, in radians; and

$\mu_a(E_k)$ is the air energy absorption coefficient for the kth photon energy group, in m^{-1}.

b. Gamma Air Dose Rates from Ground-Level Releases; Beta Air Dose Rates from Elevated and Ground-Level Releases

$$D^{\gamma}(r,\Theta) \text{ or } D^{\beta}(r,\Theta) = 3.17 \times 10^4 \sum_i Q_i'[\chi/Q']^D(r,\Theta)(DF_i^{\gamma} \text{ or } DF_i^{\beta}) \tag{7}$$

where

DF_i^{γ}, DF_i^{β} are the gamma and beta air dose factors for radionuclide i, in mrad per yr/pCi per m^3;

$D^{\gamma}(r,\Theta)$ or $D^{\beta}(r,\Theta)$ are the annual gamma and beta air doses at the distance r in the sector at angle Θ from the discharge point, in mrad/yr;

Q_i' is the release rate of the radionuclide i, in Ci/yr;

$[\chi/Q']^D(r,\Theta)$ is the annual average gaseous dispersion factor (corrected for radioactive decay) at the distance r in the sector at angle Θ from the release point, in sec/m^3 (see Regulatory Guide 1.111, "Methods for Estimating Atmospheric Transport and Dispersion of Gaseous Effluents in Routine Releases from Light-Water-Cooled Reactors," for methods to estimate χ/Q'); and

3.17×10^4 is the number of pCi per Ci divided by the number of seconds per year.

c. Total Body Dose Rates from Elevated Releases

$$D^T(r,\Theta) = 1.11\, S_F \sum_k D_k^{\gamma}(r,\Theta)\exp[-\mu_a^T(E_k)t] \tag{8}$$

where

$D^T(r,\Theta)$ is the annual total body dose at the distance r in the sector at angle Θ from the discharge point, in mrem/yr;

$D_k^{\gamma}(r,\Theta)$ is the annual gamma air dose associated with the kth photon energy group at the distance r in the sector at angle Θ from the discharge point, in mrad/yr;

S_F is the attenuation factor that accounts for the dose reduction due to shielding provided by residential structures (0.7), dimensionless;

t is the product of tissue density and depth used to determine a "whole-body" exposure. This depth is 5 cm, which is equivalent to $t = 5\ g/cm^2$;

$\mu_a^T(E_k)$ is the tissue energy absorption coefficient, in cm^2/g; and

1.11 is the average ratio of tissue to air energy absorption coefficients.

d. Skin Dose Rate from Elevated Releases

$$D^S(r,\theta) = 1.11 S_F D^\gamma(r,\theta) + 3.17 \times 10^4 \sum_i Q_i'[\chi/Q']^D(r,\theta) DFS_i \qquad (9)$$

where

DFS_i is the beta skin dose factor for the radionuclide i which includes the attenuation by the outer "dead" layer of the skin, in mrem-m^3/pCi-yr. This attenuation is for 70 micrometers or 7 mg/cm^2 of tissue; and

$D^S(r,\theta)$ is the annual skin dose at the distance r in the sector at angle θ from the discharge point, in mrem/yr.

All other parameters are as defined in preceding sections.

e. Total Body Dose Rates from Ground-Level Releases

$$D_\infty^T(r,\theta) = 1.11\ S_F \sum_i \chi_i(r,\theta) DFB_i \qquad (10)$$

where

DFB_i is the total body dose factor for the radionuclide i which includes the attenuation of 5 g/cm^2 of tissue, in mrem-m^3/pCi-yr (see Table B-1 in Appendix B of this guide);

$D_\infty^T(r,\theta)$ is the annual total body dose due to immersion in a semi-infinite cloud at the distance r in the sector at angle θ from the discharge point, in mrem/yr; and

$\chi_i(r,\theta)$ is the annual average ground-level concentration of nuclide i at the distance r in the sector at angle θ from the release point, in pCi/m^3.

All other parameters are as defined above.

f. Skin Dose Rates from Ground-Level Releases

$$D_\infty^S(r,\theta) = 1.11\ S_F \sum_i \chi_i(r,\theta) DF_i^\gamma + \sum_i \chi_i(r,\theta) DFS_i \qquad (11)$$

where

$D_\infty^S(r,\theta)$ is the annual skin dose due to immersion in a semi-infinite cloud at the distance r in the sector at angle θ from the discharge point, in mrem/yr.

All other parameters are as defined above.

3. Doses from Radioiodines and Other Radionuclides Released to the Atmosphere

The NRC staff will calculate radiation doses from radioiodines and other radionuclides released to the atmosphere using the following equations from Appendix C of this guide.

a. External Irradiation from Activity Deposited onto the Ground Surface

$$D_j^G(r,\theta) = 8760\, S_F \sum_i C_i^G(r,\theta) DFG_{ij} \qquad (12)$$

where

C_i^G is the ground plane concentration of radionuclide i, in pCi/m^2;

DFG_{ij} is the open field ground plane dose conversion factor for organ j from radionuclide i, in $mrem\text{-}m^2/pCi\text{-}hr$;

$D_j^G(r,\theta)$ is the annual dose to the organ j from the ground plane concentration of all radionuclides at location (r,θ), in mrem/yr;

S_F is a shielding factor that accounts for the dose reduction afforded by the shielding provided by residential structures and by occupancy, dimensionless; and

8760 is the number of hours in a year.

b. Inhalation

$$D_{ja}^A(r,\theta) = R_a \sum_i \chi_i(r,\theta) DFA_{ija} \qquad (13)$$

where

$D_{ja}^A(r,\theta)$ is the annual dose to organ j of an individual in the age group a at location (r,θ) due to inhalation of all radionuclides, in mrem/yr;

DFA_{ija} is the inhalation dose factor for radionuclide i, organ j, and age group a, in mrem/pCi;

R_a is the annual air intake for individuals in the age group a, in m^3/yr; and

$\chi_i(r,\theta)$ is the concentration of radionuclide i in air at location (r,θ), in pCi/m^3.

c. Ingestion

$$D_{ja}^D(r,\theta) = \sum_i DFI_{ija}\left[U_a^v f_g C_i^v(r,\theta) + U_a^m C_i^m(r,\theta) + U_a^F C_i^F(r,\theta) + U_a^L f_\ell C_i^L(r,\theta)\right] \qquad (14)$$

where

$C_i^v(r,\theta)$, $C_i^m(r,\theta)$, $C_i^L(r,\theta)$, $C_i^F(r,\theta)$ are the concentrations of radionuclide i in produce (non-leafy-vegetables, fruits, and grains), milk, leafy vegetables, and meat, respectively, at location (r,θ), in pCi/kg. These variables are determined using Equation (C-7) from Appendix C of this guide;

$D_{ja}^D(r,\theta)$ is the annual dose to the organ j of an individual in age group a from ingestion of all radionuclides at location (r,θ), in mrem/yr;

DFI_{ija} is the ingestion dose factor for radionuclide i, organ j, and age group a, from Tables A-3 through A-6 of Appendix A of this guide, in mrem/pCi;

$f_g f_\ell$ are the respective fractions of the ingestion rates of produce (vegetables, fruits, and grains) and leafy vegetables which are produced in the garden of interest (Note: f_g may be taken to be 0.76 in the absence of site-specific data which would indicate that the quantity of grain produced in the garden of interest would satisfy the intake values in Table A-2 of Appendix A of this guide); and

U_a^v, U_a^m, U_a^F, U_a^L are the annual intake (usage) of vegetables, milk, meat, and leafy vegetables respectively, for individuals in the age group a, in kg/yr.

4. Integrated Doses to the Population

The NRC staff will calculate integrated doses to the local population from all pathways discussed in Sections C.1, 2, and 3. Because of the various conditions under which the equations in Appendix D are used, they are not presented in this section. It is recommended that Appendix D be read for a detailed discussion of the staff's models.

5. Summary of Staff Position

A brief summary of the staff position on methods of evaluating compliance with Appendix I is presented in Table 1.

D. IMPLEMENTATION

The purpose of this section is to provide information to applicants and licensees regarding the NRC staff's plans for utilizing this regulatory guide.

This guide reflects current Nuclear Regulatory Commission practice. Therefore, except in those cases in which the license applicant or licensee proposes an acceptable alternative method, the method described herein for complying with specified portions of the Commission's regulations is being and will continue to be used in the evaluation of submittals for operating license or construction permit applications until the guide is revised as a result of suggestions from the public or additional staff review.

TABLE 1

SUMMARY OF STAFF POSITION -

METHODS OF EVALUATING COMPLIANCE WITH APPENDIX I

TYPE OF DOSE	APPENDIX I DESIGN OBJECTIVE	POINT OF DOSE EVALUATION	EQUATIONS TO BE USED
Liquid Effluents			
Dose to total body from all pathways	3 mrem/yr per unit	Location of the highest dose offsite* (see also Table A-1).	1, 2, 3, 4, & 5
Dose to any organ from all pathways	10 mrem/yr per unit	Same as above.	1, 2, 3, 4, & 5
Gaseous Effluents**			
Gamma dose in air	10 mrad/yr per unit	Location of the highest dose offsite.***	6 or 7, as appropriate
Beta dose in air	20 mrad/yr per unit	Same as above.	7
Dose to total body of an individual	5 mrem/yr per unit	Location of the highest dose offsite.*	8 or 10, as appropriate
Dose to skin of an individual	15 mrem/yr per unit	Same as above.	9 or 11, as appropriate
Radioiodines and Particulates† Released to the Atmosphere			
Dose to any organ from all pathways	15 mrem/yr per unit	Location of the highest dose offsite.††	12, 13, & 14

*Evaluated at a location that is anticipated to be occupied during plant lifetime or evaluated with respect to such potential land and water usage and food pathways as could actually exist during the term of plant operation.

**Calculated only for noble gases.

***Evaluated at a location that could be occupied during the term of plant operation.

†Doses due to carbon-14 and tritium intake from terrestrial food chains are included in this category.

††Evaluated at a location where an exposure pathway actually exists at time of licensing. However, if the applicant determines design objectives with respect to radioactive iodine on the basis of existing conditions and if potential changes in land and water usage and food pathways could result in exposures in excess of the guideline values given above, the applicant should provide reasonable assurance that a monitoring and surveillance program will be performed to determine: (1) the quantities of radioactive iodine actually released to the atmosphere and deposited relative to those estimated in the determination of design objectives; (2) whether changes in land and water usage and food pathways which would result in individual exposures greater than originally estimated have occurred; and (3) the content of radioactive iodine and foods involved in the changes, if and when they occur.

APPENDIX A

METHODS FOR CALCULATING DOSES TO MAN FROM RADIONUCLIDE DISCHARGES TO THE AQUATIC ENVIRONMENT

The equations for estimating radiation exposure to man from four principal exposure pathways in the aquatic environment (potable water, aquatic foods, shoreline deposits, and irrigated foods) are listed in Section C, "Regulatory Position," of this guide. The equations can be used to calculate the annual doses to various organs of a child, 0 - 11 years; a teen, 12 - 18 years; and an adult, 18+ years.

1. Equation for Calculating Radiation Dose via Liquid Pathways

Equation (A-1) is the fundamental equation for calculating the radiation dose to man via liquid effluent pathways.

$$R_{aipj} = C_{ip}U_{ap}D_{aipj} \qquad \text{(A-1)}$$

where

C_{ip} is the concentration of nuclide i in the media of pathway p, in pCi/kg;

D_{aipj} is the dose factor which is specific to a given radionuclide i, pathway p, organ j, and individual's age a. It represents the annual dose due to the intake of a radionuclide, in mrem/pCi, or from exposure to a given concentration of a radionuclide in water, in mrem per hr/pCi per liter;

R_{aipj} is the annual dose to organ j of an individual of age a from nuclide i via pathway p, in mrem/yr; and

U_{ap} is the exposure time or intake rate (usage) associated with pathway p for age group a, in hr/yr or kg/yr (as appropriate).

The three factors making up Equation (A-1) are discussed in the following sections, most of which were taken directly from the WASH-1258 report (Ref. 1). (An updated version of the portion of the WASH-1258 report describing models and computer programs is contained in the BNWL-1754 report (Ref. 2).)

a. Concentration in Environmental Media (C_{ip})

The points at which concentrations in environmental media of interest should be evaluated are shown in Table A-1. The concentrations can be estimated from the mixing ratio M_p, the bioaccumulation factor B_{ip}, the radionuclide release rate Q_i, and other terms presented in the pathway equations that appear later in this discussion.

b. Usage (U_{ap})

The second term of Equation (A-1) is the usage term U_{ap}. Usage is expressed as a consumption rate in kg/yr or liters/yr or as an exposure time in hr/yr, as appropriate for the pathway p and age group a under consideration.

The NRC staff encourages the use of site-specific data, whenever possible, for parameters such as those included in Table A-2. Such data should be documented. In the absence of site-specific data, however, the usage values (consumption rates and exposure times) presented in Table A-2 are recommended.*

*In selecting usage values, not only the present land and water uses should be considered, but also changes in land and water uses made possible by such activities as chemical pollution abatement. Radioactive material released into waterways may include long-lived radionuclides that have potential for accumulation in sediments and biota and may persist for many years -- perhaps beyond the lifetime of the nuclear power station.

TABLE A-1

DEFINITION OF POINTS AT WHICH CONCENTRATIONS IN ENVIRONMENTAL MEDIA (C_{ip}) SHOULD BE CALCULATED

PATHWAY	SURFACE - LOW VELOCITY	SURFACE - HIGH VELOCITY	SUBMERGED (single or multi-port) - HIGH VELOCITY
Fish (fresh and salt water)	Discharge canal	Edge of initial mixing zone*	Edge of initial mixing zone**
Invertebrates	Discharge canal	Edge of initial mixing zone*	Edge of initial mixing zone**
Shoreline	Discharge canal	Point of contact of diluted effluent with shoreline	Point of contact of diluted effluent with shoreline
Drinking water	Nearest anticipated downstream supply***	Nearest anticipated downstream supply***	Nearest anticipated downstream supply***
Irrigated crops	Nearest anticipated point of withdrawal for irrigation+	Nearest anticipated point of withdrawal for irrigation+	Nearest anticipated point of withdrawal for irrigation+

*Point where effluent has undergone prompt dilution near the surface (about 5:1 for large receiving water bodies).

**Point where effluent has undergone prompt dilution (about 10:1 in deep water and about 5:1 in shallow water).

***Fresh water sites only. The "nearest anticipated downstream supply" is that location which, based on land use projections over the plant lifetime, is the closest point to the site where a drinking water supply exists or could exist.

+Fresh water sites only. The "nearest anticipated point of withdrawal for irrigation" is that location which, based on land use projections over the plant lifetime, is the closest point to the site where withdrawal for irrigation purposes exists or could exist.

TABLE A-2

RECOMMENDED VALUES FOR U_{ap} TO BE USED FOR THE MAXIMUM EXPOSED INDIVIDUAL IN LIEU OF SITE-SPECIFIC DATA

PATHWAY	CHILD	TEEN	ADULT	UNITS
Fruits & vegetables & grain[a,b]	520.0	630.0	520	kg/yr
Leafy vegetables[a]	26.0	42.0	64	kg/yr
Milk[a,c]	330.0	400.0	310	liters/yr
Meat & poultry[a]	41.0	65.0	110	kg/yr
Fish (fresh or salt)[d]	6.9	16.0	21	kg/yr
Seafood[a]	1.7	3.8	5	kg/yr
Drinking water[c,e]	510.0	510.0	730	liters/yr
Shoreline recreation[e]	14.0	67.0	12	hr/yr
Boating[e]	29.0	52.0	52	hr/yr
Inhalation	2700.0[e] 1900.0(infant)[g]	5100.0[e]	7300[f]	m^3/yr

[a]Consumption rate obtained from Reference 3 for average individual and age-prorated and maximized using techniques contained in Reference 4.

[b]Consists of the following (on a mass basis): 22% fruit, 54% vegetables (including leafy vegetables), and 24% grain.

[c]An additional category of maximum individual (1-yr old) should be added for these pathways. Consumption rates are the same as the child's.

[d]Consumption rate for adult obtained by averaging data from References 4, 6-9 and age-prorating using techniques contained in Reference 4.

[e]Data obtained directly from Reference 4.

[f]Data obtained directly from Reference 15.

[g]Inhalation rate for infant obtained by averaging data from References 10-14.

c. Dose Factor (D_{aipj})

Equations for calculating internal dose factors are derived from those given by the International Commission on Radiological Protection (ICRP-Ref. 15) for body burden and maximum permissible concentration (MPC). Effective absorbed energies for the radionuclides are calculated from the ICRP model. Appendix D of Reference 16 was used as a basic source of age-dependent dose factors for ingestion. Where data are lacking, metabolic parameters for the Standard Man were used for other ages as well.

The dose factors for external exposure were based on the assumption that the contaminated medium is large enough to be considered an "infinite volume" relative to the range of the emitted radiations. Under this assumption, the energy emitted per gram of medium is equivalent to the energy absorbed per gram of medium corrected for the differences in energy absorption between air or water and tissue and for the physical geometry of each specific exposure situation.

Material deposited from sedimentation in an aquatic system or from irrigation water onto the ground represents a fairly large, nearly uniform thin sheet of contamination. The factors for converting surface contamination given in pCi/m^2 to the annual gamma dose at one meter above a uniformly contaminated plane have been described by Soldat and others (Refs. 4, 5, and 17). Dose factors for exposure to soil sediment have units of mrem/hr per pCi/m^2 surface.

A set of dose factors for 45 radionuclides was originally calculated for the year 2000 model (Ref. 4). These factors have since been recalculated using recent decay scheme information (Ref. 18) and expanded to include additional radionuclides. The revised list is given in Tables A-3 through A-7; it contains several radionuclides for which the daughter is not listed separately (e.g., Ru-Rh-106, Cs-137-Ba-137m, and Ce-Pr-144). In those instances, the daughter's decay energy has been included in the factor.

2. Equations for Liquid Pathways

This section develops the set of equations required for the liquid pathway model. The principal difference between pathways is the manner in which the radionuclide concentrations are calculated. The doses from the four pathways should be added to determine the total dose.

a. Potable Water

The annual dose from ingestion of water is calculated from Equation (A-2) below:

$$R_{apj} = 1100 \frac{M_p U_{ap}}{F} \sum_i Q_i' \exp(-\lambda_i t_p) D_{aipj} \qquad \text{(A-2)}$$

Symbols for this equation were defined earlier, in Section C.1 of this guide.

The summation process adds the dose contribution from each nuclide to yield the total dose for the pathway-organ combination selected. The Q_i'/F terms in Equation (A-2) define the concentration of nuclide i in the effluent at the point of discharge. The expression $(Q_i' M_p/F)\exp(-\lambda_i t_p)$ yields the concentration of nuclide i at the time the water is consumed. This concentration is the term C_{ip} in Equation (A-1). As a minimum, the transit time t_p may be set equal to 12 hours to allow for radionuclide transport through the water purification plant and the water distribution system. The transit time should be increased as appropriate to allow for travel from the point of effluent release to the water purification plant intake. Credit may be taken for radionuclide removal by water purification processes using techniques such as those outlined in Reference 4.

