U.S. NUCLEAR REGULATORY COMMISSION

March 1982

REGULATORY GUIDE

OFFICE OF NUCLEAR REGULATORY RESEARCH

Regulatory Guide 3.51
(Task RH 802-4)

CALCULATIONAL MODELS FOR ESTIMATING RADIATION DOSES TO MAN FROM AIRBORNE RADIOACTIVE MATERIALS RESULTING FROM URANIUM MILLING OPERATIONS

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

August 4, 1982

ERRATA

Regulatory Guide 3.51, March 1982

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Table 3, "Inhalation Dose Conversion Factors," on page 31 of this guide has the following typographical errors:

1. Under "Uranium Ore Dust," the ^{238}U bone dose value in the second row of the first column should read 7.29E+01 instead of 7.92E+01.

2. Under "Coarse Tailings Particulates," the first value for ^{226}Ra for the whole body dose should read 3.90E+01 instead of 4.90E+01.

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*See Table 12.

A. INTRODUCTION

The NRC staff is required to make analyses of radiation doses to the public, or individual members thereof, resulting from the radioactive effluents from uranium mills for the following purposes:

1. Evaluating compliance with 40 CFR Part 190, "Environmental Radiation Protection Standards for Nuclear Power Operations,"

2. Evaluating compliance with the "as low as is reasonably achievable" (ALARA) criterion embodied in 10 CFR Part 20, "Standards for Protection Against Radiation," and

3. Evaluating overall radiological impact as part of the complete environmental impact assessment required by the National Environmental Policy Act (NEPA) of 1969 (Public Law 91-190, 83 Stat. 852).

This regulatory guide describes basic features of calculational models used by the NRC staff for such evaluations and suggests values for various parameters used in the estimation of radiation doses to man from uranium milling operations. Specifically, this guide addresses the calculation of radiation doses to man from previously estimated environmental radioactivity concentrations in air. The environmental radioactivity concentrations in air required for this calculation result from extensive and detailed analyses of effluent release rates and atmospheric dispersion phenomena.

Information on the approach used for estimating source terms is included in the Final Generic Environmental Impact Statement on Uranium Milling, NUREG-0706 (Ref. 1). The methodology used by the staff for calculating atmospheric dispersion is documented in the MILDOS code user's manual, NUREG/CR-2011 (Ref. 2).

B. DISCUSSION

This guide describes models used by the NRC staff to estimate the radiological impacts resulting from uranium mills for the purpose of evaluating compliance with 40 CFR Part 190 and 10 CFR Part 20 and of assessing overall environmental radiological impacts in accordance with NEPA.

1. URANIUM MILL SOURCE TERMS

A uranium mill, unlike other types of fuel cycle facilities, goes through phases in its life cycle in which both the composition and the magnitude of its radioactive emissions (and associated impacts) vary greatly. For this reason, the NRC staff will perform impact evaluations for each individual mill at different phases of its existence. The three principal uranium mill life-cycle phases discussed in this guide are (1) operational (milling), (2) tailings pile drying and stabilization, and (3) reclamation.

Typically, a uranium mill will operate for a period of years during which there will be radon and particulate releases from the ore storage pile, the mill itself, and the tailings disposal area. During this operational period, both particulate and radon releases from the tailings pile may be somewhat curtailed by maintaining the pile at least partially under water. Mechanical sprinkler systems or chemical stabilizing agents may also be used to inhibit the suspension in air of radioactive tailings dust by the wind.

When actual milling ceases, the tailings pile is normally allowed to dry by natural evaporation until it is ready for stabilization. When the tailings are wet, there are essentially no particulate releases from the tailings pile. However, as the tailings pile dries, releases of radon and particulates from this source may increase, reaching their maximum prior to implementation of measures required to achieve long-term stabilization. After stabilization and reclamation of the tailings area, there should be no further radioactive particulate releases. However, small quantities of radon may continue to diffuse upward from the tailings and may be released to the atmosphere. These continuing radon releases, though small, are likely to persist for tens of thousands of years.

Depending on the specific details of the site, facility, effluent controls, and stabilization program, maximum individual particulate exposure could occur either during the last year of actual milling or the last year prior to stabilization of the tailings. Maximum individual doses due to radon releases are likely to occur during the last year prior to stabilization.

The radioactive isotopes comprising uranium mill radioactivity releases are mostly those belonging to the ^{238}U and ^{235}U decay series. The ^{235}U series radionuclides amount to less than 5 percent of total releases and are routinely

disregarded because of their insignificant contribution to overall radiological impact.

2. CRITICAL EXPOSURE PATHWAYS

Three exposure pathways of concern for airborne releases from uranium mills are (1) inhalation of airborne radioactive material, (2) ingestion of vegetable and animal products contaminated via deposition, and (3) direct external exposure to radiation emitted by airborne activity and activity deposited on ground surfaces. Liquid exposure pathways are not usually of concern because there are usually no discharges to surface water of liquid effluents. Liquid pathways may exist, however, and methodology similar to that used in 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," should be used for evaluating intakes via the liquid pathway. However, ingestion dose factors from Table 6 should be used in converting intakes to doses.

All individual exposure pathways of significance will be evaluated at locations where the exposure pathway and a dose receptor actually exist at the time the analysis is made. Also, the applicant may take into account any real phenomena or actual exposure conditions that may be present. Such conditions could include actual values for agricultural productivity, dietary habits and food sources, occupancy times, measured environmental transport factors, or similar values determined for a specific site. However, if the analysis is based on existing conditions and if potential changes in land use and food pathways could result in significantly higher exposures, the applicant should provide reasonable assurance that a monitoring and surveillance program will be performed on a regular and continuing basis to determine if such changes have occurred.