It should be noted that, depending on the hydrological dispersion model employed, the mixing ratio, M_p, or dilution factor may not be explicitly defined. In those instances (e.g., buildup of activity in a cooling pond), the relative concentration in the mixed stream (compared to the effluent concentration) may be supplied as a function of the radiological decay constant, with any potential effluent recycling taken into account. Suggested hydrological dispersion models will be contained in another regulatory guide now under preparation on the subject of methods for estimating aquatic dispersion of liquid effluents from routine reactor releases for the purpose of implementing Appendix I.

b. Aquatic Foods

The concentrations of radionuclides in aquatic foods are directly related to the concentrations of the nuclides in water. Equilibrium ratios between the two concentrations,

TABLE A-3

ADULT INGESTION DOSE FACTORS

(mrem/pCi ingested)

NUCLIDE		BONE	LIVER	TOTAL BODY	THYROID	KIDNEY	LUNG	GI-LLI
1H	3	0.0	1.34E-07	1.34E-07	1.34E-07	1.34E-07	1.34E-07	1.34E-07
4BE	10	3.18E-06	4.91E-07	7.95E-08	0.0	3.71E-07	0.0	2.68E-05
6C	14	2.84E-06	5.69E-07	5.69E-07	5.69E-07	5.69E-07	5.69E-07	5.69E-07
7N	13	8.37E-09	8.37E-09	8.37E-09	8.37E-09	8.37E-09	8.37E-09	8.37E-09
9F	18	6.25E-07	0.0	6.93E-08	0.0	0.0	0.0	1.85E-08
11NA	22	1.74E-05	1.74E-05	1.74E-05	1.74E-05	1.74E-05	1.74E-05	1.74E-05
11NA	24	2.26E-06	2.26E-06	2.26E-06	2.26E-06	2.26E-06	2.26E-06	2.26E-06
15P	32	1.93E-04	1.21E-05	7.47E-06	0.0	0.0	0.0	2.17E-05
20CA	41	1.87E-04	0.0	2.01E-05	0.0	0.0	0.0	1.84E-07
21SC	46	5.51E-09	1.08E-08	3.11E-09	0.0	1.00E-08	0.0	5.21E-05
24CR	51	0.0	0.0	2.66E-09	1.59E-09	5.87E-10	3.53E-09	6.69E-07
25MN	54	0.0	4.57E-06	8.73E-07	0.0	1.36E-06	0.0	1.40E-05
25MN	56	0.0	1.15E-07	2.05E-08	0.0	1.46E-07	0.0	3.67E-06
26FE	55	6.20E-06	2.79E-05	7.33E-06	0.0	0.0	3.23E-05	1.09E-05
26FE	59	4.34E-06	1.03E-05	3.92E-06	0.0	0.0	2.86E-06	3.40E-05
27CO	57	0.0	1.75E-07	2.91E-07	0.0	0.0	0.0	4.44E-06
27CO	58	0.0	7.46E-07	1.67E-06	0.0	0.0	0.0	1.51E-05
27CO	60	0.0	2.15E-06	4.72E-06	0.0	0.0	0.0	4.02E-05
28NI	59	9.77E-06	3.35E-06	1.63E-06	0.0	0.0	0.0	6.90E-07
28NI	63	1.30E-04	9.02E-06	4.36E-06	0.0	0.0	0.0	1.88E-06
28NI	65	5.29E-07	6.87E-08	3.13E-08	0.0	0.0	0.0	1.74E-06
29CU	64	0.0	8.34E-08	3.92E-08	0.0	2.10E-07	0.0	7.10E-06
30ZN	65	4.85E-06	1.54E-05	6.97E-06	0.0	1.03E-05	0.0	9.70E-06
30ZN	69M	1.70E-07	4.09E-07	3.73E-08	0.0	2.48E-07	0.0	2.49E-05
30ZN	69	1.03E-08	1.98E-08	1.37E-09	0.0	1.28E-08	0.0	2.96E-09
34SE	79	0.0	2.63E-06	4.40E-07	0.0	4.56E-06	0.0	5.38E-07
35BR	82	0.0	0.0	2.26E-06	0.0	0.0	0.0	2.59E-06
35BR	83	0.0	0.0	4.02E-08	0.0	0.0	0.0	5.79E-08
35BR	84	0.0	0.0	5.22E-08	0.0	0.0	0.0	4.09E-13
35BR	85	0.0	0.0	2.14E-09	0.0	0.0	0.0	0.0
37RB	86	0.0	2.11E-05	9.84E-06	0.0	0.0	0.0	4.16E-06
37RB	87	0.0	1.23E-05	4.28E-06	0.0	0.0	0.0	5.76E-07
37RB	88	0.0	6.06E-08	3.21E-08	0.0	0.0	0.0	8.36E-19
37RB	89	0.0	4.01E-08	2.83E-08	0.0	0.0	0.0	0.0
38SR	89	3.09E-04	0.0	8.85E-06	0.0	0.0	0.0	4.94E-05
38SR	90	7.61E-03	0.0	1.86E-03	0.0	0.0	0.0	1.02E-04
38SR	91	5.82E-06	0.0	2.56E-07	0.0	0.0	0.0	2.93E-05
38SR	92	2.16E-06	0.0	9.31E-08	0.0	0.0	0.0	4.26E-05
39Y	90	9.63E-09	0.0	2.58E-10	0.0	0.0	0.0	1.02E-04
39Y	91M	9.10E-11	0.0	3.53E-12	0.0	0.0	0.0	2.67E-10
39Y	91	1.41E-07	0.0	3.78E-09	0.0	0.0	0.0	7.76E-05

Note: 0.0 means insufficient data or that the dose factor is <1.0E-20.

TABLE A-3 (Continued)

NUCLIDE		BONE	LIVER	TOTAL BODY	THYROID	KIDNEY	LUNG	GI-LLI
39Y	92	8.46E-10	0.0	2.47E-11	0.0	0.0	0.0	1.48E-05
39Y	93	2.68E-09	0.0	7.40E-11	0.0	0.0	0.0	8.50E-05
40ZR	93	4.19E-08	2.34E-09	1.09E-09	0.0	8.88E-09	0.0	2.43E-06
40ZR	95	3.04E-08	9.76E-09	6.61E-09	0.0	1.54E-08	0.0	3.03E-05
40ZR	97	1.68E-09	3.39E-10	1.56E-10	0.0	5.12E-10	0.0	1.05E-04
41NB	93M	2.55E-08	8.33E-09	2.05E-09	0.0	9.58E-09	0.0	3.84E-06
41NB	95	6.23E-09	3.46E-09	1.36E-09	0.0	3.43E-09	0.0	2.10E-05
41NB	97	5.23E-11	1.32E-11	4.82E-12	0.0	1.54E-11	0.0	4.87E-08
42MO	93	0.0	7.52E-06	2.03E-07	0.0	2.13E-06	0.0	1.22E-06
42MO	99	0.0	4.31E-06	8.20E-07	0.0	9.77E-06	0.0	9.99E-06
43TC	99M	2.47E-10	6.98E-10	8.90E-09	0.0	1.06E-08	3.42E-10	4.13E-07
43TC	99	1.26E-07	1.86E-07	5.0UE-08	0.0	2.34E-06	1.58E-08	6.08E-06
43TC	101	2.54E-10	3.67E-10	3.60E-09	0.0	6.60E-09	1.87E-10	0.0
44RU	103	1.85E-07	0.0	7.98E-08	0.0	7.07E-07	0.0	2.16E-05
44RU	105	1.54E-08	0.0	6.08E-09	0.0	1.99E-07	0.0	9.42E-06
44RU	106	2.75E-06	0.0	3.48E-07	0.0	5.32E-06	0.0	1.78E-04
45RH	105	1.22E-07	8.86E-08	5.83E-08	0.0	3.76E-07	0.0	1.41E-05
46PD	107	0.0	1.47E-07	9.41E-09	0.0	1.32E-06	0.0	9.11E-07
46PD	109	0.0	1.77E-07	4.00E-08	0.0	1.01E-06	0.0	1.96E-05
47AG	110M	1.60E-07	1.48E-07	8.80E-08	0.0	2.91E-07	0.0	6.04E-05
47AG	111	5.82E-08	2.44E-08	1.21E-08	0.0	7.85E-08	0.0	4.46E-05
48CD	113M	0.0	3.19E-06	1.02E-07	0.0	3.50E-06	0.0	2.56E-05
48CD	115M	0.0	1.84E-06	5.88E-08	0.0	1.46E-06	0.0	7.74E-05
50SN	123	3.11E-05	5.16E-07	7.60E-07	4.38E-07	0.0	0.0	6.33E-05
50SN	125	8.36E-06	1.68E-07	3.79E-07	1.39E-07	0.0	0.0	1.04E-04
50SN	126	8.46E-05	1.68E-06	2.41E-06	4.92E-07	0.0	0.0	2.43E-05
51SB	124	2.81E-06	5.30E-08	1.11E-06	6.79E-09	0.0	2.18E-06	7.95E-05
51SB	125	2.23E-06	2.40E-08	4.48E-07	1.98E-09	0.0	2.33E-04	1.97E-05
51SB	126	1.15E-06	2.34E-08	4.15E-07	7.05E-09	0.0	7.05E-07	9.40E-05
51SB	127	2.58E-07	5.66E-09	9.92E-08	3.11E-09	0.0	1.53E-07	5.90E-05
52TE	125M	2.68E-06	9.73E-07	3.59E-07	8.07E-07	1.09E-05	0.0	1.07E-05
52TE	127M	6.78E-06	2.37E-06	8.26E-07	1.73E-06	2.75E-05	0.0	2.27E-05
52TE	127	1.10E-07	3.95E-08	2.38E-08	8.16E-08	4.48E-07	0.0	8.68E-06
52TE	129M	1.15E-05	4.30E-06	1.82E-06	3.95E-06	4.80E-05	0.0	5.79E-05
52TE	129	3.15E-08	1.19E-08	7.66E-09	2.41E-08	1.32E-07	0.0	2.37E-08
52TE	131M	1.74E-06	8.47E-07	7.06E-07	1.34E-06	8.58E-06	0.0	8.40E-05
52TE	131	1.97E-08	8.24E-09	6.22E-09	1.62E-08	8.64E-08	0.0	2.95E-09
52TE	132	2.53E-05	1.64E-06	1.53E-06	1.80E-06	1.58E-05	0.0	7.71E-05
52TE	133M	4.63E-08	2.80E-08	4.46E-08	3.92E-08	2.67E-07	0.0	4.17E-09
52TE	134	3.24E-08	2.13E-08	1.30E-08	2.83E-08	2.05E-07	0.0	4.46E-09
53I	129	3.27E-06	2.81E-06	9.22E-06	7.23E-03	6.05E-06	0.0	4.44E-07
53I	130	7.57E-07	2.24E-06	8.81E-07	2.85E-04	3.48E-06	0.0	1.92E-06
53I	131	4.16E-06	5.96E-06	3.41E-06	1.95E-03	1.02E-05	0.0	1.57E-06
53I	132	2.03E-07	5.43E-07	1.93E-07	7.15E-05	8.66E-07	0.0	1.02E-07

TABLE A-3 (Continued)

NUCLIDE		BONE	LIVER	TOTAL BODY	THYROID	KIDNEY	LUNG	GI-LLI
53I	133	1.43E-06	2.48E-06	7.57E-07	4.77E-04	4.33E-06	0.0	2.18E-06
53I	134	1.06E-07	2.88E-07	1.03E-07	3.74E-05	4.59E-07	0.0	2.51E-10
53I	135	4.43E-07	1.17E-06	4.29E-07	1.53E-04	1.86E-06	0.0	1.31E-06
55CS	134M	2.13E-08	4.49E-08	2.30E-08	0.0	2.44E-08	3.83E-09	1.58E-08
55CS	134	6.22E-05	1.48E-04	1.21E-04	0.0	4.80E-05	1.59E-05	2.59E-06
55CS	135	1.95E-05	1.80E-05	8.00E-06	0.0	6.82E-06	2.05E-06	4.21E-07
55CS	136	6.51E-06	2.57E-05	1.85E-05	0.0	1.43E-05	1.96E-06	2.92E-06
55CS	137	7.98E-05	1.09E-04	7.15E-05	0.0	3.71E-05	1.23E-05	2.10E-06
55CS	138	5.52E-08	1.09E-07	5.41E-08	0.0	8.02E-08	7.92E-09	4.65E-13
55CS	139	3.41E-08	5.08E-08	1.85E-08	0.0	4.07E-08	3.70E-09	0.0
56BA	139	9.71E-08	6.92E-11	2.84E-09	0.0	6.47E-11	3.92E-11	1.72E-07
56BA	140	2.03E-05	2.55E-08	1.34E-06	0.0	8.68E-09	1.46E-08	4.18E-05
56BA	141	0.0	3.56E-11	1.59E-09	0.0	3.31E-11	2.02E-11	2.22E-17
56BA	142	2.13E-08	2.19E-11	1.34E-09	0.0	1.85E-11	1.24E-11	0.0
57LA	140	2.50E-09	1.26E-09	3.34E-10	0.0	0.0	0.0	9.25E-05
57LA	141	3.19E-10	9.91E-11	1.62E-11	0.0	0.0	0.0	1.18E-05
57LA	142	1.28E-10	5.82E-11	1.45E-11	0.0	0.0	0.0	4.25E-07
58CE	141	9.37E-09	6.34E-09	7.18E-10	0.0	2.94E-09	0.0	2.42E-05
58CE	143	1.65E-09	1.22E-06	1.35E-10	0.0	5.38E-10	0.0	4.56E-05
58CE	144	4.89E-07	2.04E-07	2.62E-08	0.0	1.21E-07	0.0	1.65E-04
59PR	143	9.21E-09	3.70E-09	4.57E-10	0.0	2.13E-09	0.0	4.03E-05
59PR	144	3.02E-11	1.25E-11	1.53E-12	0.0	7.06E-12	0.0	4.33E-18
60ND	147	6.30E-09	7.28E-09	4.35E-10	0.0	4.25E-09	0.0	3.49E-05
61PM	147	7.55E-08	7.10E-09	2.87E-09	0.0	1.34E-08	0.0	8.93E-06
61PM	148M	3.07E-08	7.96E-09	6.08E-09	0.0	1.21E-08	0.0	6.74E-05
61PM	148	7.18E-09	1.19E-09	6.00E-10	0.0	2.25E-09	0.0	9.34E-05
61PM	149	1.52E-09	2.15E-10	8.79E-11	0.0	4.07E-10	0.0	4.03E-05
61PM	151	6.97E-10	1.17E-10	5.92E-11	0.0	2.09E-10	0.0	3.22E-05
62SM	151	6.91E-08	1.19E-08	2.86E-09	0.0	1.33E-08	0.0	5.25E-06
62SM	153	8.58E-10	7.16E-10	5.23E-11	0.0	2.32E-10	0.0	2.55E-05
63EU	152	1.95E-07	4.44E-08	3.91E-08	0.0	2.75E-07	0.0	2.56E-05
63EU	154	6.16E-07	7.57E-08	5.39E-08	0.0	3.62E-07	0.0	5.48E-05
63EU	155	8.61E-08	1.22E-08	7.88E-09	0.0	5.64E-08	0.0	9.60E-06
63EU	156	1.37E-08	1.06E-08	1.71E-09	0.0	7.09E-09	0.0	7.26E-05
65TB	160	4.70E-08	0.0	5.86E-09	0.0	1.94E-08	0.0	4.33E-05
67HO	166M	2.70E-07	8.44E-08	6.41E-08	0.0	1.26E-07	0.0	0.0
74W	181	9.92E-09	3.24E-09	3.46E-10	0.0	0.0	0.0	3.68E-07
74W	185	4.06E-07	1.35E-07	1.42E-08	0.0	0.0	0.0	1.56E-05
74W	187	1.03E-07	8.62E-08	3.02E-08	0.0	0.0	0.0	2.82E-05
82PB	210	1.53E-02	4.38E-03	5.44E-04	0.0	1.23E-02	0.0	5.42E-05
83BI	210	4.62E-07	3.19E-06	3.97E-08	0.0	3.84E-05	0.0	4.75E-05
84PO	210	3.57E-04	7.57E-04	8.60E-05	0.0	2.52E-03	0.0	6.36E-05

TABLE A-3 (Continued)

NUCLIDE	BONE	LIVER	TOTAL BODY	THYROID	KIDNEY	LUNG	GI-LLI
88RA 223	4.98E-03	7.66E-06	9.95E-04	0.0	2.17E-04	0.0	3.21E-04
88RA 224	1.62E-03	3.90E-06	3.23E-04	0.0	1.11E-04	0.0	3.40E-04
88RA 225	6.57E-03	7.79E-06	1.31E-03	0.0	2.21E-04	0.0	3.06E-04
88RA 226	3.05E-01	5.75E-06	2.21E-01	0.0	1.63E-04	0.0	3.32E-04
88RA 228	1.12E-01	3.12E-06	1.21E-01	0.0	8.84E-05	0.0	5.64E-05
89AC 225	4.41E-06	6.07E-06	2.96E-07	0.0	6.90E-07	0.0	4.07E-04
89AC 227	1.88E-03	2.48E-04	1.11E-04	0.0	8.03E-05	0.0	7.94E-05
90TH 227	1.37E-05	2.48E-07	3.96E-07	0.0	1.41E-06	0.0	5.40E-04
90TH 228	4.96E-04	8.41E-06	1.68E-05	0.0	4.67E-05	0.0	5.63E-04
90TH 229	8.06E-03	1.21E-04	3.95E-04	0.0	5.80E-04	0.0	5.12E-04
90TH 230	2.08E-03	1.18E-04	5.76E-05	0.0	5.69E-04	0.0	6.02E-05
90TH 232	1.80E-03	1.01E-04	4.92E-05	0.0	4.86E-04	0.0	1.28E-04
90TH 234	8.02E-08	4.72E-09	2.32E-09	0.0	2.67E-08	0.0	1.13E-04
91PA 231	4.14E-03	1.56E-04	1.61E-04	0.0	0.0	0.0	6.27E-04
91PA 233	5.26E-09	1.06E-09	9.28E-10	0.0	3.99E-09	0.0	1.64E-05
92U 232	4.14E-03	0.0	2.95E-04	0.0	4.47E-04	0.0	6.72E-05
92U 233	8.72E-04	0.0	5.29E-05	0.0	2.04E-04	0.0	6.27E-05
92U 234	8.37E-04	0.0	5.18E-05	0.0	1.99E-04	0.0	6.14E-05
92U 235	8.02E-04	0.0	4.86E-05	0.0	1.87E-04	0.0	7.81E-05
92U 236	8.02E-04	0.0	4.97E-05	0.0	1.91E-04	0.0	5.76E-05
92U 237	5.53E-08	0.0	1.47E-08	0.0	2.27E-07	0.0	1.94E-05
92U 238	7.67E-04	0.0	4.55E-05	0.0	1.75E-04	0.0	1.66E-04
93NP 237	1.38E-03	1.20E-04	5.59E-05	0.0	4.16E-04	0.0	7.94E-05
93NP 238	1.37E-08	3.69E-10	2.13E-10	0.0	1.26E-09	0.0	3.43E-05
93NP 239	1.20E-09	1.18E-10	6.46E-11	0.0	3.65E-10	0.0	2.40E-05
94PU 238	6.73E-04	9.31E-05	1.67E-05	0.0	7.12E-05	0.0	7.30E-05
94PU 239	7.60E-04	1.04E-04	1.88E-05	0.0	7.96E-05	0.0	6.66E-05
94PU 240	7.58E-04	1.04E-04	1.88E-05	0.0	7.96E-05	0.0	6.78E-05
94PU 241	1.56E-05	8.47E-07	3.33E-07	0.0	1.53E-06	0.0	1.40E-06
94PU 242	7.22E-04	9.90E-05	1.79E-05	0.0	7.58E-05	0.0	6.53E-05
94PU 244	8.60E-04	1.18E-04	2.13E-05	0.0	9.03E-05	0.0	9.73E-05
95AM 241	8.10E-04	2.78E-04	5.26E-05	0.0	3.96E-04	0.0	7.42E-05
95AM 242M	8.32E-04	2.78E-04	5.47E-05	0.0	4.08E-04	0.0	9.34E-05
95AM 243	8.12E-04	2.73E-04	5.24E-05	0.0	3.95E-04	0.0	9.73E-05
96CM 242	1.58E-05	1.64E-05	1.04E-06	0.0	4.87E-06	0.0	7.92E-05
96CM 243	6.43E-04	2.41E-04	3.77E-05	0.0	1.76E-04	0.0	7.81E-05
96CM 244	4.85E-04	2.07E-04	2.88E-05	0.0	1.34E-04	0.0	7.55E-05
96CM 245	1.03E-03	2.88E-04	5.81E-05	0.0	2.71E-04	0.0	7.04E-05
96CM 246	1.02E-03	2.88E-04	5.80E-05	0.0	2.71E-04	0.0	6.91E-05
96CM 247	9.95E-04	2.83E-04	5.72E-05	0.0	2.67E-04	0.0	9.09E-05
96CM 248	8.27E-03	2.33E-03	4.71E-04	0.0	2.20E-03	0.0	1.47E-03
98CF 252	1.98E-04	0.0	4.95E-06	0.0	0.0	0.0	2.88E-04

TABLE A-4

TEENAGER INGESTION DOSE FACTORS
(mrem/pCi ingested)

NUCLIDE		BONE	LIVER	TOTAL BODY	THYROID	KIDNEY	LUNG	GI-LLI
1H	3	0.0	1.06E-07	1.06E-07	1.06E-07		1.06E-07	1.06E-07
6C	14	7.55E-07	7.55E-07	7.55E-07	7.55E-07		7.55E-07	7.55E-07
11NA	22	2.35E-05	2.35E-05	2.35E-05	2.35E-05		2.35E-05	2.88E-06
27CO	58	0.0	9.92E-07	2.26E-06	0.0		0.0	1.34E-05
27CO	60	0.0	2.76E-06	6.30E-06	0.0		0.0	3.31E-05
38SR	89	4.60E-04	0.0	1.32E-05	0.0	(USE	0.0	4.99E-05
38SR	90	1.04E-02	0.0	2.57E-03	0.0		0.0	2.20E-04
39Y	90	3.30E-08	0.0	8.87E-10	0.0	ADULT	3.75E-05	1.09E-04
39Y	91	1.96E-07	0.0	5.23E-09	0.0		0.0	7.53E-05
40ZR	95	3.72E-08	1.24E-08	8.66E-09	0.0		0.0	2.68E-05
41NB	95	7.24E-09	4.36E-09	2.46E-09	0.0		0.0	1.78E-05
44RU	103	2.37E-07	0.0	1.06E-07	0.0	DOSE	0.0	1.85E-05
44RU	106	4.00E-06	0.0	5.03E-07	0.0		0.0	1.81E-04
50SN	123	4.38E-05	7.22E-07	1.08E-06	5.79E-07	FACTOR)	0.0	6.31E-05
52TE	125M	3.83E-06	1.37E-06	5.08E-07	1.08E-06		0.0	1.07E-05
52TE	127	1.51E-07	5.32E-08	3.23E-08	1.03E-07		0.0	1.22E-05
52TE	129M	1.66E-05	6.15E-06	2.61E-06	5.30E-06		0.0	5.80E-05
52TE	132	3.55E-06	2.22E-06	2.10E-06	2.36E-06		0.0	8.00E-05
53I	129	4.66E-06	3.92E-06	1.31E-05	9.55E-03		0.0	4.31E-07
53I	131	5.57E-06	7.87E-06	4.69E-06	2.27E-03		0.0	1.49E-06
53I	133	2.03E-06	3.44E-06	1.06E-06	6.25E-04		0.0	2.50E-06
55CS	134	8.05E-05	1.94E-04	9.06E-05	0.0		2.35E-05	2.24E-06
55CS	137	1.07E-04	1.44E-04	5.05E-05	0.0		1.91E-05	1.92E-06
56BA	140	2.83E-05	3.48E-08	1.82E-06	0.0		2.33E-08	4.14E-06
57LA	140	3.48E-09	1.72E-09	4.55E-10	0.0		0.0	9.48E-05
58CE	141	1.26E-08	8.46E-09	9.70E-10	0.0		0.0	2.29E-05
58CE	144	7.22E-07	2.96E-07	3.83E-08	0.0		0.0	1.70E-04
63EU	154	1.15E-06	1.00E-07	8.79E-08	0.0		0.0	5.12E-05
92U	232	6.05E-03	0.0	4.21E-04	0.0		0.0	6.72E-05
92U	234	1.22E-03	0.0	7.40E-05	0.0		0.0	6.14E-05
94PU	238	8.40E-04	1.18E-04	2.08E-05	0.0		0.0	7.30E-05
94PU	239	9.26E-04	1.29E-04	2.29E-05	0.0		0.0	6.66E-05
94PU	240	9.25E-04	1.30E-04	2.31E-05	0.0		0.0	6.66E-05
94PU	241	4.03E-07	5.85E-08	1.02E-08	0.0		0.0	1.28E-07
95AM	241	9.93E-04	4.17E-04	6.66E-05	0.0		0.0	7.17E-05
96CM	242	2.26E-05	2.33E-05	1.50E-06	0.0		0.0	7.80E-05
96CM	244	6.64E-04	3.33E-04	4.03E-05	0.0		0.0	7.42E-05

Note: 0.0 means insufficient data or that the dose factor is <1.0E-20.

TABLE A-5

CHILD INGESTION DOSE FACTORS
(mrem/pCi ingested)

NUCLIDE		BONE	LIVER	TOTAL BODY	THYROID	KIDNEY	LUNG	GI-LLI
1H	3	0.0	2.03E-07	2.03E-07	2.03E-07		2.03E-07	2.03E-07
6C	14	2.26E-06	2.26E-06	2.26E-06	2.26E-06		2.26E-06	2.26E-06
11NA	22	5.89E-05	5.89E-05	5.89E-05	5.89E-05		5.89E-05	2.57E-06
27CO	58	0.0	1.85E-06	5.58E-06	0.0		0.0	1.10E-05
27CO	60	0.0	5.17E-06	1.55E-05	0.0		0.0	2.86E-05
38SR	89	1.38E-03	0.0	3.95E-05	0.0	(USE	0.0	5.15E-05
38SR	90	1.72E-02	0.0	4.36E-03	0.0		0.0	2.29E-04
39Y	90	4.21E-08	0.0	1.13E-09	0.0	ADULT	0.0	1.20E-04
39Y	91	5.85E-07	0.0	1.56E-08	0.0		0.0	7.77E-05
40ZR	95	1.04E-07	2.42E-08	2.20E-08	0.0		0.0	2.50E-05
41NB	95	1.95E-08	8.32E-09	6.11E-09	0.0	DOSE	0.0	1.44E-05
44RU	103	6.78E-07	0.0	2.74E-07	0.0		0.0	1.78E-05
44RU	106	1.19E-05	0.0	1.48E-06	0.0		0.0	1.85E-04
50SN	123	1.31E-04	1.64E-06	3.22E-06	1.73E-06		0.0	6.50E-05
52TE	125M	1.14E-05	3.09E-06	1.52E-06	3.20E-06	FACTOR)	0.0	1.10E-05
52TE	127	4.50E-07	1.20E-07	9.65E-08	3.10E-07		0.0	1.92E-05
52TE	129M	4.95E-05	1.38E-05	7.65E-06	1.58E-05		0.0	5.96E-05
52TE	132	1.02E-05	4.50E-06	5.42E-06	6.62E-06		0.0	7.89E-05
53I	129	1.39E-05	8.54E-06	3.81E-05	2.79E-02		0.0	4.29E-07
53I	131	1.63E-05	1.67E-05	1.26E-05	5.43E-03		0.0	1.43E-06
53I	133	5.98E-06	7.38E-06	2.90E-06	1.78E-03		0.0	2.99E-06
55CS	134	2.24E-04	3.77E-04	8.02E-05	0.0		4.19E-05	2.04E-06
55CS	137	3.12E-04	3.02E-04	4.50E-05	0.0		3.54E-05	1.84E-06
56BA	140	8.26E-05	7.25E-08	4.85E-06	0.0		4.32E-08	4.21E-06
57LA	140	1.01E-08	3.52E-09	1.19E-09	0.0		0.0	1.00E-04
58CE	141	3.76E-08	1.88E-08	2.80E-09	0.0		0.0	2.36E-05
58CE	144	2.14E-06	6.70E-07	1.14E-07	0.0		0.0	1.74E-04
63EU	154	2.58E-06	2.08E-07	2.03E-07	0.0		0.0	4.74E-05
92U	232	1.77E-02	0.0	1.26E-03	0.0		0.0	6.91E-05
92U	234	3.57E-03	0.0	2.21E-04	0.0		0.0	6.32E-05
94PU	238	1.24E-03	1.52E-04	3.09E-05	0.0		0.0	7.50E-05
94PU	239	1.32E-03	1.62E-04	3.27E-05	0.0		0.0	6.85E-05
94PU	240	1.32E-03	1.63E-04	3.30E-05	0.0		0.0	6.85E-05
94PU	241	7.12E-07	8.50E-08	1.81E-08	0.0		0.0	1.32E-07
95AM	241	1.42E-03	6.24E-04	9.96E-05	0.0		0.0	7.37E-05
96CM	242	6.74E-05	5.28E-05	4.46E-06	0.0		0.0	8.03E-05
96CM	244	1.12E-03	5.40E-04	6.99E-05	0.0		0.0	7.64E-05

Note: 0.0 means insufficient data or that the dose factor is <1.0E-20.

TABLE A-6

INFANT INGESTION DOSE FACTORS
(mrem/pCi ingested)

NUCLIDE		BONE	LIVER	TOTAL BODY	THYROID	KIDNEY	LUNG	GI-LLI
1H	3	0.0	3.07E-07	3.07E-07	3.07E-07		3.07E-07	3.07E-07
6C	14	4.81E-06	4.81E-06	4.81E-06	4.81E-06		4.81E-06	4.81E-06
11NA	22	1.00E-04	1.00E-04	1.00E-04	1.00E-04		1.00E-04	2.45E-06
27CO	58	0.0	3.78E-06	9.26E-06	0.0		0.0	9.79E-06
27CO	60	0.0	1.07E-05	2.56E-05	0.0		0.0	2.64E-05
38SR	89	2.93E-03	0.0	8.42E-05	0.0	(USE	0.0	5.48E-05
38SR	90	2.51E-02	0.0	6.40E-03	0.0		0.0	2.43E-04
39Y	90	8.97E-08	0.0	2.41E-09	0.0	ADULT	0.0	1.29E-04
39Y	91	1.25E-06	0.0	3.33E-08	0.0		0.0	8.27E-05
40ZR	95	2.11E-07	5.32E-08	3.78E-08	0.0		0.0	2.38E-05
41NB	95	3.89E-08	1.75E-08	1.03E-08	0.0	DOSE	0.0	1.40E-05
44RU	103	1.41E-06	0.0	4.85E-07	0.0		0.0	1.76E-05
44RU	106	2.54E-05	0.0	3.12E-06	0.0		0.0	1.97E-04
50SN	123	2.79E-04	4.33E-06	6.86E-06	4.33E-06	FACTOR)	0.0	6.91E-05
52TE	125M	2.43E-05	8.19E-06	3.24E-06	8.00E-06		0.0	1.17E-05
52TE	127	9.58E-07	3.19E-07	2.06E-07	7.75E-07		0.0	2.27E-05
52TE	129M	1.05E-04	3.61E-05	1.60E-05	3.95E-05		0.0	6.33E-05
52TE	132	2.13E-05	1.05E-05	9.76E-06	1.55E-05		0.0	8.08E-05
53I	129	2.95E-05	2.16E-05	7.76E-05	6.79E-02		0.0	4.46E-07
53I	131	3.42E-05	4.07E-05	2.38E-05	1.31E-02		0.0	1.53E-06
53I	133	1.26E-05	1.84E-05	5.58E-06	4.35E-03		0.0	3.27E-06
55CS	134	4.58E-04	9.24E-04	6.97E-05	0.0		9.42E-05	1.96E-06
55CS	137	6.53E-04	7.31E-04	4.20E-05	0.0		8.81E-05	1.89E-06
56BA	140	1.74E-04	1.75E-07	8.99E-06	0.0		1.07E-07	4.43E-06
57LA	140	2.12E-08	8.37E-09	2.16E-09	0.0		0.0	1.04E-04
58CE	141	8.00E-08	4.91E-08	5.75E-09	0.0		0.0	2.38E-05
58CE	144	4.49E-06	1.77E-06	2.42E-07	0.0		0.0	1.85E-04
63EU	154	4.30E-06	4.84E-07	3.29E-07	0.0		0.0	4.76E-05
92U	232	3.66E-02	0.0	2.68E-03	0.0		0.0	7.34E-05
92U	234	7.40E-03	0.0	4.71E-04	0.0		0.0	6.72E-05
94PU	238	1.71E-03	2.18E-04	4.25E-05	0.0		0.0	7.98E-05
94PU	239	1.78E-03	2.26E-04	4.41E-05	0.0		0.0	7.28E-05
94PU	240	1.78E-03	2.28E-04	4.45E-05	0.0		0.0	7.28E-05
94PU	241	1.06E-06	1.37E-07	2.70E-08	0.0		0.0	1.40E-07
95AM	241	1.93E-03	1.03E-03	1.38E-04	0.0		0.0	7.84E-05
96CM	242	1.43E-04	1.40E-04	9.49E-06	0.0		0.0	8.53E-05
96CM	244	1.64E-03	9.67E-04	1.04E-04	0.0		0.0	8.12E-05

Note: 0.0 means insufficient data or that the dose factor is <1.0E-20.

TABLE A-7

EXTERNAL DOSE FACTORS FOR STANDING ON CONTAMINATED GROUND*

(mrem/hr per pCi/m²)

		TOTAL BODY	SKIN
1H	3	0.0	0.0
4BE	10	0.0	0.0
6C	14	0.0	0.0
7N	13	7.60E-09	9.80E-09
9F	18	6.80E-09	8.00E-09
11NA	22	1.60E-08	1.80E-08
11NA	24	2.50E-08	2.90E-08
15P	32	0.0	0.0
20CA	41	3.41E-09	4.01E-09
21SC	46	1.30E-08	1.50E-08
24CR	51	2.20E-10	2.60E-10
25MN	54	5.80E-09	6.80E-09
25MN	56	1.10E-08	1.30E-08
26FE	55	0.0	0.0
26FE	59	8.00E-09	9.40E-09
27CO	57	9.10E-10	1.00E-09
27CO	58	7.00E-09	9.20E-09
27CO	60	1.70E-08	2.00E-08
28NI	59	0.0	0.0
28NI	63	0.0	0.0
28NI	65	3.70E-09	4.30E-09
29CU	64	1.50E-09	1.70E-09
30ZN	65	4.00E-09	4.60E-09
30ZN	69M	2.90E-09	3.40E-09
30ZN	69	0.0	0.0
34SE	79	0.0	0.0
35BR	82	1.90E-08	2.20E-08
35BR	83	6.40E-11	9.30E-11
35BR	84	1.20E-08	1.40E-08
35BR	85	0.0	0.0
37RB	86	6.30E-10	7.20E-10
37RB	87	0.0	0.0
37RB	88	3.50E-09	4.00E-09
37RB	89	1.50E-08	1.80E-08
38SR	89	5.60E-13	6.50E-13
38SR	90	0.0	0.0
38SR	91	7.10E-09	8.30E-09
38SR	92	9.00E-09	1.00E-08
39Y	90	2.20E-12	2.60E-12
39Y	91M	3.80E-09	4.40E-09
39Y	91	2.40E-11	2.70E-11
39Y	92	1.60E-09	1.90E-09
39Y	93	5.70E-10	7.80E-10

		TOTAL BODY	SKIN
40ZR	93	0.0	0.0
40ZR	95	5.00E-09	5.80E-09
40ZR	97	5.50E-09	6.40E-09
41NB	93M	0.0	0.0
41NB	95	5.10E-09	6.00E-09
41NB	97	4.60E-09	5.40E-09
42MO	93	2.29E-11	9.32E-10
42MO	99	1.90E-09	2.20E-09
43TC	99M	9.60E-10	1.10E-09
43TC	99	0.0	0.0
43TC	101	2.70E-09	3.00E-09
44RU	103	3.60E-09	4.20E-09
44RU	105	4.50E-09	5.10E-09
44RU	106	1.50E-09	1.80E-09
45RH	105	6.60E-10	7.70E-10
46PD	107	0.0	0.0
46PD	109	3.50E-11	4.00E-11
47AG	110M	1.80E-08	2.10E-08
47AG	111	1.80E-10	2.10E-10
48CD	113M	2.30E-12	2.60E-12
48CD	115M	0.0	0.0
50SN	123	0.0	5.46E-08
50SN	125	5.70E-10	6.60E-10
50SN	126	9.00E-09	1.00E-08
51SB	124	1.30E-08	1.50E-08
51SB	125	3.10E-09	3.50E-09
51SB	126	8.90E-09	1.00E-08
51SB	127	5.70E-09	6.60E-09
52TE	125M	3.50E-11	4.80E-11
52TE	127M	1.10E-12	1.30E-12
52TE	127	1.00E-11	1.10E-11
52TE	129M	7.70E-10	9.00E-10
52TE	129	7.10E-10	8.40E-10
52TE	131M	8.40E-09	9.90E-09
52TE	131	2.20E-09	2.60E-06
52TE	132	1.70E-09	2.00E-09
52TE	133M	1.50E-08	1.70E-08
52TE	134	1.00E-09	1.20E-09
53I	129	4.50E-10	7.50E-10
53I	130	1.40E-08	1.70E-08
53I	131	2.80E-09	3.40E-09
53I	132	1.70E-08	2.00E-08
53I	133	3.70E-09	4.50E-09

*The same factors apply for adult, teen, child.

Note: 0.0 means insufficient data or that the dose factor is <1.0E-20.

TABLE A-7 (Continued)

		TOTAL BODY	SKIN
53I	134	1.60E-08	1.90E-08
53I	135	1.20E-08	1.40E-08
55CS	134M	6.20E-10	7.30E-10
55CS	134	1.20E-08	1.40E-08
55CS	135	0.0	0.0
55CS	136	1.50E-08	1.70E-08
55CS	137	4.20E-09	4.90E-09
55CS	138	2.10E-08	2.40E-08
55CS	139	6.30E-09	7.20E-09
56BA	139	2.40E-09	2.70E-09
56BA	140	2.10E-09	2.40E-09
56BA	141	4.30E-09	4.90E-09
56BA	142	7.90E-09	9.00E-09
57LA	140	1.50E-08	1.70E-08
57LA	141	2.50E-10	2.80E-10
57LA	142	1.50E-08	1.80E-08
58CE	141	5.50E-10	6.20E-10
58CE	143	2.20E-09	2.50E-09
58CE	144	3.20E-10	3.70E-10
59PR	143	0.0	0.0
59PR	144	2.00E-10	2.30E-10
60ND	147	1.00E-09	1.20E-09
61PM	147	0.0	0.0
61PM	148M	1.41E-08	9.16E-08
61PM	148	4.60E-09	5.30E-09
61PM	149	2.50E-11	2.90E-11
61PM	151	2.20E-09	2.30E-09
62SM	151	4.80E-11	2.10E-10
62SM	153	2.70E-10	3.00E-10
63EU	152	7.37E-09	8.53E-09
63EU	154	7.80E-09	9.00E-09
63EU	155	3.81E-10	4.33E-10
63EU	156	7.60E-09	8.70E-09
65TB	160	8.60E-09	1.00E-08
67HO	166M	8.90E-09	1.00E-08
74W	181	2.10E-12	2.80E-12
74W	185	0.0	0.0
74W	187	3.10E-09	3.60E-09
82PB	210	1.30E-11	1.70E-11
83BI	210	0.0	0.0
84PO	210	5.40E-14	6.20E-14

		TOTAL BODY	SKIN
88RA	223	1.50E-09	1.80E-09
88RA	224	8.90E-09	1.00E-08
88RA	225	8.40E-11	1.20E-10
88RA	226	6.40E-09	7.40E-09
88RA	228	1.20E-08	1.40E-08
89AC	225	1.60E-09	1.80E-09
89AC	227	2.00E-09	2.40E-09
90TH	227	5.10E-10	6.30E-10
90TH	228	8.90E-09	1.00E-08
90TH	229	2.20E-09	2.70E-09
90TH	230	6.50E-09	7.50E-09
90TH	232	3.00E-09	4.00E-09
90TH	234	1.10E-10	1.30E-10
91PA	231	2.20E-09	2.70E-09
91PA	233	1.30E-09	1.50E-09
92U	232	2.59E-12	2.69E-11
92U	233	2.30E-09	2.80E-09
92U	234	6.32E-13	1.59E-10
92U	235	3.20E-09	4.00E-09
92U	236	2.10E-14	1.80E-11
92U	237	1.00E-09	1.30E-09
92U	238	1.10E-10	1.50E-10
93NP	237	1.40E-09	1.60E-09
93NP	238	2.80E-09	3.20E-09
93NP	239	9.50E-10	1.10E-09
94PU	238	1.30E-12	1.80E-11
94PU	239	7.90E-13	7.70E-12
94PU	240	1.30E-12	1.80E-11
94PU	241	4.60E-12	6.80E-12
94PU	242	1.10E-12	1.60E-11
94PU	244	8.95E-10	9.62E-10
95AM	241	1.80E-10	2.60E-10
95AM	242M	2.60E-11	1.80E-10
95AM	243	1.30E-09	1.50E-09
96CM	242	5.50E-12	2.30E-11
96CM	243	2.30E-09	2.90E-09
96CM	244	2.90E-12	1.80E-11
96CM	245	9.50E-10	1.20E-09
96CM	246	1.00E-12	1.50E-11
96CM	247	2.20E-09	2.60E-09
96CM	248	6.81E-09	5.23E-09
98CF	252	6.60E-08	7.20E-08

called bioaccumulation factors in this guide, can be found in the literature (Ref. 19). The addition of the bioaccumulation factor B_{ip} to Equation (A-2) yields Equation (A-3), which is suitable for calculating the internal dose for consumption of aquatic foods.

$$R_{apj} = 1100 \frac{U_{ap}M_p}{F} \sum_i Q_i' B_{ip} D_{aipj} \exp(-\lambda_i t_p) \quad \text{(A-3)}$$

Values of B_{ip} are given in Table A-8; the other parameters have been previously defined.

The transit time t_p may be set equal to 24 hours to allow for radionuclide decay during transit through the food chain, as well as during food preparation.

c. Dose from Shoreline Deposits

The calculation of individual dose from shoreline deposits is complex since it involves estimation of sediment load, transport, and concentrations of radionuclides associated with suspended and deposited materials. One method of approaching this problem was presented in the Year 2000 Study (Refs. 4, 17, 20, and 21). Based on these references, an estimate of the radionuclide concentration in shoreline sediments can be obtained from the following expressions:

$$C_{is} = K_c \frac{C_{iw}[1 - \exp(-\lambda_i t)]}{\lambda_i} \quad \text{(A-4)}$$

where

C_{is} is the concentration of nuclide i in sediment, in pCi/kg;

C_{iw} is the concentration of nuclide i in water adjacent to the sediment, in pCi/liter;

K_c is an assumed transfer constant from water to sediment, in liters/kg per day;

t is the length of time the sediment is exposed to the contaminated water, nominally 15 years (approximate midpoint of facility operating life), in hours; and

λ_i is the decay constant* of nuclide i, in hours^{-1}. In the original evaluation of the equation, λ_i was chosen to be the radiological decay constant, but the true value should include an "environmental" removal constant.