3. REQUIRED DOSE ESTIMATES

3.1 Individual Doses

Evaluations of the dose received by an exposed individual are made to satisfy the requirements of both 40 CFR Part 190 and 10 CFR Part 20. The Environmental Protection Agency (EPA) regulation, 40 CFR Part 190, speaks to

individual radiation doses from all pathways and all nuclear power and fuel cycle facilities combined, except that exposure from radon and its daughters need not be included. The NRC regulation, 10 CFR Part 20, includes a requirement to keep all radiation exposures "as low as is reasonably achievable" (ALARA). ALARA is a general concept that has not to date been interpreted in the form of numerical design objectives for uranium mills as it has been for light-water-cooled nuclear reactors (see Appendix I, "Numerical Guides for Design Objectives and Limiting Conditions for Operation to Meet the Criteria 'As Low As Is Reasonably Achievable' for Radioactive Material in Light-Water-Cooled Nuclear Power Reactor Effluents," to 10 CFR Part 50, "Domestic Licensing of Production and Utilization Facilities"). However, a case-by-case evaluation will be made to ensure that doses are kept as low as is reasonably achievable. ALARA evaluations will address all releases, including radon and its daughters, and will consider population doses as well as individual doses.

For the purpose of evaluating compliance with 40 CFR Part 190, the whole body and organ doses to any individual for all pathways combined and from all activity releases except radon and its daughters are evaluated for (1) the last year of actual mill operation and (2) the last year prior to tailings pile reclamation. These evaluations are adequate for assessing ALARA compliance except that exposure to radon and its daughters should be included and radon and daughter exposure for the first year after tailings pile reclamation should also be evaluated. Postreclamation exposure to radon and its daughters should be evaluated at the location of greatest radon concentration where unrestricted land use after mill decommissioning may be permitted.

Exposed individuals are characterized by food consumption, occupancy, and other uses of the region in the vicinity of the mill site. All physiological and metabolic parameters for the exposed individuals are assumed to have those characteristics that represent the averages for the various age groups in the general population. Although specific individuals will almost certainly display dietary, recreational, and other living habits considerably different from those suggested here and actual physiological and metabolic parameters may vary considerably, the NRC staff considers the use of these reference values to be acceptable because the actual physiological and metabolic characteristics of specific individuals cannot usually be determined. Applicants are encouraged to use information and data applicable to a specific region or site when possible.

When site-specific information and data are used, their origin or derivation should be documented for the NRC staff's review.

In this guide, the term "dose" is used instead of the more precise term "dose equivalent." When applied to the evaluation of internal deposition of radioactivity, the term "dose," as used here, includes the prospective dose component arising from retention in the body beyond the period of environmental exposure, i.e., the committed dose equivalent. The committed dose equivalent is evaluated over a period of 50 years.

The committed dose equivalent per unit intake, either by inhalation or ingestion, usually varies by age as well as by organ. For the purpose of calculating collective (population) doses, the population has been assumed to be composed of four age groups: infants (0 to 1 year), children (1 to 11 years), teenagers (11 to 17 years), and adults (17 years and older). Four sets of ingestion-dose conversion factors are presented in this guide, one for each of these four age groups. Available data are not sufficient to permit the calculation of age-specific dose conversion factors for inhalation exposure, and adult dose conversion factors are assumed to apply for all age groups for this exposure pathway.

3.2 Population Doses

Evaluations of population doses resulting from uranium milling operations are required to satisfy NEPA requirements for assessing the total environmental impact associated with the operation of each facility. Calculated estimates of resulting population doses therefore need to reflect, insofar as practicable, the overall radiological impact of each uranium mill over the duration of its existence.

For a typical uranium mill, the total radiological impact is composed of the impacts of the three major phases of its existence: the operational phase, the prereclamation phase, and the postreclamation phase. The first two phases may involve substantial releases of radon gas and particulates but are of relatively short duration. The postreclamation phase involves only small releases of radon, but these releases may persist for periods of tens of thousands of years. For each phase, the average annual radiological impact will be estimated by the NRC staff using the following basic procedure:

1. Annual average releases over the duration of the particular mill phase will be estimated for each radionuclide.

2. The radiological impact resulting from 1 year of average releases will be evaluated in terms of population dose using the EPA concept of "environmental dose commitment" (Ref. 3). The environmental dose commitment will be evaluated for a period of 100 years following release as per the procedure used by EPA in setting the standards in 40 CFR Part 190.

The total dose commitments for the operational and prereclamation phases will be calculated by multiplying the annual population dose commitments by the number of years the mill is expected to be in each phase. The sum of these two products represents an approximation of the combined radiological impact of the facility prior to tailings pile reclamation. The annual population dose commitments from postreclamation radon releases are also calculated and represent the continuously recurring impact of this residual activity source.

Consideration of particulate releases will generally be limited geographically to the area within 80 km (50 mi) of the mill site. Within this area, exposure pathways requiring assessment include all those considered in the evaluation of maximum individual exposure. Outside the 80-km (50-mi) radius, only radon and daughters require consideration and these are treated separately from particulate releases (see Regulatory Position 3.2).