The value of K_c was derived for several radionuclides by using data from water and sediment samples collected over a period of several years in the Columbia River between Richland, Washington, and the river mouth and in Tillamook Bay, Oregon, 75 km south of the river mouth (Refs. 22 and 23). Since the primary use of the equation is to facilitate estimates of the exposure rate from gamma emitters one meter above the sediment, an effective surface contamination was estimated. This surface contamination was assumed to be contained within the top 2.5 cm (1 in.) of sediment.** The dose contribution from the radionuclides at depths below 2.5 cm was ignored. The resulting equation is

$$S_i^* = 100 T_i C_{iw} W[1 - \exp(-\lambda_i t)] \quad \text{(A-5)}$$

where

S_i^* is the "effective" surface contamination, in pCi/m^2, that is used in subsequent calculations;

---

*If the presence of a radionuclide in water and sediment is controlled primarily by radioactive equilibrium with its parent nuclide, the water concentration and decay constant of the parent should be used in Equations (A-4) and (A-5).

**With a mass of 40 kg/m^2 of surface.

TABLE A-8

BIOACCUMULATION FACTORS
(pCi/kg per pCi/liter)

ELEMENT	FRESHWATER FISH	FRESHWATER INVERTEBRATE	FRESHWATER PLANT	SALTWATER FISH	SALTWATER INVERTEBRATE	SALTWATER PLANT
H	9.0E-01	9.0E-01	9.0E-01	9.0E-01	9.3E-01	9.3E-01
HE	1.0E 00	1.0E 00	1.0E 00	1.0E 00	1.0E 00	1.0E 00
LI	5.0E-01	4.0E 01	3.0E 00	5.0E-01	5.0E-01	3.0E 00
BE	2.0E 00	1.0E 01	2.0E 01	2.0E 02	2.0E 02	1.0E 03
B	2.2E-01	5.0E 01	2.2E 00	2.2E-01	4.4E-01	2.2E 00
C	4.6E 03	9.1E 03	4.6E 03	1.8E 03	1.4E 03	1.8E 03
N	1.5E 05	1.5E 05	1.3E 04	6.0E 04	1.7E 04	1.0E 04
O	9.2E-01	9.2E-01	9.2E-01	9.6E-01	9.6E-01	9.6E-01
F	1.0E 01	1.0E 02	2.0E 00	3.6E 00	3.6E 00	1.4E 00
NE	1.0E 00	1.0E 00	1.0E 00	1.0E 00	1.0E 00	1.0E 00
NA	1.0E 02	2.0E 02	5.0E 02	6.7E-02	1.9E-01	9.5E-01
MG	5.0E 01	1.0E 02	1.0E 02	7.7E-01	7.7E-01	7.7E-01
AL	1.0E 01	6.3E 01	4.2E 02	1.0E 01	6.0E 01	6.0E 02
SI	2.5E 00	2.5E 01	1.3E 02	1.0E 01	3.3E 01	6.7E 01
P	1.0E 05	2.0E 04	5.0E 05	2.9E 04	3.0E 04	3.0E 03
S	7.5E 02	1.0E 02	1.0E 02	1.7E 00	4.4E-01	4.4E-01
CL	5.0E 01	1.0E 02	5.0E 01	1.3E-02	1.9E-02	7.6E-02
AR	1.0E 00	1.0E 00	1.0E 00	1.0E 00	1.0E 00	1.0E 00
K	1.0E 03	8.3E 02	6.7E 02	1.1E 01	5.6E 00	2.6E 01
CA	4.0E 01	3.3E 02	1.3E 02	5.0E-01	1.3E 01	5.0E 00
SC	2.0E 00	1.0E 03	1.0E 04	2.0E 00	1.0E 04	1.0E 05
TI	1.0E 03	3.0E 03	5.0E 02	1.0E 03	1.0E 03	2.0E 03
V	1.0E 01	3.0E 03	1.0E 02	1.0E 01	5.0E 01	1.0E 02
CR	2.0E 02	2.0E 03	4.0E 03	4.0E 02	2.0E 03	2.0E 03
MN	4.0E 02	9.0E 04	1.0E 04	5.5E 02	4.0E 02	5.5E 03
FE	1.0E 02	3.2E 03	1.0E 03	3.0E 03	2.0E 04	7.3E 02
CO	5.0E 01	2.0E 02	2.0E 02	1.0E 02	1.0E 03	1.0E 03
NI	1.0E 02	1.0E 02	5.0E 01	1.0E 02	2.5E 02	2.5E 02
CU	5.0E 01	4.0E 02	2.0E 03	6.7E 02	1.7E 03	1.0E 03
ZN	2.0E 03	1.0E 04	2.0E 04	2.0E 03	5.0E 04	1.0E 03
GA	3.3E 02	6.7E 02	1.7E 03	3.3E 02	6.7E 02	1.7E 03
GE	3.3E 03	3.3E 01	3.3E 01	3.3E 03	1.7E 04	3.3E 02
AS	1.0E 02	4.0E 01	3.0E 03	3.3E 02	3.3E 02	1.7E 03
SE	1.7E 02	1.7E 02	1.0E 03	4.0E 03	1.0E 03	1.0E 03
BR	4.2E 02	3.3E 02	5.0E 01	1.5E-02	3.1E 00	1.5E 00
KR	1.0E 00	1.0E 00	1.0E 00	1.0E 00	1.0E 00	1.0E 00
RB	2.0E 03	1.0E 03	1.0E 03	8.3E 00	1.7E 01	1.7E 01
SR	3.0E 01	1.0E 02	5.0E 02	2.0E 00	2.0E 01	1.0E 01
Y	2.5E 01	1.0E 03	5.0E 03	2.5E 01	1.0E 03	5.0E 03
ZR	3.3E 00	6.7E 00	1.0E 03	2.0E 02	8.0E 01	1.0E 03
NB	3.0E 04	1.0E 02	8.0E 02	3.0E 04	1.0E 02	5.0E 02
MO	1.0E 01	1.0E 01	1.0E 03	1.0E 01	1.0E 01	1.0E 01
TC	1.5E 01	5.0E 00	4.0E 01	1.0E 01	5.0E 01	4.0E 03
RU	1.0E 01	3.0E 02	2.0E 03	3.0E 00	1.0E 03	2.0E 03
RH	1.0E 01	3.0E 02	2.0E 02	1.0E 01	2.0E 03	2.0E 03
PD	1.0E 01	3.0E 02	2.0E 02	1.0E 01	2.0E 03	2.0E 03
AG	2.3E 00	7.7E 02	2.0E 02	3.3E 03	3.3E 03	2.0E 02
CD	2.0E 02	2.0E 03	1.0E 03	3.0E 03	2.5E 05	1.0E 03
IN	1.0E 05	1.0E 05	1.0E 05	1.0E 05	1.0E 05	1.0E 05
SN	3.0E 03	1.0E 03	1.0E 02	3.0E 03	1.0E 03	1.0E 02
SB	1.0E 00	1.0E 01	1.5E 03	4.0E 01	5.0E 00	1.5E 03
TE	4.0E 02*	1.0E 05	1.0E 02*	1.0E 01**	1.0E 05	1.0E 03**
I	1.5E 01	5.0E 00	4.0E 01	1.0E 01	5.0E 01	1.0E 03

TABLE A-8 (Continued)

ELEMENT	FRESHWATER FISH	FRESHWATER INVERTEBRATE	FRESHWATER PLANT	SALTWATER FISH	SALTWATER INVERTEBRATE	SALTWATER PLANT
XE	1.0E 00	1.0E 00	1.0E 00	1.0E 00	1.0E 00	1.0E 00
CS	2.0E 03	1.0E 02	5.0E 02	4.0E 01	2.5E 01	5.0E 01
BA	4.0E 00	2.0E 02	5.0E 02	1.0E 01	1.0E 02	5.0E 02
LA	2.5E 01	1.0E 03	5.0E 03	2.5E 01	1.0E 03	5.0E 03
CE	1.0E 00	1.0E 03	4.0E 03	1.0E 01	6.0E 02	6.0E 02
PR	2.5E 01	1.0E 03	5.0E 03	2.5E 01	1.0E 03	5.0E 03
ND	2.5E 01	1.0E 03	5.0E 03	2.5E 01	1.0E 03	5.0E 03
PM	2.5E 01	1.0E 03	5.0E 03	2.5E 01	1.0E 03	5.0E 03
SM	2.5E 01	1.0E 03	5.0E 03	2.5E 01	1.0E 03	5.0E 03
EU	2.5E 01	1.0E 03	5.0E 03	2.5E 01	1.0E 03	5.0E 03
GD	2.5E 01	1.0E 03	5.0E 03	2.5E 01	1.0E 03	5.0E 03
TB	2.5E 01	1.0E 03	5.0E 03	2.5E 01	1.0E 03	5.0E 03
DY	2.5E 01	1.0E 03	5.0E 03	2.5E 01	1.0E 03	5.0E 03
HO	2.5E 01	1.0E 03	5.0E 03	2.5E 01	1.0E 03	5.0E 03
ER	2.5E 01	1.0E 03	5.0E 03	2.5E 01	1.0E 03	5.0E 03
TM	2.5E 01	1.0E 03	5.0E 03	2.5E 01	1.0E 03	5.0E 03
YB	2.5E 01	1.0E 03	5.0E 03	2.5E 01	1.0E 03	5.0E 03
LU	2.5E 01	1.0E 03	5.0E 03	2.5E 01	1.0E 03	5.0E 03
HF	3.3E 00	6.7E 00	1.0E 03	2.0E 02	2.0E 01	2.0E 03
TA	3.0E 04	6.7E 02	8.0E 02	3.0E 04	1.7E 04	1.0E 03
W	1.2E 03	1.0E 01	1.2E 03	3.0E 01	3.0E 01	3.0E 01
RE	1.2E 02	6.0E 01	2.4E 02	4.8E 00	6.0E 01	2.4E 02
OS	1.0E 01	3.0E 02	2.0E 02	1.0E 01	2.0E 03	2.0E 03
IR	1.0E 01	3.0E 02	2.0E 02	1.0E 01	2.0E 03	2.0E 03
PT	1.0E 02	3.0E 02	2.0E 02	1.0E 02	2.0E 03	2.0E 03
AU	3.3E 01	5.0E 01	3.3E 01	3.3E 01	3.3E 01	3.3E 01
HG	1.0E 03	1.0E 05	1.0E 03	1.7E 03	3.3E 04	1.0E 03
TL	1.0E 04	1.5E 04	1.0E 05	1.0E 04	1.5E 04	1.0E 05
PB	1.0E 02	1.0E 02	2.0E 02	3.0E 02	1.0E 03	5.0E 03
BI	1.5E 01	2.4E 01***	2.4E 01***	1.5E 01	2.4E 01***	2.4E 01***
PO	5.0E 02	2.0E 04	2.0E 03	3.0E 02	5.0E 03	2.0E 03
AT	1.5E 01	5.0E 00	4.0E 01	1.0E 01	5.0E 01	4.0E 03
RN	1.0E 00	1.0E 00	1.0E 00	1.0E 00	1.0E 00	1.0E 00
FR	4.0E 02	1.0E 02	8.0E 01	3.0E 01	2.0E 01	2.0E 01
RA	5.0E 01	2.5E 02	2.5E 03	5.0E 01	1.0E 02	1.0E 02
AC	2.5E 01	1.0E 03	5.0E 03	2.5E 01	1.0E 03	5.0E 03
TH	3.0E 01	5.0E 02	1.5E 03	1.0E 04	2.0E 03	3.0E 03
PA	1.1E 01	1.1E 02	1.1E 03	1.0E 01	1.0E 01	6.0E 00
U	2.0E 00	6.0E 01	5.0E-01	1.0E 01	1.0E 01	6.7E 01
NP	1.0E 01	4.0E 02	3.0E 02	1.0E 01	1.0E 01	6.0E 00
PU	3.5E 00	1.0E 02	3.5E 02	3.0E 00	2.0E 02	1.0E 03
AM	2.5E 01	1.0E 03	5.0E 03	2.5E 01	1.0E 03	5.0E 03
CM	2.5E 01	1.0E 03	5.0E 03	2.5E 01	1.0E 03	5.0E 03
BK	2.5E 01	1.0E 03	5.0E 03	2.5E 01	1.0E 03	5.0E 03
CF	2.5E 01	1.0E 03	5.0E 03	2.5E 01	1.0E 03	5.0E 03
ES	1.0E 01	1.0E 02	1.0E 03	1.0E 01	1.0E 01	6.0E 01
FM	1.0E 01	1.0E 02	1.0E 03	1.0E 01	1.0E 01	6.0E 01

*ORNL - Private Communication

**Freke, A.M., "A Model for the Approximate Calculation of Safe Rates of Discharge into Marine Environments," Health Physics, Vol. 13, p. 749, 1967.

***Derived from data in Bowen, H.J.M., Trace Elements in Biochemistry, New York, Academic Press (1966).

T_i is the radiological half-life of nuclide i, in days; and

W is a shore-width factor that describes the geometry of the exposure.

Shore-width factors were derived from experimental data (Ref. 24) and are summarized in Table A-9. They represent the fraction of the dose from an infinite plane source that is estimated for these shoreline situations.

The combination of Equations (A-4) and (A-5) into the general Equation (A-1) leads to Equation (A-6) below for calculation of radiation dose from exposure to shoreline sediments.

$$R_{apj} = U_{ap} \sum_i S_i^* D_{aipj} = 100\, U_{ap} W \sum_i C_{iw} T_i D_{aij} [1 - \exp(-\lambda_i t)] \tag{A-6}$$

$$= 110{,}000\, \frac{U_{ap} M_p W}{F} \sum_i Q_i' T_i D_{aipj} [\exp(-\lambda_i t_p)][1 - \exp(-\lambda_i t)] \tag{A-7}$$

d. <u>Dose from Foods Grown on Land Irrigated by Contaminated Water</u>

The equations in the following paragraphs can be used to calculate doses from radionuclides in irrigated crops. Separate expressions are presented for tritium because of its unique environmental behavior.

(1) <u>Vegetation</u>

The concentration of radioactive material in vegetation results from deposition onto the plant foliage and from uptake from the soil of activity deposited on the ground. The model used for estimating the transfer of radionuclides from irrigation water to crops through water deposited on leaves and uptake from soil was derived for a study of the potential doses to people from a nuclear power complex in the year 2000 (Ref. 4).

The equation for the model (for radionuclides except tritium) is presented below in slightly modified form. The first term in brackets relates to the concentration derived from direct foliar deposition during the growing season. The second term relates to uptake from soil and reflects the long-term deposition during operation of the nuclear facility. Thus for a uniform release rate, the concentration C_{iv} of radionuclide i in the edible portion of crop species v, in units of pCi/kg, is given by:

$$C_{iv} = d_i' \left[\frac{r[1 - \exp(-\lambda_{Ei} t_e)]}{Y_v \lambda_{Ei}} + \frac{B_{iv}[1 - \exp(-\lambda_i t_b)]}{P \lambda_i} \right] \exp(-\lambda_i t_h) \tag{A-8}$$

The deposition rate, d_i', from irrigated water is defined by the relation

$$d_i' = C_{iw} I \text{ (water deposition)} \tag{A-9}$$

where

C_{iw} is the concentration of radionuclide i in water used for irrigation, in pCi/liter, and

I is the irrigation rate, in liters/m^2/hr; i.e., volume of water (liters) sprinkled on unit area of field in 1 hour.

For tritium, the equation for estimating C_{iv} is (see Ref. 25):

$$C_v = C_w \tag{A-10}$$

For a cow grazing on fresh forage, t_e in Equation (A-8) is set equal to 720 hours (30 days), the typical time for a cow to return to a particular portion of the grazing site.

TABLE A-9

SHORE-WIDTH FACTORS FOR USE IN EQUATIONS (A-5) and (A-6)

EXPOSURE SITUATION	SHORE-WIDTH FACTOR, W
Discharge canal bank	0.1
River shoreline	0.2
Lake shore	0.3
Nominal ocean site	0.5
Tidal basin	1.0

TABLE A-10

ANIMAL CONSUMPTION RATES*

ANIMAL	Q_F FEED OR FORAGE (kg/day [wet weight])	Q_{Aw} WATER (ℓ/day)
Milk cow	50 (pasture grass)	60
Beef cattle	50 (stored feed grain)	50

*From Reference 4, Tables III-8 and -10.

(2) Animal Products

The radionuclide concentration in an animal product such as meat or milk is dependent on the amount of contaminated feed or forage eaten by the animal and its intake of contaminated water. The radionuclide concentration in animal products C_{iA} in terms of pCi/liter or pCi/kg (Ref. 4) is proportional to the animal's intake of the radionuclide in feed or forage (subscript F) and in water (subscript w):

$$C_{iA} = F_{iA}[C_{iF}Q_F + C_{iAw}Q_{Aw}] \tag{A-11}$$

The second set of terms in the brackets in Equation (A-11) can be omitted if the animal does not drink contaminated water. Values for Q_F and Q_{Aw} are presented in Table A-10. Values for B_{iv} and F_{iA} are given in Table C-5 (see Appendix C).*

The total dose R_{apj} from irrigated foods (excluding tritium) is given by:

$$R_{apj} = U_{ap}^{veg} \sum_i C_{iv}D_{aipj} + U_{ap}^{animal} \sum_i C_{iA}D_{aipj} \tag{A-12}$$

If values for C_{iv} from Equation (A-8) and C_{iA} from Equation (A-11) are substituted in Equation (A-12):

$$\begin{aligned} R_{apj} = {} & U_{ap}^{veg} \sum_i d_i \exp(-\lambda_i t_h) D_{aipj} \left[\frac{r[1 - \exp(-\lambda_{Ei}t_e)]}{Y_v \lambda_{Ei}} + \frac{B_{iv}[1 - \exp(-\lambda_i t_b)]}{P\lambda_i}\right] \\ & + U_{ap}^{animal} \sum_i F_{iA}D_{aipj} \left\{Q_F d_i \exp(-\lambda_i t_h)\left[\frac{r[1 - \exp(-\lambda_{Ei}t_e)]}{Y_v \lambda_{Ei}}\right.\right. \\ & \left.\left. + \frac{B_{iv}[1 - \exp(-\lambda_i t_b)]}{P\lambda_i}\right] + C_{iAw}Q_{Aw}\right\} \end{aligned} \tag{A-13}$$

It should be noted that the two components of Equation (A-12) imply that contributions from the individual vegetable and animal products have already been summed. In actual use, it will be necessary to compute separately the milk and meat portions of the dose due to animal products (also applicable to Equation (A-17)).

For tritium, the concentration in animal products is given by the following equation (adapted from Reference 25):

$$C_A = \frac{kwC_v}{\lambda_m} + \frac{kQ_{Aw}C_{Aw}}{\lambda_m} \tag{A-14}$$

Since by Equation (A-10) $C_v = C_w$, and since for all practical purposes $C_{Aw} = C_w$, Equation (A-14) can be rearranged as follows:

$$C_A = \frac{kC_w}{\lambda_m}(w + Q_{Aw}) \tag{A-15}$$

Similarly, the above equations for tritium concentration can be combined with the general Equation (A-1):

$$R_{apj} = U_{ap}^{veg}C_vD_{apj} + U_{ap}^{animal}C_AD_{apj} \tag{A-16}$$

$$= U_{ap}^{veg}C_vD_{apj} + U_{ap}^{animal}D_{apj}\frac{kC_w}{\lambda_m}(w + Q_{Aw}) \tag{A-17}$$

*Values for F_{iA} appear as F_m and F_f in Table C-5.

REFERENCES FOR APPENDIX A

1. "Final Environmental Statement Concerning Proposed Rule Making Action: Numerical Guides for Design Objectives and Limiting Conditions for Operation to Meet the Criterion 'As Low As Practicable' for Radioactive Material in Light-Water-Cooled Power Reactor Effluents," USAEC Report WASH-1258, Washington, D.C., July 1973.

2. J. K. Soldat et al, "Models and Computer Codes for Evaluating Environmental Radiation Doses," USAEC Report BNWL-1754, Pacific Northwest Laboratories, February 1974.

3. "Food Consumption, Prices, and Expenditures," AER-138, U.S. Department of Agriculture, Washington, D.C., December 1974.

4. J. F. Fletcher and W. L. Dotson (compilers), "HERMES - A Digital Computer Code for Estimating Regional Radiological Effects from the Nuclear Power Industry," USAEC Report HEDL-TME-71-168, Hanford Engineering Development Laboratory, 1971.

5. J. K. Soldat, "Conversion of Survey Meter Readings to Concentration ($\mu Ci/m^2$)," Item 04.3.4 in "Emergency Radiological Plans and Procedures," K. R. Heid (ed.), USAEC Report HW-70935, Hanford Laboratories, 1962.

6. L. K. Bustad and J. L. Terry, "Basic Anatomical, Dietary, and Physiological Data for Radiological Calculations," HW-41638, General Electric Co., Richland, Wash., February 1956.

7. M. M. Miller and D. A. Nash, "Regional and Other Related Aspects of Shellfish Consumption - Some Preliminary Findings of the 1969 Consumer Panel Survey," NMFS Circular 361, USDC/NOAA, Seattle, Wash., June 1971.

8. "The Potential Radiological Implications of Nuclear Facilities in the Upper Mississippi River Basin in the Year 2000," USAEC Report WASH-1209, Washington, D.C., January 1973.

9. "Draft Environmental Statement - Waste Management Operations, Hanford Reservation, Richland, Washington," USAEC Report WASH-1538, Washington, D.C., September 1974.

10. "Radiological Health Handbook," USPHS, Rockville, Md., January 1970.

11. F. O. Hoffman, "Parameters To Be Considered When Calculating the Age-Dependent ^{131}I Dose to the Thyroid," IRS-W-5, Institute for Reactor Safety, Cologne, Germany, April 1973.

12. P. S. Rohwer and S. V. Kaye, "Age-Dependent Models for Estimating Internal Dose in Feasibility Evaluations of Plowshare Events," ORNL-TM-2220, Oak Ridge, Tenn., April 1968.

13. P. M. Bryant, "Data for Assessments Concerning Controlled and Accidental Releases of ^{131}I and ^{137}Cs to the Atmosphere," Health Physics, Vol. 17, pp. 51-57, July 1969.

14. W. S. Snyder, "Dosimetry of Internal Emitters for Population Exposure," in Population Exposures, CONF-741018, Proceedings of the Eighth Midyear Topical Symposium of the Health Physics Society, Knoxville, Tenn., October 1974.

15. "Report of ICRP Committee II on Permissible Dose for Internal Radiation, International Commission on Radiological Protection," ICRP Publication 2, Pergamon Press, 1959.

16. J. K. Soldat, "Modeling of Environmental Pathways and Radiation Doses from Nuclear Facilities," USAEC Report BNWL-SA-3939, Pacific Northwest Laboratory, 1971.

17. C. M. Lederer et al, Table of Isotopes, 6th Ed., John Wiley and Sons, Inc., 1967.

18. S. E. Thompson et al, "Concentration Factors of Chemical Elements in Edible Aquatic Organisms," USAEC Report UCRL-50564, Rev. 1, Lawrence Radiation Laboratory, October 1972.

19. J. K. Soldat, "A Statistical Study of the Habits of Fishermen Utilizing the Columbia River Below Hanford," Chapter 35 in Environmental Surveillance in the Vicinity of Nuclear Facilities, W. C. Reinig (ed.), Charles C. Thomas Publishers, 1970.

20. J. F. Honstead, "Recreational Use of the Columbia River--Evaluation of Environmental Exposure," USAEC Report BNWL-CC-2299, Pacific Northwest Laboratory, 1969.

21. J. L. Nelson, "Distribution of Sediments and Associated Radionuclides in the Columbia River below Hanford," p. 3.80 in "Hanford Radiological Sciences Research and Development Annual Report for 1964," D. W. Pearce and J. K. Green (eds.), USAEC Report BNWL-36, Pacific Northwest Laboratories, 1965.

22. G. L. Toombs and P. B. Cutler (compilers), "Comprehensive Final Report for the Lower Columbia River Environmental Survey in Oregon June 5, 1961 - July 31, 1967," Oregon State Board of Health, Div. of Sanitation and Engineering, 1968.

23. "Handbook of Radiological Protection, Part I: Data," prepared by a panel of the Radioactivity Advisory Committee (H. J. Dunster, Chairman), Dept. of Employment, Dept. of Health and Social Security, Ministry of Health and Social Services, Northern Ireland, Number SNB 11 360079 8, Her Majesty's Stationery Office, London, England, 1971.

24. L. R. Anspaugh et al, "The Dose to Man via Food-Chain Transfer Resulting from Exposure to Tritiated Water Vapor," in Tritium (A. A. Moghissi and M. W. Carter, eds.), CONF-710809, 1973.

APPENDIX B

MODELS FOR CALCULATING DOSES FROM NOBLE GASES DISCHARGED TO THE ATMOSPHERE

The following analytical models are used for calculating doses from exposure to gaseous effluents. Separate models are given for air and tissue doses due to gamma and beta rays. Except for the case of noble gas doses resulting from elevated releases, all models assume submersion in an infinite cloud at the exposure point.

1. Annual Gamma Air Dose* from Elevated** Releases of Noble Gases

Slade (Ref. 1) describes the derivation of the equations for estimating annual air doses from photon emitters dispersed in the atmosphere. The following expression can be used for calculating annual doses:

$$D^{\gamma}(r,\theta) = \frac{260}{r(\Delta\theta)} \sum_n \frac{1}{u_n} \sum_s f_{ns} \sum_k \mu_a(E_k) E_k I(H,u,s,\sigma_z,E_k) \sum_i Q'^D_{ni} A_{ki} \qquad \text{(B-1)}$$

Symbols for this equation were defined earlier, in Regulatory Position C.2.a of this guide.

The photons were combined into energy groups, and each photon intensity within a group was weighted by its energy and energy absorption coefficient. Thus, the effective fraction of disintegrations of the nuclide i yielding photons corresponding to the photon energy group k, A_{ki}, was determined to be

$$A_{ki} = \sum_m [A_m E_m \mu_a(E_m)]/[E_k \mu_a(E_k)] \qquad \text{(B-2)}$$

where

A_m is the fraction of the disintegrations of nuclide i yielding photons of energy E_m;

E_m is the energy of the mth photon within the kth energy group, in MeV; and

$\mu_a(E_m)$ is the energy absorption coefficient in air associated with the photon energy E_m, in m^{-1}

All other parameters are as previously defined. The summation is carried out over all photons within energy group k. Data for the photon energies and abundances for most of the noble gas nuclides were taken from Reference 2. For radionuclides not contained in Reference 2, data were obtained from Reference 3.

Decay during travel from the point of release to the receptor is

$$Q'^D_{ni} = Q'_i \exp(-\lambda_i r/u_n) \qquad \text{(B-3)}$$

---

*The term "gamma air dose" refers to the components of the air dose associated with photons emitted during nuclear and atomic transformations, i.e., gamma and x-rays. Annihilation and bremsstrahlung photon radiations are possible contributors to this component of the air dose.

**Elevated release conditions are assumed to occur when the point of release is higher than twice the height of adjacent solid structures. (See Regulatory Guide 1.111, "Methods for Estimating Atmospheric Transport and Dispersion for Gaseous Effluents in Routine Releases from Light-Water-Cooled Reactors.")

where

Q_i' is the initial release rate of nuclide i, in Ci/yr, and

λ_i is the decay constant of nuclide i, in sec^{-1}

All other parameters are as previously defined.

2. Annual Gamma Air Dose from Ground-Level* Releases of Noble Gases and Annual Beta Air Dose**

Plumes of gaseous effluents are considered semi-infinite in the case of noble gases released from vents. The concentration of the radionuclides in air at the receptor location may be determined from atmospheric dispersion model described in Regulatory Guide 1.111. The annual average ground-level concentration of gaseous effluent species i at location (r,θ) from the release point is determined from

$$\chi_i(r,\theta) = 3.17 \times 10^4 Q_i'[\chi/Q']^D(r,\theta) \qquad \text{(B-4)}$$

where

$\chi_i(r,\theta)$ is the annual average ground-level concentration of nuclide i at the distance r in the sector at angle θ from the release point, in pCi/m^3, and

$[\chi/Q']^D(r,\theta)$ is the annual average gaseous dispersion factor (corrected for radioactive decay) in the sector at angle θ at the distance r from the release point, in sec/m^3.

The constant 3.17×10^4 represents the number of pCi per Ci divided by the number of seconds per year. All other parameters are as previously defined.

The annual gamma or beta air dose associated with the airborne concentration of the effluent species is then

$$D^\gamma(r,\theta) \text{ or } D^\beta(r,\theta) = \sum_i \chi_i(r,\theta)(DF_i^\gamma \text{ or } DF_i^\beta) \qquad \text{(B-5)}$$

where the terms are as defined in Regulatory Position C.2.b.

Table B-1 presents a tabulation of the dose factors for the noble gases and daughters of interest.

3. Annual Dose to Tissue from Noble Gas Effluents

It is also necessary to determine annual doses to real individuals in unrestricted areas. The staff computes the total body dose from external radiation at a depth of 5 cm into the body and the skin dose at a depth of 7 mg/cm^2 of tissue.

a. Elevated Releases

The annual total body dose is computed as follows:

$$D^T(r,\theta) = 1.11 \times S_F \sum_k D_k^\gamma(r,\theta)\exp[-\mu_a^T(E_k)t] \qquad \text{(B-6)}$$

*Ground-level release conditions are assumed to exist when the release point is less than or equal to twice the height of adjacent solid structures and the vertical exit velocity is less than five times the horizontal wind speed. (See Regulatory Guide 1.111.)

**The term "beta air dose" refers to the component of the air dose associated with particle emissions during nuclear and atomic transformations, i.e., β+, β-, and conversion electrons.

TABLE B-1

DOSE FACTORS FOR NOBLE GASES AND DAUGHTERS

Nuclide	β-air* (DF_i^β)	β-Skin** (DFS_i)	γ-Air* (DF_i^γ)	γ-Body** (DFB_i)
Kr-83m	2.88E-04***	---	1.93E-05	7.56E-08
Kr-85m	1.97E-03	1.46E-03	1.23-03	1.17E-03
Kr-85	1.95E-03	1.34E-03	1.72E-05	1.61E-05
Kr-87	1.03E-02	9.73E-03	6.17E-03	5.92E-03
Kr-88	2.93E-03	2.37E-03	1.52E-02	1.47E-02
Kr-89	1.06E-02	1.01E-02	1.73E-02	1.66E-02
Kr-90	7.83E-03	7.29E-03	1.63E-02	1.56E-02
Xe-131m	1.11E-03	4.76E-04	1.56E-04	9.15E-05
Xe-133m	1.48E-03	9.94E-04	3.27E-04	2.51E-04
Xe-133	1.05E-03	3.06E-04	3.53E-04	2.94E-04
Xe-135m	7.39E-04	7.11E-04	3.36E-03	3.12E-03
Xe-135	2.46E-03	1.86E-03	1.92E-03	1.81E-03
Xe-137	1.27E-02	1.22E-02	1.51E-03	1.42E-03
Xe-138	4.75E-03	4.13E-03	9.21E-03	8.83E-03
Ar-41	3.28E-03	2.69E-03	9.30E-03	8.84E-03

* $\frac{\text{mrad-m}^3}{\text{pCi-yr}}$

** $\frac{\text{mrem-m}^3}{\text{pCi-yr}}$

*** 2.88E-04 = 2.88×10^{-4}

Symbols for this equation were defined earlier in Regulatory Position C.2.c of this guide. The constant 1.11 represents the ratio of the energy absorption coefficient for tissue to that for air.

The skin dose has two components, the gamma and beta contributions. The skin dose rate is computed by

$$D^S(r,\theta) = 1.11 \times S_F D^\gamma(r,\theta) + 3.17 \times 10^4 \sum_i Q_i'[\chi/Q']^D(r,\theta)DFS_i \qquad \text{(B-7)}$$

Symbols for this equation were defined earlier in Regulatory Position C.2.d of this guide.

The skin beta dose factors DFS were determined using the decay scheme source documents cited above and the methods used in References 4, 5, and 6.

b. <u>Ground-Level Releases</u>

The annual total body dose is computed as follows:

$$D_\infty^T(r,\theta) = 1.11 \times S_F \sum_i \chi_i(r,\theta)DFB_i \qquad \text{(B-8)}$$

Symbols for this equation were defined earlier in Regulatory Position C.2.e of this guide.

The annual skin dose is computed as follows:

$$D_\infty^S(r,\theta) = 1.11 \times S_F \sum_i \chi_i(r,\theta)DF_i + \sum_i \chi_i(r,\theta)DFS_i \qquad \text{(B-9)}$$

where

$D_\infty^S(r,\theta)$ is the annual skin dose due to immersion in a semi-infinite cloud in the sector at angle θ, at the distance r from the release point, in mrem/yr, and

$\chi_i(r,\theta)$ is the airborne concentration of radionuclide i at point (r,θ), in pCi/m^3.

REFERENCES FOR APPEND.X B

1. "Meteorology and Atomic Energy 1968," D. H. Slade (ed.), USAEC Report TID-24190, 1968.

2. M. J. Martin, "Radioactive Atoms, Supplement I," USAEC Report ORNL-4923, November 1973.

3. M. E. Meek and R. S. Gilbert, "Summary of Gamma and Beta Energy and Intensity Data," NEDO-12037, 1970.

4. R. Loevinger et al, in Radiation Dosimetry (G. S. Hine and G. L. Brownell, eds.), Academic Press, New York, 1956.

5. M. J. Berger, "Improved Point Kernels for Electron and Beta-Ray Dosimetry," NBS Report NBSIR 73-107, 1973.

6. M. J. Berger, "Beta-Ray Dose in Tissue - Equivalent Material Immersed in a Radioactive Cloud," Health Physics, Vol. 26, pp. 1-12, January 1974.

APPENDIX C

MODELS FOR CALCULATING DOSES VIA ADDITIONAL PATHWAYS FROM RADIOIODINES AND OTHER RADIONUCLIDES* DISCHARGED TO THE ATMOSPHERE

1. Annual External Dose from Direct Exposure to Activity Deposited on the Ground Plane

The ground plane concentration of radionuclide i at the location (r,θ) with respect to the release point may be determined by

$$C_i^G(r,\theta) = \frac{1.1 \times 10^8 \cdot \delta_i(r,\theta)\, Q_i'}{\lambda_i}\left[1 - \exp(-\lambda_i t)\right] \qquad \text{(C-1)}$$

where

$C_i^G(r,\theta)$ is the ground plane concentration of the radionuclide i in the sector at angle θ at the distance r from the release point, in pCi/m^2;

Q_i' is the annual release rate of nuclide i to the atmosphere, in Ci/yr;

t is the time period over which the accumulation is evaluated, which is 15 years (mid-point of plant operating life). This is a simplified method of approximating the average deposition over the operating lifetime of the facility;

$\delta_i(r,\theta)$ is the annual average relative deposition of effluent species i at location (r,θ), considering depletion of the plume during transport, in m^{-2}; and

λ_i is the radiological decay constant for nuclide i, in yr^{-1}.

The annual dose from nuclide i resulting from direct exposure to the contaminated ground plant is then

$$D_{ij}^G(r,\theta) = 8760\, S_F C_i^G(r,\theta) DFG_{ij} \qquad \text{(C-2)}$$

where

$D_{ij}^G(r,\theta)$ is the annual dose to organ j from the ground plane concentration of nuclide i at the location (r,θ), in mrem/yr;

and other terms are as defined previously in Regulatory Position C.3.a of this guide.

The annual dose to organ j is therefore

$$D_j^G(r,\theta) = 8760\, S_F \sum_i C_i^G(r,\theta) DFG_{ij} \qquad \text{(C-3)}$$

Values for the open field ground plane dose conversion factors for the skin and total body are given in Tables A-3 to A-7. The annual dose to all other organs is taken to be equivalent to the total body dose.

---

*Does not include noble gases or their short-lived daughters; see Appendix B.

2. Annual Dose from Inhalation of Radionuclides in Air

The annual average airborne concentration of radionuclide i at the location (r,θ) with respect to the release point may be determined as

$$\chi_i(r,\theta) = 3.17 \times 10^4 Q_i'[\chi/Q']^D(r,\theta) \qquad \text{(C-4)}$$

where

Q_i'	is the release rate of nuclide i to the atmosphere, in Ci/yr;
$\chi_i(r,\theta)$	is the annual average ground-level concentration of nuclide i in air in the sector at angle θ at distance r from the release point, in pCi/m^3;
$[\chi/Q']^D(r,\theta)$	is the annual average atmosphere dispersion factor, in sec/m^3 (see Regulatory Guide 1.111). This includes depletion (for radioiodines and particulates) and radioactive decay of the plume; and
3.17×10^4	is the product of the number of pCi/Ci and sec/yr.

The annual dose associated with inhalation of nuclide i at the airborne concentration $\chi_i(r,\theta)$ is then

$$D_{ija}^A(r,\theta) = \chi_i(r,\theta)R_a DFA_{ija} \qquad \text{(C-5)}$$

Values for DFA_{ija} are given in Tables C-1 to C-4, and all other symbols are as defined earlier in Regulatory Position C.3.b.

The annual dose to organ j in age group a from all nuclides in the effluent is:

$$D_{ja}^A(r,\theta) = R_a \sum_i \chi_i(r,\theta) DFA_{ija} \qquad \text{(C-6)}$$

3. Concentrations of Airborne Radionuclides in Foods

The concentration of radioactive material in vegetation results from deposition onto the plant foliage and from uptake of activity initially deposited on the ground. The model used for estimating the transfer of radionuclides from the atmosphere to food products is similar to the model developed for estimating the transfer of radionuclides from irrigation water given in Appendix A of this guide.

For all radioiodines and particulate radionuclides, except tritium and carbon-14, the concentration of nuclide i in and on vegetation at the location (r,θ) is estimated using

$$C_i^V(r,\theta) = d_i'(r,\theta)\left[\frac{r[1 - \exp(-\lambda_{Ei}t_e)]}{Y_v\lambda_{Ei}} + \frac{B_{iv}[1 - \exp(-\lambda_i t_b)]}{P\lambda_i}\right]\exp(-\lambda_i t_h) \qquad \text{(C-7)}$$

See Regulatory Position C.1 of this guide for definitions of terms.

Carbon-14 is assumed to be in oxide form (CO and CO_2). The concentration of carbon-14 in vegetation is calculated by assuming that its ratio to the natural carbon in the vegetation is the same as the ratio of carbon-14 to natural carbon in the atmosphere surrounding the vegetation (see Refs. 1 and 2).

TABLE C-1

ADULT INHALATION DOSE FACTORS
(mrem/pCi inhaled)

NUCLIDE		BONE	LIVER	TOTAL BODY	THYROID	KIDNEY	LUNG	GI-LLI
1H	3	0.0	1.34E-07	1.34E-07	1.34E-07	1.34E-07	1.34E-07	1.34E-07
4BE	10	1.98E-04	3.06E-05	4.96E-06	0.0	0.0	2.23E-04	1.67E-05
6C	14	2.28E-06	4.27E-07	4.27E-07	4.27E-07	4.27E-07	4.27E-07	4.27E-07
7N	13	6.27E-09	6.27E-09	6.27E-09	6.27E-09	6.27E-09	6.27E-09	6.27E-09
9F	18	4.71E-07	0.0	5.20E-08	0.0	0.0	0.0	9.24E-09
11NA	22	1.30E-05	1.30E-05	1.30E-05	1.30E-05	1.30E-05	1.30E-05	1.30E-05
11NA	24	1.69E-06	1.69E-06	1.69E-06	1.69E-05	1.69E-06	1.69E-06	1.69E-06
15P	32	1.65E-04	9.65E-06	6.27E-06	0.0	0.0	0.0	1.08E-05
20CA	41	3.83E-05	0.0	4.13E-06	0.0	0.0	0.0	2.86E-07
21SC	46	5.51E-05	1.07E-04	3.11E-05	0.0	1.00E-04	0.0	3.23E-05
24CR	51	0.0	0.0	1.25E-08	7.44E-09	2.85E-09	1.80E-06	4.15E-07
25MN	54	0.0	4.95E-06	7.87E-07	0.0	1.23E-06	1.75E-04	9.67E-06
25MN	56	0.0	1.55E-10	2.29E-11	0.0	1.63E-10	1.18E-06	2.53E-06
26FE	55	7.62E-06	3.43E-05	9.01E-06	0.0	0.0	9.98E-05	7.54E-06
26FE	59	1.47E-06	3.47E-03	1.32E-06	0.0	0.0	1.27E-04	2.35E-05
27CO	57	0.0	8.65E-08	8.39E-08	0.0	0.0	4.62E-05	3.93E-06
27CO	58	0.0	1.98E-07	2.59E-07	0.0	0.0	1.16E-04	1.33E-05
27CO	60	0.0	1.44E-06	1.85E-06	0.0	0.0	7.47E-04	3.56E-05
28NI	59	4.06E-06	1.46E-06	6.77E-07	0.0	0.0	8.21E-06	6.11E-07
28NI	63	5.40E-05	3.92E-06	1.81E-06	0.0	0.0	2.23E-05	1.67E-06
28NI	65	1.92E-10	2.62E-11	1.14E-11	0.0	0.0	7.01E-07	1.54E-06
29CU	64	0.0	1.83E-10	7.69E-11	0.0	5.78E-10	8.49E-07	6.12E-06
30ZN	65	4.05E-06	1.29E-05	5.82E-06	0.0	8.62E-06	1.09E-04	6.68E-06
30ZN	69M	1.02E-09	2.45E-09	2.24E-10	0.0	1.48E-09	2.39E-06	1.71E-05
30ZN	69	4.23E-12	8.13E-12	5.65E-13	0.0	5.27E-12	1.15E-07	2.04E-09
34SE	79	0.0	3.83E-07	6.09E-08	0.0	5.69E-07	4.48E-05	3.33E-06
35BR	82	0.0	0.0	1.69E-06	0.0	0.0	0.0	1.30E-06
35BR	83	0.0	0.0	3.01E-08	0.0	0.0	0.0	2.90E-08
35BR	84	0.0	0.0	3.91E-08	0.0	0.0	0.0	2.05E-13
35BR	85	0.0	0.0	1.60E-09	0.0	0.0	0.0	0.0
37RB	86	0.0	1.69E-05	7.38E-06	0.0	0.0	0.0	2.08E-06
37RB	87	0.0	9.87E-06	3.21E-06	0.0	0.0	0.0	2.88E-07
37RB	88	0.0	4.85E-08	2.41E-08	0.0	0.0	0.0	4.18E-19
37RB	89	0.0	3.21E-08	2.12E-08	0.0	0.0	0.0	0.0
38SR	89	3.80E-05	0.0	1.09E-06	0.0	0.0	1.75E-04	4.37E-05
38SR	90	1.24E-02	0.0	7.62E-04	0.0	0.0	1.20E-03	9.02E-05
38SR	91	7.94E-09	0.0	3.49E-10	0.0	0.0	4.92E-06	2.59E-05
38SR	92	8.43E-10	0.0	3.64E-11	0.0	0.0	2.06E-06	5.38E-06
39Y	90	2.61E-07	0.0	7.01E-09	0.0	0.0	2.12E-05	6.32E-05
39Y	91M	3.26E-11	0.0	1.27E-12	0.0	0.0	2.41E-07	1.66E-10
39Y	91	5.78E-05	0.0	1.55E-06	0.0	0.0	2.13E-04	4.81E-05

Note: 0.0 means insufficient data or that the dose factor is <1.0E-20.