4. USE OF THIS GUIDE

Present NRC staff practice with regard to the calculation of radioactive emission rates from uranium milling facilities involves the characterization of such releases by radionuclide, particle size, and density (Ref. 1). The data required as input for use of the calculational models described in this guide consist of annual average air concentrations resulting directly from such releases at specific locations (not including resuspended air concentrations of radioactive materials previously deposited on ground surfaces). The required input air concentrations for a particular location are denoted in this guide by the symbol C_{adip} (in pCi/m^3), where the subscripts indicate air concentration (a), direct (d), radionuclide (i), and particle size (p). Direct air concentrations required are those for values of the subscripts i and p as identified and defined in Table 1.

The primary calculational tool employed by the staff in performing radiological impact evaluations of uranium milling operations is the MILDOS code (Ref. 2), a modified version of the Argonne National Laboratory Uranium Dispersion and Dosimetry (UDAD) Code (Ref. 4). As used by the NRC staff, the MILDOS code has only five primary radionuclides in the ^{238}U decay chain that are treated explicitly as source terms. These radionuclides are ^{238}U, ^{230}Th, ^{226}Ra, ^{210}Pb, and ^{222}Rn. Release rates for these radionuclides are required for each potential onsite source (for particle sizes 1 through 4 in Table 1). For ^{222}Rn daughters, which grow in during transport of ^{222}Rn from the site, the resulting ingrowth concentrations (particle size 5 in Table 1) are also required. These ^{222}Rn daughters include ^{218}Po, ^{214}Pb, ^{214}Bi, ^{210}Pb, and ^{210}Po. The dosimetry model accounts for releases and ingrowth of other radionuclides, using assumptions of secular equilibrium.

Appendix A identifies and describes the various other site-specific information and data routinely used by the NRC staff in performing radiological impact assessments for uranium milling facilities. Appendix B provides a more detailed discussion of the method used in this guide for calculating environmental dose commitments. Appendix C provides a detailed explanation of the derivation of the radon dose conversion factor used in this guide.

C. REGULATORY POSITION

Equations and other data by which the NRC staff will estimate radiation exposure for individuals and the population in general from uranium mills are presented below. These equations are appropriate for the exposure pathways that the staff routinely considers in its evaluations. In addition, other pathways that may be present because of unique conditions at a specific site should be considered if they are likely to provide a significant contribution to total dose. A pathway is considered significant if a conservative evaluation yields an additional dose increment of more than 10 percent of the total from all other pathways considered in this guide.

1. CONCENTRATIONS IN ENVIRONMENTAL MEDIA

As discussed in Section B.4, annual average direct air concentrations are required as input data for use in the equations that follow. These equations

yield resulting concentrations in environmental media of interest, including total ground surface concentrations, air concentrations, and concentrations in edible vegetation, meat, and milk. These concentration calculations are explicitly performed only for certain radionuclides of the ^{238}U decay chain. Concentrations in environmental media of other radionuclides of the chain are inferred from those for which concentrations are explicitly calculated.

The basic calculational procedure first involves treatment of the direct air concentrations to obtain ground surface concentrations and resuspended air concentrations. Resuspension of radioactive materials deposited on ground surfaces is not treated as a loss mechanism for ground concentrations. For this reason, deposition of resuspended air concentrations onto ground surfaces is not considered. Resuspended particulate concentrations in air are added to the airborne concentrations arising directly from the source to obtain total air concentrations. The calculated total air concentrations are then used to obtain total deposition rates onto vegetation (resuspension losses of activity deposited on vegetation are assumed to be accounted for by the application of a weathering half-life). Total deposition rates and ground concentrations are used to compute concentrations in various vegetation types, including hay and forage. Radionuclide concentrations in hay and animal forage are initial inputs for the calculation of radionuclide concentrations in meat and milk ingested by man. This basic calculational process, the resulting environmental media concentrations, and the exposure pathways for which they are used are indicated schematically in Figure 1.

1.1 Radionuclide Accumulation on the Ground

Radionuclide ground concentrations are computed from the calculated airborne particulate concentrations arising directly from onsite sources (not including air concentrations resulting from resuspension). Resuspended particulate concentrations are not considered for evaluating ground concentrations. The direct deposition rate of radionuclide i is calculated, using the following relationship:

$$D_{di} = \sum_{p} C_{adip} V_{p} \qquad (1)$$

where

C_{adip} is the calculated direct air concentration of radionuclide i in particle size p in pCi/m^3;

D_{di} is the resulting direct deposition rate of radionuclide i in pCi/m^2 per sec; and

V_p is the deposition velocity of particle size p in m/sec (see Table 1).

The concentration of radionuclide i on a ground surface due to constant deposition at the rate D_{di} over time interval t is obtained from

$$C_{gi}(t) = D_{di}\left[\frac{1 - \exp[-(\lambda_i + \lambda_e)t]}{\lambda_i + \lambda_e}\right] \qquad (2)$$

where

$C_{gi}(t)$ is the calculated ground surface concentration of radionuclide i at time t in pCi/m^2;

t is the time interval over which deposition has occurred in sec;

λ_e is the assumed rate constant for environmental loss in sec^{-1}; and

λ_i is the radioactive decay constant* for radionuclide i in sec^{-1}.

The environmental loss constant λ_e corresponds to an assumed half-time for loss of environmental availability of 50 years (Ref. 1). This parameter accounts for downward migration in soil and loss of availability due to chemical binding. It is assumed to apply to all radionuclides deposited on the ground.

*Radiological decay constants employed by the NRC staff are obtained from data given in Reference 5.