TABLE C-1 (Continued)

NUCLIDE		BONE	LIVER	TOTAL BODY	THYROID	KIDNEY	LUNG	GI-LLI
39Y	92	1.29E-09	0.0	3.77E-11	0.0	0.0	1.96E-06	9.19E-06
39Y	93	1.18E-08	0.0	3.26E-10	0.0	0.0	6.07E-06	5.27E-05
40ZR	93	5.22E-05	2.92E-06	1.37E-06	0.0	1.11E-05	2.13E-05	1.51E-06
40ZR	95	1.34E-05	4.30E-06	2.91E-06	0.0	6.77E-06	2.22E-04	1.88E-05
40ZR	97	1.21E-08	2.45E-09	1.13E-09	0.0	3.71E-09	9.85E-06	6.54E-05
41NB	93M	3.10E-05	1.01E-05	2.49E-06	0.0	1.16E-05	3.11E-05	2.38E-06
41NB	95	1.76E-06	9.77E-07	5.26E-07	0.0	9.67E-07	6.32E-05	1.30E-05
41NB	97	2.78E-11	7.03E-12	2.56E-12	0.0	8.18E-12	3.00E-07	3.02E-08
42MO	93	0.0	1.17E-06	3.17E-08	0.0	3.55E-07	5.11E-05	3.79E-06
42MO	99	0.0	1.51E-08	2.87E-09	0.0	3.54E-08	1.14E-05	3.10E-05
43TC	99M	0.0	3.64E-13	4.63E-12	0.0	5.52E-12	9.56E-08	5.20E-07
43TC	99	0.0	4.64E-08	1.37E-04	0.0	5.95E-07	1.01E-04	7.54E-06
43TC	101	0.0	7.52E-15	7.38E-14	0.0	1.35E-13	4.99E-08	0.0
44RU	103	1.91E-07	0.0	8.23E-08	0.0	7.29E-07	6.32E-05	1.38E-05
44RU	105	9.88E-11	0.0	3.89E-11	0.0	1.27E-10	1.38E-06	6.02E-06
44RU	106	8.64E-06	0.0	1.09E-06	0.0	1.67E-05	1.18E-03	1.14E-04
45RH	105	9.24E-10	6.73E-10	4.43E-10	0.0	2.86E-09	2.41E-06	1.09E-05
46PD	107	0.0	8.27E-08	5.87E-09	0.0	6.57E-07	9.48E-06	7.06E-07
46PD	109	0.0	4.63E-10	1.16E-10	0.0	2.35E-09	1.85E-06	1.52E-05
47AG	110M	1.35E-06	1.25E-06	7.43E-07	0.0	2.46E-06	5.80E-04	3.78E-05
47AG	111	4.25E-08	1.78E-08	8.87E-09	0.0	5.74E-08	2.34E-05	2.79E-05
48CD	113M	0.0	1.54E-04	4.97E-06	0.0	1.71E-04	2.08E-04	1.59E-05
48CD	115M	0.0	2.46E-05	7.95E-07	0.0	1.98E-05	1.76E-04	4.80E-05
50SN	123	3.02E-05	6.66E-07	9.82E-07	5.66E-07	0.0	2.88E-04	3.92E-05
50SN	125	1.16E-06	3.13E-08	7.03E-08	2.59E-08	0.0	7.42E-05	6.81E-05
50SN	126	1.58E-04	4.18E-06	6.00E-06	1.23E-06	0.0	1.17E-03	1.59E-05
51SB	124	3.90E-06	7.36E-08	1.55E-06	9.44E-09	0.0	3.10E-04	5.08E-05
51SB	125	8.26E-06	8.91E-08	1.66E-06	7.34E-09	0.0	2.75E-04	1.26E-05
51SB	126	4.50E-07	9.13E-09	1.62E-07	2.75E-09	0.0	9.58E-05	6.01E-05
51SB	127	3.30E-08	7.22E-10	1.27E-08	3.97E-10	0.0	2.05E-05	3.77E-05
52TE	125M	4.27E-07	1.98E-07	5.84E-08	1.31E-07	1.55E-06	3.92E-05	8.83E-06
52TE	127M	1.58E-06	7.02E-07	1.96E-07	4.11E-07	5.72E-06	1.20E-04	1.87E-05
52TE	127	1.75E-10	8.03E-11	3.87E-11	1.32E-10	6.37E-10	8.15E-07	7.17E-06
52TE	129M	1.22E-06	5.84E-07	1.98E-07	4.30E-07	4.57E-06	1.45E-04	4.79E-05
52TE	129	6.22E-12	2.99E-12	1.55E-12	4.87E-12	2.34E-11	2.42E-07	1.96E-08
52TE	131M	8.74E-09	5.45E-09	3.63E-09	6.88E-09	3.86E-08	1.82E-05	6.95E-05
52TE	131	1.39E-12	7.44E-13	4.49E-13	1.17E-12	5.46E-12	1.74E-07	2.44E-09
52TE	132	3.25E-07	2.69E-08	2.02E-08	2.37E-08	1.82E-07	3.60E-05	6.37E-05
52TE	133M	7.24E-12	5.60E-12	7.14E-12	6.27E-12	3.74E-11	5.51E-07	3.45E-09
52TE	134	3.84E-12	3.22E-12	1.57E-12	3.44E-12	2.18E-11	4.34E-07	3.69E-09
53I	129	2.48E-06	2.11E-06	6.91E-06	5.55E-03	4.54E-06	0.0	2.22E-07
53I	130	5.73E-07	1.68E-06	6.61E-07	2.18E-04	2.61E-06	0.0	9.61E-07
53I	131	3.15E-06	4.47E-06	2.56E-06	1.49E-03	7.67E-06	0.0	7.85E-07
53I	132	1.45E-07	4.07E-07	1.45E-07	5.48E-05	6.49E-07	0.0	5.08E-08

TABLE C-1 (Continued)

NUCLIDE	BONE	LIVER	TOTAL BODY	THYROID	KIDNEY	LUNG	GI-LLI
53I 133	1.08E-06	1.86E-06	5.67E-07	3.66E-04	3.25E-06	0.0	1.09E-06
53I 134	8.06E-08	2.16E-07	7.70E-08	2.87E-05	3.44E-07	0.0	1.26E-10
53I 135	3.36E-07	8.74E-07	3.22E-07	1.17E-04	1.39E-06	0.0	6.56E-07
55CS 134M	1.60E-08	3.20E-08	1.72E-08	0.0	1.83E-08	2.94E-09	7.92E-09
55CS 134	4.67E-05	1.06E-04	9.11E-05	0.0	3.60E-05	1.22E-05	1.30E-06
55CS 135	1.46E-05	1.29E-05	6.00E-06	0.0	5.11E-06	1.57E-06	2.11E-07
55CS 136	4.89E-06	1.83E-05	1.39E-05	0.0	1.07E-05	1.50E-06	1.46E-06
55CS 137	5.98E-05	7.77E-05	5.36E-05	0.0	2.78E-05	9.41E-06	1.05E-06
55CS 138	4.14E-08	7.77E-08	4.06E-08	0.0	6.01E-08	6.07E-09	2.33E-13
55CS 139	2.56E-08	3.63E-08	1.39E-08	0.0	3.05E-08	2.84E-09	0.0
56BA 139	1.17E-10	8.32E-14	3.42E-12	0.0	7.78E-14	4.70E-07	1.12E-07
56BA 140	4.88E-06	6.13E-09	3.21E-07	0.0	2.09E-09	1.59E-04	2.73E-05
56BA 141	1.25E-11	9.41E-15	4.20E-13	0.0	8.75E-15	2.42E-07	1.45E-17
56BA 142	3.29E-12	3.38E-15	2.07E-13	0.0	2.86E-15	1.49E-07	0.0
57LA 140	4.30E-08	2.17E-08	5.73E-09	0.0	0.0	1.70E-05	5.73E-05
57LA 141	5.34E-10	1.66E-10	2.71E-11	0.0	0.0	1.35E-06	7.31E-06
57LA 142	8.54E-11	3.88E-11	9.65E-12	0.0	0.0	7.92E-07	2.64E-07
58CE 141	2.49E-06	1.69E-06	1.91E-07	0.0	7.83E-07	4.52E-05	1.50E-05
58CE 143	2.33E-08	1.72E-08	1.91E-09	0.0	7.60E-09	9.98E-06	2.83E-05
58CE 144	4.29E-04	1.79E-04	2.30E-05	0.0	1.06E-04	9.73E-04	1.02E-04
59PR 143	1.17E-06	4.69E-07	5.79E-08	0.0	2.70E-07	3.51E-05	2.50E-05
59PR 144	3.76E-12	1.56E-12	1.91E-13	0.0	8.81E-13	1.27E-07	2.69E-18
60ND 147	6.59E-07	7.62E-07	4.56E-08	0.0	4.45E-07	2.76E-05	2.16E-05
61PM 147	8.37E-05	7.87E-06	3.18E-06	0.0	1.49E-05	6.61E-05	5.54E-06
61PM 148M	9.82E-06	2.54E-06	1.94E-06	0.0	3.85E-06	2.14E-04	4.18E-05
61PM 148	3.84E-07	6.37E-08	3.20E-08	0.0	1.20E-07	3.91E-05	5.80E-05
61PM 149	3.44E-08	4.87E-09	1.99E-09	0.0	9.19E-09	7.22E-06	2.50E-05
61PM 151	8.50E-09	1.42E-09	7.21E-10	0.0	2.55E-09	3.94E-06	2.00E-05
62SM 151	8.59E-05	1.48E-05	3.55E-06	0.0	1.66E-05	4.46E-05	3.25E-06
62SM 153	1.70E-08	1.42E-08	1.04E-09	0.0	4.59E-09	4.15E-06	1.58E-05
63EU 152	2.38E-04	5.40E-05	4.76E-05	0.0	3.35E-04	3.43E-04	1.59E-05
63EU 154	7.40E-04	9.10E-05	6.48E-05	0.0	4.36E-04	5.85E-04	3.40E-05
63EU 155	1.01E-04	1.43E-05	9.21E-06	0.0	6.59E-05	9.47E-05	5.95E-06
63EU 156	1.93E-06	1.48E-06	2.40E-07	0.0	9.95E-07	8.57E-05	4.50E-05
65TB 160	2.21E-05	0.0	2.75E-06	0.0	9.10E-06	1.92E-04	2.68E-05
67HO 166M	3.37E-04	1.05E-04	8.00E-05	0.0	1.57E-04	3.94E-04	1.59E-05
74W 181	6.23E-09	2.03E-09	2.17E-10	0.0	0.0	1.72E-06	2.53E-07
74W 185	1.95E-07	6.47E-08	6.81E-09	0.0	0.0	5.57E-05	1.07E-05
74W 187	1.06E-09	8.85E-10	3.10E-10	0.0	0.0	3.63E-06	1.94E-05
82PB 210	2.64E-02	6.72E-03	8.37E-04	0.0	2.12E-02	2.63E-02	3.65E-05
83BI 210	0.0	1.59E-06	1.32E-07	0.0	1.92E-05	1.11E-03	2.95E-05
84PO 210	3.97E-04	8.60E-04	9.58E-05	0.0	2.95E-03	3.14E-02	4.19E-05

TABLE C-1 (Continued)

NUCLIDE	BONE	LIVER	TOTAL BODY	THYROID	KIDNEY	LUNG	GI-LLI
88RA 223	1.80E-04	2.77E-07	3.60E-05	0.0	7.85E-06	2.55E-02	2.84E-04
88RA 224	1.98E-05	4.78E-08	3.96E-06	0.0	1.35E-06	8.78E-03	3.01E-04
88RA 225	3.00E-04	3.56E-07	5.99E-05	0.0	1.01E-05	2.92E-02	2.71E-04
88RA 226	1.25E-01	2.39E-06	9.13E-02	0.0	6.77E-05	1.17E-01	2.94E-04
88RA 228	4.41E-02	1.23E-06	4.78E-02	0.0	3.48E-05	1.61E-01	5.00E-05
89AC 225	4.23E-04	5.82E-04	2.84E-05	0.0	6.63E-05	2.21E-02	2.52E-04
89AC 227	2.30E 00	3.05E-01	1.36E-01	0.0	9.82E-02	2.41E-01	4.92E-05
90TH 227	2.17E-04	3.92E-06	6.25E-06	0.0	2.22E-05	3.78E-02	3.34E-04
90TH 228	2.00E-01	3.39E-03	6.77E-03	0.0	1.89E-02	1.01E 00	3.49E-04
90TH 229	8.88E 00	1.33E-01	4.36E-01	0.0	6.52E-01	3.50E 00	3.17E-04
90TH 230	2.29E 00	1.31E-01	6.36E-02	0.0	6.40E-01	6.22E-01	3.73E-05
90TH 232	1.99E 00	1.12E-01	5.43E-02	0.0	5.47E-01	5.31E-01	7.94E-05
90TH 234	1.63E-06	9.56E-08	4.70E-08	0.0	5.41E-07	1.89E-04	7.03E-05
91PA 231	5.08E 00	1.91E-01	1.98E-01	0.0	0.0	5.75E-02	3.89E-04
91PA 233	1.21E-06	2.42E-07	2.09E-07	0.0	9.15E-07	3.52E-05	1.02E-05
92U 232	5.14E-02	0.0	3.66E-03	0.0	5.56E-03	2.23E-01	4.16E-05
92U 233	1.09E-02	0.0	6.59E-04	0.0	2.54E-03	5.33E-02	3.89E-05
92U 234	1.04E-02	0.0	6.46E-04	0.0	2.49E-03	5.22E-02	3.81E-05
92U 235	1.00E-02	0.0	6.07E-04	0.0	2.34E-03	4.90E-02	4.84E-05
92U 236	1.00E-02	0.0	6.20E-04	0.0	2.39E-03	5.01E-02	3.57E-05
92U 237	3.67E-08	0.0	9.77E-09	0.0	1.51E-07	1.02E-05	1.20E-05
92U 238	9.58E-03	0.0	5.67E-04	0.0	2.18E-03	4.58E-02	1.03E-04
93NP 237	1.69E 00	1.47E-01	6.87E-02	0.0	5.10E-01	5.22E-02	4.92E-05
93NP 238	2.96E-07	7.99E-09	4.61E-09	0.0	2.72E-08	1.02E-05	2.13E-05
93NP 239	2.87E-08	2.82E-09	1.55E-09	0.0	8.75E-09	4.71E-06	1.49E-05
94PU 238	2.69E 00	3.73E-01	6.66E-02	0.0	2.85E-01	1.76E-01	4.52E-05
94PU 239	3.05E 00	4.19E-01	7.53E-02	0.0	3.20E-01	1.67E-01	4.13E-05
94PU 240	3.04E 00	4.19E-01	7.53E-02	0.0	3.20E-01	1.67E-01	4.20E-05
94PU 241	6.05E-02	3.28E-03	1.29E-03	0.0	5.93E-03	1.52E-04	8.65E-07
94PU 242	2.89E 00	3.99E-01	7.17E-02	0.0	3.05E-01	1.59E-01	4.05E-05
94PU 244	3.45E 00	4.76E-01	8.54E-02	0.0	3.64E-01	1.89E-01	6.03E-05
95AM 241	9.93E-01	3.46E-01	6.47E-02	0.0	4.87E-01	5.86E-02	4.60E-05
95AM 242M	1.02E 00	3.46E-01	6.73E-02	0.0	5.01E-01	2.45E-02	5.79E-05
95AM 243	9.94E-01	3.40E-01	6.45E-02	0.0	4.86E-01	5.65E-02	6.03E-05
96CM 242	1.14E-02	1.18E-02	7.50E-04	0.0	3.50E-03	3.74E-02	4.91E-05
96CM 243	7.85E-01	2.97E-01	4.61E-02	0.0	2.15E-01	6.32E-02	4.84E-05
96CM 244	5.90E-01	2.54E-01	3.51E-02	0.0	1.64E-01	6.07E-02	4.68E-05
96CM 245	1.26E 00	3.59E-01	7.14E-02	0.0	3.33E-01	5.86E-02	4.36E-05
96CM 246	1.25E 00	3.59E-01	7.13E-02	0.0	3.33E-01	5.97E-02	4.29E-05
96CM 247	1.22E 00	3.53E-01	7.03E-02	0.0	3.28E-01	5.86E-02	5.63E-05
96CM 248	1.01E 01	2.91E 00	5.79E-01	0.0	2.70E 00	4.83E-01	9.09E-04
98CF 252	7.33E-01	0.0	1.83E-02	0.0	0.0	1.56E-01	1.78E-04

TABLE C-2

TEENAGER INHALATION DOSE FACTORS
(mrem/pCi inhaled)

NUCLIDE		BONE	LIVER	TOTAL BODY	THYROID	KIDNEY	LUNG	GI-LLI
1H	3	0.0	1.06E-07	1.06E-07	1.06E-07		1.06E-07	1.06E-07
6C	14	5.66E-07	5.66E-07	5.66E-07	5.66E-07		5.66E-07	5.66E-07
11NA	22	1.76E-05	1.76E-05	1.76E-05	1.76E-05		1.76E-05	1.44E-06
27CO	58	0.0	2.20E-08	2.93E-08	0.0		1.71E-04	1.19E-05
27CO	60	0.0	1.55E-07	2.06E-07	0.0		1.07E-03	2.94E-05
38SR	89	4.84E-06	0.0	1.39E-07	0.0	(USE	3.13E-04	4.42E-05
38SR	90	1.48E-03	0.0	9.04E-05	0.0		2.07E-03	9.05E-05
39Y	90	1.41E-08	0.0	3.79E-10	0.0		0.0	6.79E-05
39Y	91	6.72E-06	0.0	1.80E-07	0.0	ADULT	3.57E-04	4.67E-05
40ZR	95	1.36E-06	4.54E-07	3.17E-07	0.0		3.20E-04	1.66E-05
41NB	95	1.70E-07	1.03E-07	5.78E-08	0.0		8.96E-05	1.10E-05
44RU	103	2.04E-08	0.0	9.15E-09	0.0	DOSE	9.39E-05	1.18E-05
44RU	106	1.05E-06	0.0	1.32E-07	0.0		2.05E-03	1.16E-04
50SN	123	3.49E-06	7.68E-08	1.15E-07	6.15E-08		4.89E-04	3.91E-05
52TE	125M	5.09E-08	2.32E-08	6.91E-09	1.46E-08	FACTOR)	6.70E-05	8.85E-06
52TE	127	1.62E-11	7.30E-12	4.02E-12	1.34E-11		1.33E-06	1.01E-05
52TE	129M	1.49E-07	7.05E-08	2.40E-08	4.88E-08		2.54E-04	4.80E-05
52TE	132	3.75E-09	3.00E-09	2.29E-09	2.58E-09		5.67E-05	6.61E-05
53I	129	3.53E-06	2.94E-06	9.81E-06	7.32E-03		0.0	2.16E-07
53I	131	4.21E-06	5.90E-06	3.52E-06	1.74E-03		0.0	7.45E-07
53I	133	1.54E-06	2.58E-06	7.93E-07	4.79E-04		0.0	1.25E-06
55CS	134	6.04E-05	1.38E-04	6.80E-05	0.0		1.80E-05	1.12E-06
55CS	137	8.02E-05	1.03E-04	3.79E-05	0.0		1.47E-05	9.60E-07
56BA	140	6.62E-07	6.06E-10	4.27E-08	0.0		2.53E-04	2.65E-06
57LA	140	1.79E-09	4.72E-10	1.67E-10	0.0		2.70E-05	5.81E-05
58CE	141	2.84E-07	1.90E-07	2.18E-08	0.0		7.29E-05	1.42E-05
58CE	144	5.24E-05	2.17E-05	2.80E-06	0.0		1.72E-03	1.05E-04
63EU	154	9.95E-05	1.02E-05	9.07E-06	0.0		9.29E-04	3.41E-05
92U	232	6.14E-03	0.0	4.37E-04	0.0		3.84E-01	4.16E-05
92U	234	1.25E-03	0.0	7.72E-05	0.0		9.00E-02	3.81E-05
94PU	238	3.22E-01	4.43E-02	7.98E-03	0.0		3.14E-01	4.52E-05
94PU	239	3.67E-01	5.00E-02	9.06E-03	0.0		2.98E-01	4.13E-05
94PU	240	3.66E-01	5.04E-02	9.13E-03	0.0		3.01E-01	4.13E-05
94PU	241	1.29E-04	1.84E-05	3.26E-06	0.0		1.92E-04	7.94E-08
95AM	241	1.20E-01	4.11E-02	7.79E-03	0.0		1.01E-01	4.44E-05
96CM	242	1.35E-03	1.40E-03	8.97E-05	0.0		6.47E-02	4.83E-05
96CM	244	6.99E-02	2.99E-02	4.16E-03	0.0		1.05E-01	4.60E-05

Note: 0.0 means insufficient data or that the dose factor is <1.0E-20.

TABLE C-3

CHILD INHALATION DOSE FACTORS
(mrem/pCi inhaled)

NUCLIDE		BONE	LIVER	TOTAL BODY	THYROID	KIDNEY	LUNG	GI-LLI
1H	3	0.0	2.03E-07	2.03E-07	2.03E-07		2.03E-07	2.03E-07
6C	14	1.69E-06	1.69E-06	1.69E-06	1.69E-06		1.69E-06	1.69E-06
11NA	22	4.42E-05	4.42E-05	4.42E-05	4.42E-05		4.42E-05	1.28E-06
27CO	58	0.0	4.11E-08	7.23E-08	0.0		3.04E-04	9.78E-06
27CO	60	0.0	2.90E-07	5.07E-07	0.0	(USE	1.87E-03	2.53E-05
38SR	89	1.45E-05	0.0	4.16E-07	0.0		6.06E-04	4.56E-05
38SR	90	4.43E-03	0.0	2.70E-04	0.0		4.00E-03	9.31E-05
39Y	90	9.87E-08	0.0	2.65E-09	0.0		7.26E-05	7.43E-05
39Y	91	2.01E-05	0.0	5.36E-07	0.0	ADULT	6.90E-04	4.82E-05
40ZR	95	3.81E-06	9.86E-07	8.05E-07	0.0		5.72E-04	1.55E-05
41NB	95	4.60E-07	1.96E-07	1.44E-07	0.0	DOSE	1.58E-04	8.96E-06
44RU	103	5.84E-08	0.0	2.36E-08	0.0		1.71E-04	1.14E-05
44RU	106	3.12E-06	0.0	3.88E-07	0.0		3.93E-03	1.18E-04
50SN	123	1.04E-05	1.74E-07	3.43E-07	1.84E-07	FACTOR)	9.46E-04	4.03E-05
52TE	125M	1.52E-07	5.25E-08	2.06E-08	4.35E-09		1.30E-04	9.13E-06
52TE	127	4.83E-11	1.65E-11	1.20E-11	4.01E-11		2.58E-06	1.58E-05
52TE	129M	4.44E-07	1.58E-07	7.03E-08	1.46E-07		4.87E-04	4.93E-05
52TE	132	1.08E-08	6.08E-09	5.91E-09	7.24E-09		1.03E-04	6.52E-05
53I	129	1.05E-05	6.40E-06	2.86E-05	2.14E-02		0.0	2.15E-07
53I	131	1.23E-05	1.25E-05	9.47E-06	4.16E-03		0.0	7.17E-07
53I	133	4.53E-06	5.53E-06	2.17E-06	1.36E-03		0.0	1.50E-06
55CS	134	1.68E-04	2.69E-04	6.02E-05	0.0		3.21E-05	1.02E-06
55CS	137	2.34E-04	2.16E-04	3.38E-05	0.0		2.71E-05	9.22E-07
56BA	140	1.93E-06	1.26E-09	1.14E-07	0.0		4.69E-04	2.68E-06
57LA	140	5.20E-09	9.63E-10	4.34E-10	0.0		4.92E-05	6.14E-05
58CE	141	8.47E-07	4.24E-07	6.30E-08	0.0		1.39E-04	1.47E-05
58CE	144	1.57E-04	4.91E-05	8.37E-06	0.0		3.32E-03	1.08E-04
63EU	154	2.87E-04	2.12E-05	2.09E-05	0.0		1.67E-03	3.51E-05
92U	232	1.83E-02	0.0	1.31E-03	0.0		7.43E-01	4.28E-05
92U	234	3.73E-03	0.0	2.31E-04	0.0		1.74E-01	3.92E-05
94PU	238	9.62E-01	1.00E-01	2.38E-02	0.0		5.87E-01	4.65E-05
94PU	239	1.10E 00	1.13E-01	2.71E-02	0.0		5.56E-01	4.24E-05
94PU	240	1.09E 00	1.14E-01	2.73E-02	0.0		5.61E-01	4.24E-05
94PU	241	3.84E-04	4.16E-05	9.73E-06	0.0		3.61E-04	8.16E-08
95AM	241	3.57E-01	9.31E-02	2.33E-02	0.0		1.95E-01	4.57E-05
96CM	242	4.05E-03	3.17E-03	2.68E-04	0.0		1.25E-01	4.98E-05
96CM	244	2.09E-01	6.77E-02	1.24E-02	0.0		2.02E-01	4.73E-05

Note: 0.0 means insufficient data or that the dose factor is <1.0E-20.

TABLE C-4

INFANT INHALATION DOSE FACTORS
(mrem/pCi inhaled)

NUCLIDE		BONE	LIVER	TOTAL BODY	THYROID	KIDNEY	LUNG	GI-LLI
1H	3	0.0	3.07E-07	3.07E-07	3.07E-07		3.07E-07	3.07E-07
6C	14	3.60E-06	3.60E-06	3.60E-06	3.60E-06		3.60E-06	3.60E-06
11NA	22	7.53E-05	7.53E-05	7.53E-05	7.53E-05		7.53E-05	1.22E-06
27CO	58	0.0	8.39E-08	1.20E-07	0.0		5.28E-04	8.67E-06
27CO	60	0.0	5.00E-07	8.38E-07	0.0		3.98E-03	2.34E-05
38SR	89	3.08E-05	0.0	8.85E-07	0.0	(USE	1.65E-03	4.86E-[illegible]
38SR	90	9.44E-03	0.0	5.76E-04	0.0		1.09E-02	9.89E-[illegible]
39Y	90	2.10E-07	0.0	5.65E-09	0.0		1.98E-04	8.02E-[illegible]
39Y	91	4.27E-05	0.0	1.14E-06	0.0	ADULT	1.88E-03	5.12E-05
40ZR	95	7.74E-06	1.95E-06	1.39E-06	0.0		1.29E-03	1.01E-05
41NB	95	9.16E-07	4.11E-07	2.41E-07	0.0		3.41E-04	8.67E-06
44RU	103	1.21E-07	0.0	4.18E-08	0.0	DOSE	4.04E-04	1.13E-05
44RU	106	6.65E-06	0.0	8.16E-07	0.0		1.07E-02	1.26E-04
50SN	123	2.22E-05	4.61E-07	7.30E-07	4.61E-07		2.58E-03	4.28E-05
52TE	125M	3.24E-07	1.39E-07	4.40E-08	1.09E-07	FACTOR)	3.54E-04	9.71E-06
52TE	127	1.03E-10	4.38E-11	2.56E-11	1.00E-10		7.03E-06	1.87E-05
52TE	129M	9.44E-07	4.14E-07	1.47E-07	3.63E-07		1.31E-03	5.23E-05
52TE	132	2.25E-08	1.42E-08	1.06E-08	1.70E-08		2.48E-04	6.68E-05
53I	129	2.23E-05	1.62E-05	5.82E-05	5.21E-02		0.0	2.23E-07
53I	131	2.59E-05	3.05E-05	1.79E-05	1.01E-02		0.0	7.66E-07
53I	133	9.56E-06	1.38E-05	4.19E-06	3.33E-03		0.0	1.63E-06
55CS	134	3.43E-04	5.89E-04	5.23E-05	0.0		7.22E-05	9.80E-07
55CS	137	4.90E-04	5.22E-04	3.15E-05	0.0		6.75E-05	9.45E-07
56BA	140	4.07E-06	3.05E-09	2.11E-07	0.0		1.17E-03	2.77E-06
57LA	140	1.09E-08	2.29E-09	7.91E-10	0.0		1.21E-04	6.43E-05
58CE	141	1.80E-06	1.11E-06	1.29E-07	0.0		3.74E-04	1.47E-05
58CE	144	3.34E-04	1.30E-04	1.78E-05	0.0		9.06E-03	1.15E-04
63EU	154	5.99E-04	4.95E-05	3.72E-05	0.0		3.99E-03	3.73E-05
92U	232	3.91E-02	0.0	2.78E-03	0.0		2.02E 00	4.55E-05
92U	234	7.94E-03	0.0	4.91E-04	0.0		4.74E-01	4.16E-05
94PU	238	2.05E 00	2.66E-01	5.08E-02	0.0		1.51E 00	4.95E-05
94PU	239	2.33E 00	3.00E-01	5.77E-02	0.0		1.43E 00	4.51E-05
94PU	240	2.33E 00	3.02E-01	5.81E-02	0.0		1.45E 00	4.51E-05
94PU	241	3.18E-04	1.10E-04	2.07E-05	0.0		9.40E-04	8.68E-08
95AM	241	7.61E-01	2.47E-01	4.96E-02	0.0		5.32E-01	4.86E-05
96CM	242	8.62E-03	8.40E-03	5.71E-04	0.0		3.41E-01	5.29E-05
96CM	244	4.45E-01	1.79E-01	2.65E-02	0.0		5.51E-01	5.03E-05

Note: 0.0 means insufficient data or that the dose factor is <1.0E-20.

This yields

$$C^{v}_{14}(r,\theta) = 3.17 \times 10^{7}\ Q'_{14}[\chi/Q'](r,\theta)\ 0.11/0.16$$

$$= 2.2 \times 10^{7}\ Q'_{14}[\chi/Q'](r,\theta) \qquad \text{(C-8)}$$

where

$C^{v}_{14}(r,\theta)$	is the concentration of carbon-14 in vegetation grown at location (r,θ), in pCi/kg;
Q'_{14}	is the annual release rate of carbon-14, in Ci/yr;
0.11	is the fraction of total plant mass that is natural carbon, dimensionless;
0.16	is equal to the concentration of natural carbon in the atmosphere, in g/m^3; and
3.17×10^7	is equal to $(1.0 \times 10^{12}$ pCi/Ci$)(1.0 \times 10^3$ g/kg$)/(3.15 \times 10^7$ sec/yr).

The concentration of tritium in vegetation is calculated from its concentration in the air surrounding the vegetation. Using the method described in Reference 3, the NRC staff derived the following equation:

$$C^{v}_{T}(r,\theta) = 3.17 \times 10^{7}\ Q'_{T}[\chi/Q'](r,\theta)(0.75)(0.5/H)$$

$$= 1.2 \times 10^{7}\ Q'_{T}[\chi/Q'](r,\theta)/H \qquad \text{(C-9)}$$

where

$C^{v}_{T}(r,\theta)$	is the concentration of tritium in vegetation grown at location (r,θ), pCi/kg;
H	is the absolute humidity of the atmosphere at location (r,θ) in g/m^3;
Q'_T	is the annual release rate of tritium, Ci/yr;
0.5	is the ratio of tritium concentration in atmospheric water to tritium concentration in plant water, dimensionless; and
0.75	is the fraction of total plant mass that is water, dimensionless.

The deposition rate from the plume is defined by:

$$d'_i(r,\theta) = 1.1 \times 10^{8} \delta_i(r,\theta) Q'_i \qquad \text{(C-10)}$$

where

$\delta_i(r,\theta)$	is the relative deposition of nuclide i, considering depletion and decay in transit to location (r,θ), in m^{-2} (see Regulatory Guide 1.111) and
1.1×10^8	is the number of pCi per Ci (10^{12}) divided by the number of hours per year (8760).

For radioiodines the model considers only the elemental fraction of the effluent. The deposition should be computed only for that fraction of the effluent that is estimated to be elemental iodine. Measurements at operating facilities indicate that about half the radioiodine emissions may be considered nonelemental (Reference 4). With this consideration included, Equation (C-10) for radioiodine becomes:

$$d_i(r,\theta) = 5.5 \times 10^7 \delta_i(r,\theta)Q_i'$$ (C-11)

and Q_i' is the total (elemental and nonelemental) radioiodine emission rate. The retention factor r for elemental radioiodine on vegetation should be taken as unity, since the experimental measurement (References 5, 6, and 7) techniques used to evaluate this transfer mechanism consisted of direct comparison of the gross radioiodine concentration on vegetation and the concentration in air (References 8, 9, and 10).

For radioiodines, the deposition model is based only on the dry deposition process. Wet deposition, including "washout" of the organic and non-organic iodine fractions, should be considered at some sites depending on the meteorological conditions (see Regulatory Guide 1.111).

For particulates, the deposition model considers both wet and dry deposition. There is also a retention factor (r of Equation (C-7)) that accounts for the interception and capture of the deposited activity by the vegetative cover. A value of 0.2 is taken for this factor (References 11 and 12). All nuclides except noble gases, tritium, carbon-14, and the iodines are treated as particulates.

a. Parameters for Calculating Nuclides Concentrations in Vegetation Consumed by Man

When the radionuclide concentration in vegetation directly ingested by man is estimated using Equation (C-7), the following parameters are used:

Parameter		Value
Y_v	(vegetation yield)	2.0 kg/m^2
t_e	(exposure time to plume)	60 days
t_h	(holdup after harvest)	1 day for garden-fresh leafy vegetables
		60 days for stored vegetables
t_b	(soil exposure time)	15 years (midpoint of reactor operating lifetime)

All other parameters in this equation are given in Regulatory Position C of this guide.

b. Parameters for Calculating Nuclide Concentrations in Milk

The radionuclide concentration in milk is dependent on the amount and contamination level of the feed consumed by the animal. The radionuclide concentration in milk is estimated as

$$C_i^m(r,\theta) = F_m C_i^v(r,\theta) Q_F \exp(-\lambda_i t)$$ (C-12)

where

$C_i^m(r,\theta)$ is the concentration in milk of nuclide i, in pCi/liter;

$C_i^v(r,\theta)$ is the concentration of radionuclide i in the animal's feed, in pCi/kg;

F_m is the average fraction of the animal's daily intake of radionuclide i which appears in each liter of milk, in days/liter (see Tables C-5 and C-6 for cow and goat data, respectively; for nuclides not listed in Table C-6, use the values in Table C-5);

TABLE C-5

STABLE ELEMENT TRANSFER DATA*

ELEM	B_{iv} VEG/SOIL	$F_{m(Cow)}$ MILK(D/L)	F_f MEAT(D/KG)	ELEM	B_{iv} VEG/SOIL	$F_{m(Cow)}$ MILK(D/L)	F_f MEAT(D/KG)
H	4.8E 00	1.0E-02**	1.2E-02	SB	1.1E-02	1.5E-03	4.0E-03
HE	5.0E-02	2.0E-02	2.0E-02	TE	1.3E 00	1.0E-03	7.7E-02
LI	8.3E-04	5.0E-02	1.0E-02	I	2.0E-02	6.0E-03†	2.9E-03
BE	4.2E-04	1.0E-04	1.0E-03	XE	1.0E 01	2.0E-02	2.0E-02
B	1.2E-01	2.7E-03	8.0E-04	CS	1.0E-02	1.2E-02***	4.0E-03
C	5.5E 00	1.2E-02	3.1E-02	BA	5.0E-03	4.0E-04***	3.2E-03
N	7.5E 00	2.2E-02	7.7E-02	LA	2.5E-03	5.0E-06	2.0E-04
O	1.6E 00	2.0E-02	1.6E-02	CE	2.5E-03	6.0E-0[illegible]***	1.2E-03
F	6.5E-04	1.4E-02	1.5E-01	PR	2.5E-03	5.0E-06	4.7E-03
NE	1.4E-01	2.0E-02	2.0E-02	ND	2.4E-03	5.0E-06	3.3E-03
NA	5.2E-02	4.0E-02***	3.0E-02	PM	2.5E-03	5.0E-06	4.8E-03
MG	1.3E-01	1.0E-02	5.0E-03	SM	2.5E-03	5.0E-06	5.0E-03
AL	1.8E-04	5.0E-04	1.5E-03	EU	2.5E-03	5.0E-06	4.8E-03
SI	1.5E-04	1.0E-04	4.0E-05	GD	2.5E-03	5.0E-06	3.6E-03
P	1.1E 00	2.5E-02	4.6E-02	TB	2.5E-03	5.0E-06	4.4E-03
S	5.9E-01	1.8E-02	1.0E-01	DY	2.5E-03	5.0E-06	5.3E-03
CL	5.0E 00	5.0E-02	8.0E-02	HO	2.5E-03	5.0E-06	4.4E-03
AR	6.0E-01	2.0E-02	2.0E-02	ER	2.5E-03	5.0E-06	4.0E-03
K	3.7E-01	1.0E-02	1.2E-02	TM	2.5E-03	5.0E-06	4.4E-03
CA	[illegible].6E-02	8.0E-03***	4.0E-03	YB	2.5E-03	5.0E-06	4.0E-03
SC	1.1E-03	5.0E-06	1.6E-02	LU	2.5E-03	5.0E-06	4.4E-03
TI	5.4E-05	5.0E-06	3.1E-02	HF	1.7E-04	5.0E-06	4.0E-01
V	1.3E-03	1.0E-03	2.3E-03	TA	6.3E-03	2.5E-02	1.6E 00
CR	2.5E-04	2.2E-03	2.4E-03	W	1.9E-02	5.0E-04	1.3E-03
MN	2.9E-02	2.5E-04	8.0E-04	RE	2.5E-01	2.5E-02	8.0E-03
FE	6.6E-04	1.2E-03	4.0E-02	OS	5.0E-02	5.0E-03	4.0E-01
CO	9.4E-03	1.0E-03	1.3E-02	IR	1.3E 01	5.0E-03	1.5E-03
NI	1.9E-02	6.7E-03	5.3E-03	PT	5.0E-01	5.0E-03	4.0E-03
CU	1.2E-01	1.4E-02	8.0E-03	AU	2.5E-03	5.0E-03	8.0E-03
ZN	4.0E-01	3.9E-02	3.0E-02	HG	3.8E-01	3.8E-02	2.6E-01
GA	2.5E-04	5.0E-05	1.3E 00	TL	2.5E-01	2.2E-02	4.0E-02
GE	1.0E-01	5.0E-04	2.0E 01	PB	6.8E-02	6.2E-04	2.9E-04
AS	1.0E-02	6.0E-03	2.0E-03	BI	1.5E-01	5.0E-04	1.3E-02
SE	1.3E 00	4.5E-02	1.5E-02	PO	1.5E-01	3.0E-04	1.2E-02††
BR	7.6E-01	5.0E-02	2.6E-02	AT	2.5E-01	5.0E-02	8.0E 00
KR	3.0E 00	2.0E-02	2.0E-02	RN	3.5E 00	2.0E-02	2.0E-02
RB	1.3E-01	3.0E-02	3.1E-02	FR	1.0E-02	5.0E-02	2.0E-02††
SR	1.7E-02	8.0E-04***	6.0E-04	RA	3.1E-04	8.0E-03***	3.4E-02
Y	2.6E-03	1.0E-05	4.6E-03	AC	2.5E-03	5.0E-06	6.0E-02††
ZR	1.7E-04	5.0E-06	3.4E-02	TH	4.2E-03	5.0E-06	2.0E-04††
NB	9.4E-03	2.5E-03	2.8E-01	PA	2.5E-03	5.0E-06	8.0E 02
MO	1.2E-01	7.5E-03	8.0E-03	U	2.5E-03	5.0E-04	3.4E-04††
TC	2.5E-01	2.5E-02	4.0E-01	NP	2.5E-03	5.0E-06	2.0E-04††
RU	5.0E-02	1.0E-06	4.0E-01	PU	2.5E-04	2.0E-06	1.4E-05††
RH	1.3E 01	1.0E-02	1.5E-03	AM	2.5E-04	5.0E-06	2.0E-04††
PD	5.0E 00	1.0E-02	4.0E-03	CM	2.5E-03	5.0E-06	2.0E-04††
AG	1.5E-01	5.0E-02	1.7E-02	BK	2.5E-03	5.0E-06	2.0E-04††
CD	3.0E-01	1.2E-04	5.3E-04	CF	2.5E-03	5.0E-06	2.0E-04††
IN	2.5E-01	1.0E-04	8.0E-03	ES	2.5E-03	5.0E-06	2.0E-04††
SN	2.5E-03	2.5E-03	8.0E-02	FM	2.5E-03	5.0E-06	2.0E-04††

*Ref. 1.

**Ref. 3.

***Ref. 13.

†Refs. 7, 8, 9, 10, 14, 15, 16, 17.