Ground concentrations are explicitly computed only for ^{238}U, ^{230}Th, ^{226}Ra, and ^{210}Pb. For all other radionuclides, the ground concentration is assumed equal to that of the first parent radionuclide for which the ground concentration is explicitly calculated. For ^{210}Pb, ingrowth from deposited ^{226}Ra can be significant. The concentration of ^{210}Pb on the ground due to ^{226}Ra deposition is calculated by the staff, using the standard Bateman equation and ignoring the very-short-lived daughter radionuclides. This is equivalent to assuming that ^{226}Ra decays directly to ^{210}Pb. Using i = 6 for ^{226}Ra and i = 12 for ^{210}Pb (see Table 1), the following equation is obtained:

$$C_{g12}(Pb \leftarrow Ra) = \frac{\lambda_{12} D_{d6}}{\lambda_6^*} \left[\frac{1 - e^{-\lambda_{12}^* t}}{\lambda_{12}^*} + \frac{e^{-\lambda_6^* t} - e^{-\lambda_{12}^* t}}{\lambda_6^* - \lambda_{12}^*} \right] \qquad (3)$$

where

$C_{g12}(Pb \leftarrow Ra)$ is the incremental ^{210}Pb ground concentration resulting from ^{226}Ra deposition in pCi/m^2; and

λ_n^* is the effective rate constant for loss by radioactive decay and migration of a ground-deposited radionuclide and is equal to $\lambda_n + \lambda_e$ in sec^{-1}.

1.2 Total Air Concentrations

For use of the models described in this guide, air concentrations arising directly from onsite sources are required for each receptor location as a function of particle size (for particulates). Direct air concentrations are assumed to include the effects of depletion by deposition (particulates) or ingrowth and decay in transit (for radon and its daughters). In order to compute inhalation doses, the total air concentration of each radionuclide at each location (as a function of particle size) is computed as the sum of the direct air concentration and the resuspended air concentration:

$$C_{aip}(t) = C_{adip} + C_{arip}(t) \qquad (4)$$

where

C_{adip} is the calculated direct air concentration of radionuclide i in particle size p in pCi/m^3;

$C_{aip}(t)$ is the calculated total air concentration of radionuclide i in particle size p at time t in pCi/m^3; and

$C_{arip}(t)$ is the calculated resuspended air concentration of radionuclide i in particle size p at time t in pCi/m^3.

The resuspended air concentration is computed using a time-dependent and particle-size-dependent resuspension factor, which, for deposits of age t years, is defined by

$$R_p(t) = (0.01/V_p)10^{-5}\ e^{-\lambda_R t} \quad (\text{for } t \leq 1.82 \text{ yr}) \tag{5a}$$

$$R_p(t) = (0.01/V_p)10^{-9} \quad (\text{for } t > 1.82 \text{ yr}) \tag{5b}$$

where

$R_p(t)$ is the ratio of the resuspended air concentration to the ground concentration for a ground deposit of age t yr for particle size p in m^{-1};

λ_R is the assumed decay constant of the resuspension factor (equivalent to a 50-day half-life), 5.06 yr^{-1};

0.01 is the deposition velocity for the particle size for which the initial resuspension factor value is 10^{-5}/m in m/sec;

10^{-5} is the initial value of the resuspension factor for particles with a deposition velocity of 0.01 m/sec in m^{-1};

10^{-9} is the terminal value of the resuspension factor for particles with a deposition velocity of 0.01 m/sec in m^{-1}; and

1.82 is the time required to reach the terminal resuspension factor in yr.

The basic formulation of the above expression for the resuspension factor, the initial and final values, and the assigned decay constant derive from experimental observations (Ref. 1). The decrease with age primarily accounts for agglomeration with other larger particles. The inverse relationship to deposition velocity physically accounts for decreased resuspendibility of larger particles; mathematically, it eliminates mass balance problems for the 35-μm particle size. Based on this formulation, the resuspended air concentration is given by

$$C_{arip}(t) = 0.01 C_{adip} 10^{-5} \left[\frac{1 - \exp[-(\lambda_i^* + \lambda_R)(t - a)]}{(\lambda_i^* + \lambda_R)} + 10^{-4}\ \delta(t)\ \frac{\exp[-\lambda_i^*(t - a)] - \exp(-\lambda_i^* t)}{\lambda_i^*} \right] (3.156 \times 10^7) \quad (6)$$

where

- a is equal to $(t - 1.82)$ if $t > 1.82$ and is otherwise equal to zero in yr;
- $\delta(t)$ is zero if $t \leq 1.82$ and is unity otherwise, dimensionless;
- λ_i^* is the effective removal constant for radionuclide i on soil in yr^{-1}; and
- 3.156×10^7 is the number of seconds per year.

Equation 6 yields the resuspended air concentration of radionuclide i in particle size p because of deposition over time span t in years. Total air concentrations are computed using Equations 6 and 4 (in that order) for all particulates in particle sizes 1 through 4 as given in Table 1. Particulate daughters of ^{222}Rn (particle size 5 in Table 1) are not assumed to be depleted because of deposition and are also not assumed to resuspend.

1.3 Vegetation Concentrations

As illustrated in Figure 1, vegetation concentrations are derived from ground concentrations and total deposition rates. Total deposition rates are given by the following summation:

$$D_i = \sum_p C_{aip} V_p \quad (7)$$

where

- D_i is the total deposition rate, including deposition of resuspended activity, of radionuclide i in pCi/m^2 per sec.

Concentrations of released particulate materials can be environmentally transferred to the edible portions of vegetables or to hay or pasture grass consumed by animals by two mechanisms--direct foliar retention and root uptake. Five categories of vegetation are treated by the staff. They are edible above-ground vegetables, potatoes, other edible below-ground vegetables, pasture grass, and hay. Vegetation concentrations are computed using the following equation:

$$C_{vi} = D_i F_r E_v \left[\frac{1 - \exp(-\lambda_w t_v)}{Y_v \lambda_w} \right] + C_{gi} \frac{B_{vi}}{p} \qquad (8)$$

where

B_{vi} is the soil-to-plant transfer coefficient for radionuclide i and vegetation type v (pCi/kg(wet) plant per pCi/kg(dry) soil);

C_{vi} is the resulting concentration of radionuclide i in vegetation v in pCi/kg(wet weight);

E_v is the fraction of the foliar deposition reaching edible portions of vegetation v, dimensionless;

F_r is the fraction of the total deposition retained on plant surfaces, 0.2, dimensionless;

p is the assumed soil areal density for surface mixing, 240 kg(dry weight)/m^2;

t_v is the assumed duration of exposure while vegetation v is growing in sec;

Y_v is the assumed yield density of vegetation v in kg(wet weight)/m^2; and

λ_w is the decay constant accounting for weathering losses (equivalent to a 14-day half-life), 5.73×10^{-7} sec^{-1}.

The value of E_v is assumed to be 1.0 for all above-ground vegetation and 0.1 for all below-ground vegetables (Ref. 6). The value of t_v is taken to be 60 days, except for pasture grass for which a value of 30 days is assumed. The yield density Y_v is taken to be 2.0 kg/m^2, except for pasture grass for which a value of 0.75 kg/m^2 is applied. Values of the soil-to-plant transfer coefficients B_{vi} are provided in Table 2.

1.4 Meat and Milk Concentrations

Radioactive materials can be deposited on grasses, hay, or silage that are eaten by meat animals that are in turn eaten by man. The equation used to estimate radionuclide concentrations in meat is

$$C_{bi} = QF_{bi}(F_{pg}C_{pgi} + F_hC_{hi}) \quad (9)$$

where

C_{bi} is the resulting average concentration of radionuclide i in meat in pCi/kg;

C_{hi} is the concentration of radionuclide i in hay (or other stored feed) in pCi/kg(wet weight);

C_{pgi} is the concentration of radionuclide i in pasture grass in pCi/kg(wet weight);

F_{bi} is the feed-to-meat transfer coefficient for radionuclide i in pCi/kg per pCi/day ingested (see Table 2);

F_{pg},F_h are the fractions of the total annual feed requirement assumed to be satisfied by pasture grass or locally grown stored feed (hay), respectively, dimensionless; and

Q is the assumed feed ingestion rate, 50 kg(wet weight)/day (Ref. 6).

The equation used to estimate milk concentrations from cows ingesting contaminated feed is

$$C_{mi} = QF_{mi}(F_{pg}C_{pgi} + F_hC_{hi}) \quad (10)$$

where

C_{mi} is the resulting average concentration of radionuclide i in milk in pCi/L; and

F_{mi} is the feed-to-milk transfer coefficient for radionuclide i in pCi/L per pCi/day ingested (see Table 2).

1.5 Concentrations at Different Times

Maximum doses to individuals are calculated for the last year of mill operation and for the last year prior to tailings pile reclamation. This section explains the procedures used by the NRC staff to obtain annual average environmental media concentrations for these years.

In order to estimate average environmental media concentrations during the final year of actual mill operation, for an operational lifetime of T_o years, the value of the time variable t appearing in Equations 2, 3, 4, and 6 is set equal to T_o (in appropriate units). The resulting concentration values are those predicted for the end of the final year of operation and are assumed to represent average values existing over that year.

Environmental concentrations existing during the final prereclamation year result from postoperational releases and residual contamination due to releases during the period of mill operation. Because direct air concentrations from operational releases vanish, environmental concentrations due to operational releases at the time of reclamation arise only from residual ground and resuspended air concentrations. Ground concentrations at the end of the milling period are calculated using Equations 2 and 3, with the value of t set to T_o, the operational lifetime. Residual ground concentrations at the end of the final prereclamation year are then determined by

$$C_{gi}(T_d) = C_{gi}(T_o)\exp[-\lambda_i^*(T_d)] \qquad (11)$$

where

$C_{gi}(T_d)$ is the residual ground concentration of radionuclide i resulting from operational releases at the end of the T_d-year drying period in pCi/m^2;

$C_{gi}(T_o)$ is the ground concentration of radionuclide i at the time of mill shutdown in pCi/m^2; and

T_d is the duration of time required to dry the tailings pile prior to reclamation per yr.

Residual resuspended air concentrations resulting from operational releases are determined at the end of the final prereclamation year by

$$C_{arip}(T_d) = 0.01 C_{adip} 10^{-9} \exp[-\lambda_i^*(T_d)] \times \left[\frac{1 - \exp(-\lambda_i^* T_o)}{\lambda_i^*}\right] (3.156 \times 10^7) \quad (12)$$

where

C_{adip} is the direct air concentration of radionuclide i in particle size p resulting from operational releases in pCi/m^3; and

$C_{arip}(T_d)$ is the residual resuspended air concentration of radionuclide i in particle size p resulting from operational releases at the end of the T_d-year drying period in pCi/m^3.