††Ref. 18.

TABLE C-6

NUCLIDE TRANSFER PARAMETERS FOR GOAT'S MILK

ELEMENT	F_m (days/liter)
H	0.17*
B	0.012*
C	0.10*
Mg	0.042*
P	0.25*
Cl	0.5*
K	0.057*
Ca	0.47*
Fe	1.3E-04*
Cu	0.013*
Sr	0.014**
I	0.06**
Cs	0.30**
Po	0.0018**

*Computed from the data of Refs. 1 and 19.
**Ref. 13.

Q_F is the amount of feed consumed by the animal per day, in kg/day;

t is the average transport time of the activity from the feed into the milk and to the receptor (a value of 2 days is assumed); and

λ_i is the radiological decay constant of nuclide i, in days^{-1}.

Milk-producing animals are assumed to be on open pasture for the following grazing periods:

Region	Pasture Period
Southern U.S.	Whole year ($f_p = 1$)
Northern U.S.	May - Sept. ($f_p = 1/2$)

where

f_p is the fraction of the year that animals graze on pasture.

These data may be supplemented by information on site-specific dairy practices. The concentration of radionuclide i in the animal's feed is then

$$C_i^v(r,\theta) = f_p f_s C_i^p(r,\theta) + (1 - f_p)C_i^s(r,\theta) + f_p(1 - f_s)C_i^s(r,\theta) \qquad \text{(C-13)}$$

where

$C_i^p(r,\theta)$ is the concentration of radionuclide i on pasture grass, in pCi/kg;

$C_i^s(r,\theta)$ is the concentration of radionuclide i in stored feeds, in pCi/kg; and

f_s is the fraction of daily feed that is pasture grass when the animal grazes on pasture.

The following parameters will be employed in evaluating the milk pathway, unless site-specific data is supplied.

	Parameter	Value
Q_F	(animal's daily feed)	50 kg/day (wet weight) for cattle
		6 kg/day (wet weight) for goats
t_h	(storage time of animal's food)	0 for pasture
		90 days for stored feed
t_e	(crop exposure time)	30 days
Y_v	(crop yield)	0.75 kg/m^2 (wet weight) for pasture
		2.0 kg/m^2 (wet weight) for stored feed

c. Parameters for Calculating Nuclide Concentration in Meat

As in the milk pathway, the radionuclide concentration in meat is dependent on the amount and contamination level of the feed consumed by the animal. The radionuclide concentration in meat is estimated as

$$C_i^F(r,\theta) = F_f C_i^v(r,\theta) Q_F \exp(-\lambda_i t) \quad \text{(C-14)}$$

where

$C_i^F(r,\theta)$ is the concentration of nuclide i in animal flesh, in pCi/kg;

F_f is the fraction of the animal's daily intake of nuclide i which appears in each kilogram of flesh, in days/kg (see Table C-5 for values); and

t is the average time from slaughter to consumption, which is assumed to be 20 days.

All the other symbols are as previously defined.

Beef cattle will be assumed to be on open pasture for the grazing periods outlined for milk cattle.

4. Annual Dose from Atmospherically Released Radionuclides in Foods

The annual dose resulting from ingestion of radionuclide i in the diet is given by

$$D_{ija}^D(r,\theta) = DFI_{ija} \left[U_a^v f_g C_i^v(r,\theta) + U_a^m C_i^m(r,\theta) + U_a^F C_i^F(r,\theta) + U_a^L f_\ell C_i^L(r,\theta)\right] \quad \text{(C-15)}$$

where

$D_{ija}^D(r,\theta)$ is the annual dose to organ j of an individual in age group a for nuclide i, in mrem/yr;

DFI_{ija} is the dose conversion factor for the ingestion of nuclide i, organ j, and age group a, in mrem/pCi (from Tables A-3 through A-6 of Appendix A of this guide); and

U_a^v, U_a^m, U_a^F, U_a^L are the ingestion rates of produce (non-leafy vegetables, fruit, and grains), milk, meat, and leafy vegetables, respectively, for individuals in age group a (from Table A-2 of Appendix A of this guide).

All the other symbols are as previously defined.

The annual dose to organ j of an individual in age group a from consumption of vegetables, milk, and meat is therefore

$$D_{ja}^D = \sum_i DF_{ija} \left[U_a^v f_g C_i^v(r,\theta) + U_a^m C_i^m(r,\theta) + U_a^F C_i^F(r,\theta) + U_a^L f_\ell C_i^L(r,\theta)\right] \quad \text{(C-16)}$$

REFERENCES FOR APPENDIX C

1. Y. C. Ng et al, "Prediction of the Maximum Dosage to Man from the Fallout of Nuclear Devices, IV Handbook for Estimating the Maximum Internal Dose from Radionuclides Released to the Biosphere," USAEC Report UCRL-50163, Part IV, 1968.

2. R. C. Weast (ed.), "Handbook of Chemistry and Physics," CRC Press, Cleveland, Ohio, 1970.

3. L. R. Anspaugh et al, "The Dose to Man via the Food-Chain Transfer Resulting from Exposure to Tritiated Water Vapor," USAEC Report UCRL-73195, Rev. 1, 1972.

4. B. H. Weiss et al, "Detailed Measurement of I-131 in Air, Vegetation and Milk Around Three Operating Reactor Sites," NUREG-75/021, U.S. Nuclear Regulatory Commission, Washington, D.C., March 1975.

5. D. F. Bunch (ed.), "Controlled Environmental Radioiodine Test, Progress Report Number Two," USAEC Report IDO-12063, January 1968.

6. J. D. Zimbrick and P. G. Voilleque, "Controlled Environmental Radioiodine Tests at the National Reactor Testing Station, Progress Report Number Four," USAEC Report IDO-12065, December 1968.

7. B. H. Weiss et al, "Detailed Measurement of ^{131}I in Air, Vegetation and Milk around Three Operating Reactor Sites," Environmental Surveillance around Nuclear Installations, International Atomic Energy Agency, IAEA/SM-180/44, Vienna, Austria, Vol. I: pp. 169-190, 1974.

8. F. O. Hoffman, "Environmental Variables Involved with the Estimation of the Amount of ^{131}I in Milk and the Subsequent Dose to the Thyroid," Institute für Reaktorsicherheit, Cologne, West Germany, IRS-W-6, June 1973.

9. F. O. Hoffman, "Parameters To Be Considered When Calculating the Age-Dependent ^{131}I Dose to the Thyroid," Institute für Reaktorsicherheit, IRS-W-5, April 1973.

10. F. O. Hoffman, "A Reassessment of the Parameters Used To Predict the Environmental Transport of ^{131}I from Air to Milk," Institute für Reaktorsicherheit, IRS-W-13, April 1975.

11. C. A. Pelletier and P. G. Voilleque, "The Behavior of ^{137}Cs and Other Fallout Radionuclides on a Michigan Dairy Farm," Health Phys., Vol. 21, p. 777, 1971.

12. P. G. Voilleque and C. A. Pelletier, "Comparison of External Irradiation and Consumption of Cow's Milk as Critical Pathways for ^{137}Cs, ^{54}Mn and ^{144}Ce-^{144}Pr Released to the Atmosphere," Health Phys., Vol. 27, p. 189, 1974.

13. R. J. Garner, "Transfer of Radioactive Materials from the Terrestrial Environment to Animals and Man," CRC Press, Cleveland, Ohio, 1972.

14. F. W. Lengemann, "Radioiodine in the Milk of Cows and Goats After Oral Administration of Radioiodate and Radioiodide," Health Phys., Vol. 17, pp. 565-9, 1969.

15. R. J. Garner and R. S. Russell, Radioactivity and Human Diet, R. Scott Russell (ed.), Pergamon Press, Oxford, England, 1966.

16. P. M. Bryant, "Data for Assessments Concerning Controlled and Accidental Releases of ^{131}I and ^{137}Cs to the Stratosphere," Health Phys., Vol. 17, p. 51, 1969.

REFERENCES (Continued)

17. J. D. Zimbrick and P. G. Voilleque (eds.), "1967 CERT Progress Report," USAEC Report IDO-12067, p. 36, 1968.

18. R. S. Booth et al, "A Systems Analysis Methodology for Predicting Dose to Man from a Radioactivity Contaminated Terrestrial Environment," Proceedings of the Third National Symposium on Radioecology, USAEC Report CONF-710501, Oak Ridge, Tenn., pp. 877-893, 1971.

19. D. S. Altman and P. L Altman (eds.), "Metabolism," Federation of American Societies for Experimental Biology, Bethesda, Md., 1968.

APPENDIX D

MODELS FOR CALCULATING POPULATION DOSES FROM NUCLEAR POWER PLANT EFFLUENTS

Calculation of the annual population-integrated total body and thyroid doses* should be performed for the three effluent types identified in this guide. These doses should be evaluated for the population within a 50-mile radius of the site, as specified in paragraph D, Section II of Appendix I to 10 CFR Part 50.

For the purpose of calculating the annual population-integrated dose, the 50-mile region should be divided into a number of subregions consistent with the nature of the region. These subregions may represent, for example, the reaches of a river or land areas over which the appropriate dispersion factor is averaged. Dispersion factors, population data, and other information describing existing or planned uses of the subregions should be developed.

1. *General Expressions for Population Dose*

For pathways in which the permanent and transient population of the subregion can be considered to be exposed to the average radionuclide concentrations estimated for the subregion, the annual population-integrated dose is calculated as follows:

$$D_j^P = 0.001 \sum_d P_d \sum_a D_{jda} f_{da} \qquad \text{(D-1)}$$

where

D_{jda} is the annual dose to organ j (total body or thyroid) of an average individual of age group a in subregion d, in mrem/yr;

D_j^P is the annual population-integrated dose to organ j (total body or thyroid), in man-rems or thyroid man-rems;

f_{da} is the fraction of the population in subregion d that is in age group a;

P_d is the population associated with subregion d; and

0.001 is the conversion factor from millirems to rems.

The annual dose to the total body or thyroid of an average individual should be evaluated with the usage factors of Table D-1. Models and equations for the detailed dose calculations are presented in Appendices A, B, and C of this guide. The annual population-integrated doses from ingestion of potable water, inhalation of airborne effluents, and external exposure to airborne or deposited radionuclides should be evaluated.

For pathways that involve food products produced in the subregion, the food products may be distributed to other areas for consumption. For all the food that is produced within the 50-mile radius, the radioactivity concentrations are averaged over the entire area by weighting the concentrations in each subregion by the amount produced in each subregion. This average concentration is used in calculating the population doses. The 50-mile average concentration of nuclide i in food p is computed as

$$\overline{C}_{ip} = (1/V_p) \exp(-\lambda_i t_p) \sum_d C_{dip} v_{dp} \qquad \text{(D-2)}$$

---

*The population-integrated dose is the summation of the dose received by all individuals and has units of man-rem when applied to the total body dose and units of man-thyroid-rem when applied to the summation of thyroid dose.

TABLE D-1

RECOMMENDED VALUES TO BE USED FOR THE AVERAGE INDIVIDUAL
IN LIEU OF SITE-SPECIFIC DATA

	PER CAPITA USAGE FACTORS (U_{ap})			
PATHWAY	CHILD	TEEN	ADULT	UNITS
Fruits & Vegetables & grain	200.00	240.00	190.0	kg/yr
Milk*	170.00	200.00	110.0	l/yr
Meat & Poultry*	37.00	59.00	95.0	kg/yr
Fish*	2.20	5.20	6.9	kg/yr
Seafood*	0.33	0.75	1.0	kg/yr
Drinking water**	260.00	260.00	370.0	l/yr
Shoreline recreation**	9.50	47.00	8.3	hr/yr
Inhalation	2700.00**	5100.00**	7300.0***	m^3/yr
External Exposure from Deposited Airborne Radioactive Materials	8760.00	8760.00	8760.0	hr/yr

*Consumption rate obtained from Reference 3 of Appendix A and age-prorated using techniques in Reference 4 of Appendix A.

**Data obtained directly from Reference 4 of Appendix A.

***Data obtained directly from Reference 15 of Appendix A.

where

C_{dip} is the average concentration over subregion d of the nuclide i in pathway p, in pCi/kg or pCi/liter (see Appendices A and C of this guide for models and equations for calculation of pathway concentrations);

$\overline{C}_{ip}$ is the 50-mile average concentration of nuclide i in pathway p, in pCi/kg or pCi/liter;

t_p is the transport time of the food medium p through the distribution system, in days (Table D-2 presents estimates of the transport times that may be used in lieu of site-specific data);

v_{dp} is the annual mass or volume of food medium p produced in subregion d, in kg or liters;

V_p is the mass or volume of the food medium p produced annually with the 50-mile radius about the site, in kg or liters; and

λ_i is the radiological decay constant for nuclide i, in days^{-1}.

The population served by all the food produced within 50 miles of the site is estimated as

$$P_p^* = V_p / \sum_a U_{ap} f_a \tag{D-3}$$

where

f_a is the fraction of the population within the age group a;

P_p^* is the estimated population that can be served by the quantity of food p likely to be produced within 50 miles of the site;

U_{ap} is the use or consumption factor of food medium p for the average individual in age group a, in kg/yr or liters/yr (taken from Table D-1); and

V_p is the annual mass or volume of food medium p likely to be produced within a 50-mile radius about the site, in kg or liters.

The annual population-integrated dose is then calculated as

$$D_j^P = 0.001 \sum_p P_p \sum_i \sum_a f_a \overline{C}_{ip} U_{ap} DF_{ai} \tag{D-4}$$

where

$$P_p = \begin{cases} P_p^* & \text{if } P_p^* < P_{50} \\ P_{50} & \text{if } P_p^* \geq P_{50} \end{cases}$$

and

DF_{ai} is the dose factor for age group a and nuclide i, in mrem/pCi (taken from Tables A-3 to A-7 and C-1 to C-4);

TABLE D-2

RECOMMENDED VALUES FOR THE TRANSPORT TIMES IN THE FOOD DISTRIBUTION SYSTEM*

FOOD MEDIUM	DISTRIBUTION TRANSPORT TIME (in days)
Fruits, grains, and vegetables	14
Milk	4
Meat and poultry	20
Sport fish	7
Commercial fish	10
Drinking water	1

*To be used in lieu of site-specific data on food distribution.

D_j^P is the annual population-integrated dose to organ j (total body or thyroid), in man-rem/yr or thyroid man-rem/yr;

P_p is the population consuming food medium p; and

P_{50} is the total population within 50 miles.

All other factors are as defined above.

Note that the above formulation limits the evaluation of the exposed population evaluation to the population residing within 50 miles as specified in paragraph D, Section II of Appendix I to 10 CFR Part 50. In calculating the annual population-integrated total body and thyroid doses, the current age distribution of the population within 50 miles may be assumed to be the same as the current age distribution of the U.S. population (see Reference for Appendix D). Models and equations for the detailed dose calculations are presented in Appendices A, B, and C.

2. Use of the Models

a. Population-Integrated Doses from Liquid Effluents

The annual total body and thyroid population-integrated doses due to exposure to liquid effluents should be evaluated for the following principal pathways: potable water, aquatic food products, external irradiation from shoreline deposits, and terrestrial food products irrigated with water that has received the liquid effluent. In addition to these pathways, other exposure pathways that arise from unique conditions at a specific site should be evaluated if they provide a significant* contribution to the annual dose received by an exposed population group.

(1) Doses from Potable Water

The annual population-integrated total body and thyroid doses from water consumption are evaluated for all subregions that have water intakes existing or designated at the time of the license application. The products of the individual doses and the population exposed in each such subregion within 50 miles from the site are summed to obtain the total dose. The formulation expressed in Equation (D-1) may be used.

The total body and thyroid dose of the individuals should be evaluated using Equation (A-2) in Appendix A of this guide, together with the age-dependent usage factors U_{ap} obtained from Table D-1. The dilution from the discharge point to the usage point should be evaluated using appropriate hydrological models for the various subregions.

If the population served by a particular water supply system is not known, it can be estimated by the following:

$$P_w = v/c \qquad \text{(D-5)}$$

where

c is the average daily usage of individuals on the system, in gal/day per person;

P_w is the estimated population served by the water system; and

v is the average daily intake of the water supply system, in gal/day.

If the industrial usage from the water supply system is known, it can be subtracted from the average daily intake of the system before this value is entered into Equation (D-5).

*For the purpose of this guide, any additional pathway is deemed to be significant if a conservative evaluation of the pathway yields an additional dose contribution equal to or greater than 10% of the total from all the pathways described here. Any pathway so identified should then be evaluated by a model similar to that used above.

The population served by a water supply system whose intake is within the 50-mile radius may include individuals who reside outside the circle. This population may be pro-rated to include only the population within the 50-mile radius. Conversely, a water supply system with an intake beyond the 50-mile radius may serve the population within the 50-mile radius. Such exposed population should be included in the 50-mile population dose evaluation.

(2) Doses from Food Products

The annual population-integrated total body and thyroid doses from consumption of aquatic food products are evaluated using the production of sport and commercial harvests in the various subregions. The mixing ratio (or dilution) should be evaluated for each subregion using an appropriate hydrological model. For sport harvests, the entire edible harvest is assumed to be ingested by the population within 50 miles. The formulation expressed by Equation (D-4) should be used with the population P_p given by the results of Equation (D-3). The age-specific ingestion factors of Table D-1 may be used in lieu of site-specific data.

For commercial harvests, the production within 50 miles from the site is considered as part of the total U.S. harvest. Equation (D-2) should be used to compute the average concentration, with V_p as the total estimated U.S. commercial harvest of the aquatic food medium p. The annual population-integrated dose is then computed using Equation (D-4) with $P_p = P_{50}$. The age-specific factors of Table D-1 may be used in lieu of site-specific data.

(3) Doses from Shoreline Deposits

The annual population-integrated total body and thyroid doses from recreational activities on the shoreline of the receiving water body are evaluated by summing the product of the individual doses in each subregion and the population exposed therein. All subregions within the 50-mile radius should be considered where existing or designated recreational facilities exist. If available, actual recreational usage in the vicinity of each facility should be used. The formulation of Equation (D-1) is appropriate.

(4) Doses from Consumption of Terrestrial Food Products Irrigated by Waters Receiving the Liquid Effluent

The annual population-integrated total body and thyroid doses from consumption of food irrigated with water from the body receiving the liquid effluent are evaluated following the procedures outlined in the development of Equation (D-4). Note that the term V_p of Equations (D-2) and (D-3) denotes the total production of food medium p within 50 miles, not just the total production of irrigated food medium p. The consumption rate data of Table D-1 may be used in lieu of site-specific data in the evaluation of Equation (D-4).

b. Population-Integrated Doses from Airborne Effluents

The annual total body and thyroid population-integrated doses should be evaluated for the following principal exposure pathways: noble gas submersion, inhalation of airborne effluents, ingestion of contaminated terrestrial foods (milk, meat, and vegetation), and external irradiation from activity deposited on the ground. In addition to these pathways, other exposure pathways that arise from unique conditions at a specific site should be evaluated if they provide a significant contribution to the annual dose received by an exposed population group. (See Regulatory Position C.1 of this guide.)

For the evaluation of exposures from atmospheric releases, the 50-mile region should be divided into 160 subregions formed by sectors centered on the 16 compass points (N, NNE, NE, etc.) and annuli at distances of 1, 2, 3, 4, 5, 10, 20, 30, 40, and 50 miles from the center of the facility. The atmospheric dispersion factors (χ/Q') or similar factors should be evaluated at the radial midpoint for each of the subregions using appropriate atmospheric dispersion models such as those described in Regulatory Guide 1.111.

(1) Doses due to Exposure to Noble Gases

The annual population-integrated total body dose due to noble gas effluents should be evaluated by summing the products of the individual doses in each subregion and the population in each subregion. Equation (D-1) may be used. For external exposure, the model does not differentiate between age groups. A structural shielding factor of 0.5 should be applied in conjunction with the dose factor data of Table B-1.

(2) Doses due to Inhalation of Radioiodines and Particulates

The annual population-integrated total body and thyroid doses from inhalation of airborne effluents should be evaluated by summing the products of the individual doses received in each subregion and the population in each subregion. Equation (D-1) may be used. The age-specific inhalation rates of Table D-1 may be used with the data of Tables C-1 to C-4.

(3) Doses due to Ingestion of Terrestrial Food Products

The annual population-integrated total body and thyroid doses from ingestion of terrestrial food products should be evaluated using the production data for each subregion. For milk, meat, and commercial vegetables, the formulation of Equation (D-2) should be used to calculate the average concentrations in the foods. These concentrations are then used in Equation (D-4), along with the data of Tables D-1, D-2, and A-1 to calculate population doses.

(4) Doses due to External Irradiation from Activity Deposited on the Ground

The annual population-integrated total body and thyroid doses from external exposure to surface deposition of the effluent should be evaluated using Equation (D-1). A household shielding and occupancy factor of 0.5 should be applied in conjunction with the dose factors of Tables A-3 to A-7.

REFERENCE FOR APPENDIX D

"Current Population Reports," Bureau of the Census, Series P-25, No. 541, U.S. Dept. of Commerce, 1975.