Ground and resuspended air concentrations resulting from postoperational releases at the end of the final prereclamation year are calculated using Equations 2, 3, 4, and 6 with the value of t equal to T_d. These concentrations are then incremented by the residual concentrations due to operational releases. These residual concentrations are calculated using Equations 11 and 12 to obtain the required totals. Total air concentrations and concentrations in vegetation, meat, and milk are then calculated from the total ground and resuspended air concentrations.

2. DOSE CALCULATIONS FOR INDIVIDUALS

Doses to individuals are calculated for inhalation, external exposure to air and ground concentrations, and ingestion of vegetables, milk, and meat. Internal doses are calculated using dose conversion factors that yield the 50-year committed dose equivalent, i.e., the entire dose received over a period of 50 years following either inhalation or ingestion. The annual doses are actually the 50-year committed dose equivalents resulting from a 1-year exposure period. The 1-year exposure period is taken to be the year when environmental concentrations resulting from plant operations are expected to be at their highest level.

2.1 Inhalation Doses

Inhalation doses are calculated from the total radionuclide concentration in air, including resuspended material. The inhalation dose conversion factors for radioactive particulate materials used in this analysis are presented in Table 3. With the exception of the dose conversion factors presented for "mass average lung," these dose conversion factors have been computed by Argonne National Laboratory's UDAD computer code (Ref. 4) in accordance with the Task Group Lung Model (TGLM) of the International Commission on Radiological Protection (Ref. 7). Dose conversion factors for the mass average lung have been computed by mass-averaging the UDAD-calculated dose conversion factors for the four regions of the TGLM: nasopharyngeal, tracheobronchial, pulmonary, and lymph. Ordinarily, the dose computed specifically for the pulmonary region is reported or presented as the "lung" dose. For the principal lung dose contributors (uranium and thorium), doses computed for the mass average lung are slightly higher than those calculated for the pulmonary region. The net overall effect, considering all radionuclides, is thus a slight increase in the reported lung dose.

In addition to the physical characteristics of the particulate matter involved, use of the TGLM demands the assignment of a solubility class, denoted by Y (years, slowly soluble or insoluble), W (weeks, moderately soluble), or D (days, quite soluble). Solubility classifications have been assigned on the basis of experimental data reported and summarized by Kalkwarf in NUREG/CR-0530 (Ref. 8). These data indicate that thorium, lead, and polonium are 100% class Y in ore, yellowcake, or tailings dusts. Radium was determined to be best characterized by the split-solubility classification 10% class D, 90% class Y. Uranium in ore dust was determined to be 100% class W; uranium solubility for tailings dusts was not analyzed and is assumed to be class Y. Data for uranium in yellowcake were mixed and showed a pronounced dependence on the specific source of the yellowcake sample. Results reported by Kalkwarf indicate a split-solubility classification is appropriate, and on review of those results (particularly those given on page 55 of Reference 8), the staff has assumed uranium in yellowcake to be 50% class D and 50% class Y. The computed inhalation dose conversion factors are given in Table 3.

Doses to the bronchial epithelium from ^{222}Rn and short-lived daughters are computed based on the assumption of indoor exposure with 100% occupancy.

The dose conversion factor for bronchial epithelium exposure from ^{222}Rn is derived as follows (see Appendix C for detailed basis):

1. 1 pCi/m^3 ^{222}Rn in outdoor air will yield an average indoor concentration of about 5 x 10^{-6} Working Level (WL).*
2. Continuous exposure to 1 WL = 25 cumulative working-level months (WLM) per year.
3. 1 WLM = 5000 mrem (Ref. 9).

Therefore,

$$1 \text{ pCi/m}^3\ ^{222}Rn \times \left(5 \times 10^{-6} \frac{\text{WL}}{\text{pCi/m}^3}\right) \times \left(25 \frac{\text{WLM}}{\text{WL}}\right)$$

$$\times \left(5000 \frac{\text{mrem}}{\text{WLM}}\right) = 0.625 \text{ mrem}$$

and the ^{222}Rn bronchial epithelium dose conversion factor is taken to be 0.625 mrem/yr per pCi/m^3.

Inhalation doses are computed by the staff by use of the following equation:

$$d_j(\text{inh}) = \sum_{ip} C_{aip} DCF_{ijp}(\text{inh}) \qquad (13)$$

where

$d_j(\text{inh})$ is the inhalation dose to organ j in mrem/yr; and

$DCF_{ijp}(\text{inh})$ is the inhalation dose conversion factor for radionuclide i, organ j, and particle size p in mrem/yr per pCi/m^3.

2.2 External Doses

External doses resulting from exposure to air and ground activity concentrations are computed, using the dose conversion factors presented in Table 4 and assuming 100 percent occupancy at a given location. Indoor exposure is assumed to occur 14 hours per day at a dose rate of 70 percent of the outdoor

*One WL concentration is defined as any combination of short-lived radioactive decay products of ^{222}Rn per liter of air that will release 1.3 x 10^5 MeV of alpha-particle energy during their radioactive decay to ^{210}Pb.

dose rate, which is equivalent to a dose reduction factor for structural shielding of 0.825. The following equation is used by the staff to calculate external doses:

$$d_j(\text{ext}) = 0.825 \sum_i C_{ai} DCF_{ij}(\text{cld}) + C_{gi} DCF_{ij}(\text{gnd}) \qquad (14)$$

where

C_{ai} is the total air concentration of radionuclide i in pCi/m^3;

$d_j(\text{ext})$ is the external dose to organ j in mrem/yr;

$DCF_{ij}(\text{cld})$ is the dose conversion factor for cloud exposure from radionuclide i to organ j in mrem/yr per pCi/m^3;

$DCF_{ij}(\text{gnd})$ is the dose conversion factor for ground exposure from radionuclide i to organ j in mrem/yr per pCi/m^2; and

0.825 is the effective reduction factor because of structural shielding for indoor exposure periods.

2.3 Ingestion Doses

Ingestion doses are routinely calculated for ingestion of vegetables and meat (beef, unprocessed pork, and lamb). Milk ingestion doses are also computed if that pathway exists at the time of licensing. Ingestion doses are based on environmental concentrations established using Equations 8, 9, and 10, ingestion rates given in Table 5, and dose conversion factors given in Table 6. Ingestion doses from vegetable consumption are computed under the assumption that an average of 50 percent of the initial activity will be lost in food preparation (Ref. 6), usually involving washing, peeling, boiling, etc. The following equation is used to compute the annual radionuclide intake via ingestion:

$$I_{ik} = U_{mk} C_{mi} + U_{bk} C_{bi} + 0.5 \sum_v U_{vk} C_{vi} \qquad (15)$$

where

I_{ik} is the activity ingestion rate of radionuclide i by an individual in age group k in pCi/yr;

U_{mk},U_{bk} are milk (in L/yr) and meat (in kg/yr) ingestion rates for an individual in age group k;

U_{vk} is the ingestion rate of vegetable category v for age group k in kg(wet weight)/yr; and

0.5 is the fraction of vegetable activity remaining after food preparation, dimensionless.

Ingestion doses are then computed by

$$d_{jk}(ing) = \sum_i I_{ik} DCF_{ijk}(ing) \qquad (16)$$

where

$d_{jk}(ing)$ is the ingestion dose for organ j of an individual in age group k in mrem/yr; and

$DCF_{ijk}(ing)$ is the ingestion dose conversion factor for radionuclide i in organ j of an individual in age group k in units of mrem/pCi ingested.

2.4 Individual Dose Totals

Individual doses are calculated by the NRC staff for purposes of evaluating compliance with 10 CFR Part 20 and 40 CFR Part 190. For evaluating compliance with 40 CFR Part 190, dose contributions from ^{222}Rn and daughters are excluded. Total doses to individuals are calculated for both purposes using the following equation, which sums the dose contributions from inhalation, external dose, and ingestion:

$$d_{jk}(tot) = d_j(inh) + d_j(ext) + d_{jk}(ing) \qquad (17)$$

where

$d_{jk}(tot)$ is the total dose to organ j of an individual in age group k from all exposure pathways in mrem/yr.

To evaluate compliance with 40 CFR Part 190, the staff will compute total doses to appropriate individual receptors, using the above equation and all other models, data, and assumptions described in this guide, except that--

1. all dose contributions from radiation emitted by ^{222}Rn, ^{218}Po, ^{214}Pb, ^{214}Bi, and ^{214}Po will be excluded, and

2. all dose contributions from radiation emitted by ^{210}Pb, ^{210}Bi, and ^{210}Po formed by decay of released ^{222}Rn will be excluded.

With reference to Table 1 of this guide, the dose contributions eliminated for the purpose of evaluating compliance with 40 CFR Part 190 include those due to any radiation emitted by (a) radionuclides for which i = 7, 8, 9, 10, or 11 and (b) radionuclides present in particle size category p = 5 (radon daughters). The staff will add to dose totals computed for evaluating compliance with 40 CFR Part 190 any known significant doses resulting from any other light-water-cooled nuclear power generating or fuel cycle facilities, as appropriate (excluding doses from ^{222}Rn and its daughters as stipulated above and excluding doses from any radioactive materials released by nuclear or other facilities or operations not included under 40 CFR Part 190).

3. POPULATION DOSE CALCULATIONS

Population doses are calculated, using the environmental dose commitment concept with an integrating period of 100 years (Ref. 3). Under this approach, radiological impacts for a given release of activity are integrated over a time interval of 100 years following the release. The 100-year environmental dose commitment resulting from average release rates over a 1-year period is computed for (1) the period of actual uranium milling and (2) the period of time after the cessation of milling during which tailings are allowed to dry prior to final stabilization and reclamation. The NRC staff's rationale for the selection and use of a 100-year integrating period and the staff's technique for computing environmental dose commitments are addressed in Appendix B to this guide.

Population doses resulting from particulate and radon releases are evaluated over the general region of the facility site for the first two phases of the mill life cycle: operational (milling) and prereclamation. For these two time intervals and for the postreclamation era, annual population dose commitments resulting from transcontinental dispersion of ^{222}Rn are also evaluated.

3.1 Regional Population Doses

Population doses resulting from environmental radioactivity concentrations in the region of the site are evaluated for all exposure pathways considered in the evaluation of maximum individual doses; other pathways should also be considered if they are likely to result in an increase of more than 10 percent to the total result. Regional population dose commitments are generally computed on the basis of the population and agricultural productivity within a distance of 80 km (50 mi). Individual localized population centers lying beyond this distance should also be considered if their inclusion would increase the population dose estimates by more than 10 percent.

3.1.1 Inhalation and External Doses

Inhalation and external doses are computed by the NRC staff, using the identical models, equations, data, and assumptions as previously described for individual dose calculations in Regulatory Positions 1 and 2 of this guide. The procedure for calculating regional population doses from those pathways is to (1) divide the geographical site region into segments by radius and direction, (2) establish average individual doses within each segment, (3) multiply these individual doses by the estimated population lying within each segment, and (4) sum over all segments.

The population distribution required is that projected for the final year of mill operation. The appropriate population projection should be presented for each segment formed by radii extending outward from the site and bisecting the 16 compass directions (forming 22.5° sectors) and concentric circles drawn at distances of 1, 2, 3, 4, 5, 10, 20, 30, 40, 50, 60, 70, and 80 km. The 13 circles and 16 radii then form a grid composed of 192 individual segments. Average doses over the population within each segment are computed by the NRC staff along the segment directional centerline at a distance midway between the inner and outer boundaries of each annulus.

The population dose in the site region from inhalation and external exposure pathways is computed by the staff using the following equation:

$$M_j(\text{inh} + \text{ext}) = 10^{-3} \sum_s P_s[d_{js}(\text{inh}) + d_{js}(\text{ext})] \qquad (18)$$

where

$d_{js}(ext)$ is the average external dose to organ j in segment s in mrem/yr;

$d_{js}(inh)$ is the average inhalation dose to organ j in segment s in mrem/yr;

$M_j(inh+ext)$ is the resulting population dose from inhalation and external exposure pathways in rem/yr;

P_s is the population residing in segment s; and

10^{-3} is the conversion factor from millirem to rem.

3.1.2 Food Ingestion Doses

Collective population doses from food ingestion are calculated on the basis of the region's agricultural productivity rather than its population. This is because the total population dose from food pathways is proportional to the total quantity of radionuclides in all food produced in the region rather than the number of people exposed. The model employed by the NRC staff considers population doses resulting from radioactive contamination of vegetable, meat, and milk products produced in the region. For population dose calculations, the vegetable category includes fruit and grain crops as well. The procedure followed by the staff to compute food ingestion doses is similar to that used for inhalation and external doses and is composed of the following procedural steps:

1. The site region is divided into segments and each segment is assigned a productivity rate for each food category (vegetables, meat, and milk in kg/yr per km^2);

2. The average activity concentrations for each food type are computed and multiplied by the segment productivity factor and by the segment area;

3. Total activity content of the regional food production is then determined by summing over the segments; and

4. Population doses are determined assuming that all food produced in the region is consumed by a population with the same age distribution as the U.S. population.

Agricultural productivity data required for use in this analysis are generally available on a county-by-county basis for a relatively recent year.

The available raw data should be projected forward in time to provide a reasonable estimate of productivity during the final year of mill operation. If other means are not available, the NRC staff considers it acceptable to assume that regional agricultural productivity will remain in constant proportion to the U.S. population. Should other site-specific data not be available, the staff will rely on the statewide average productivity data presented in Table 7. The following equation is used to obtain segment average radionuclide concentrations in vegetables:

$$C_{vis}(avg) = \sum_{v} W_{vs} C_{vis} \qquad (19)$$

where

C_{vis} is the average concentration of radionuclide i in vegetable type v produced in segment s in pCi/kg(wet weight);

$C_{vis}(avg)$ is the average concentration of radionuclide i averaged over all types of vegetables in segment s in pCi/kg; and

W_{vs} is the weighting factor for vegetable type v in segment s (fraction of total production), dimensionless.

When relying on the state-average production data given in Table 7, the NRC staff will use values of W_v that have been selected to roughly correspond to the fractions of the three vegetable types in the average diet. From Reference 1, these W_v values are 0.78 for above-ground vegetables, 0.20 for potatoes, and 0.02 for other below-ground vegetables.

The gross activity content of the regional food production for each food type (vegetables, meat, or milk) is obtained by

$$Q_{fi} = \sum_{s} G_{fs} A_s C_{fis} \qquad (20)$$

where

A_s is the area of segment s in km^2;

C_{fis} is the concentration of radionuclide i in food category f in segment s in pCi/kg(wet weight);

G_{fs} is the productivity factor for food f in segment s in kg/yr per km^2; and

Q_{fi} is the gross activity content of radionuclide i in food f in pCi/yr.

Since the food produced may be eaten at different rates by different age groups and since ingestion dose conversion factors are also age dependent, it is necessary to establish the fractions of the Q_{fi} values determined by Equation 20 that are ingested by the various age groups. The following relationship applies:

$$F_{fk} = \frac{F_{pk}U_{fk}}{\sum_{k} F_{pk}U_{fk}} \qquad (21)$$

where

F_{fk} is the fraction of the production of food type f ingested by individuals in age group k, dimensionless;

F_{pk} is the fraction of the regional population belonging to age group k, dimensionless; and

U_{fk} is the average consumption rate in kg/yr or L/yr (for milk or other liquids) of food type f for an individual in age group k (see Table 8 for values). In the absence of suitable site-specific information, the NRC staff will assume average consumption rates for the population at large as given in Table 8 and population age fractions and fractional consumption rates as given in Table 9.

Using values obtained from Equations 20 and 21, total population ingestion doses from all food categories are calculated by

$$M_j(ing) = 10^{-3} \sum_{fik} E_f Q_{fi} F_{fk} DCF_{ijk}(ing) \qquad (22)$$

where

E_f is a factor to account for activity remaining after food preparation, dimensionless; and

$M_j(ing)$ is the resulting regional population dose from food ingestion for organ j in rem/yr.

The value of E_f is assumed to be 0.5 for vegetables and 1.0 for meat and milk. Fractions of the population belonging to the various age groups used in Equation 20 are determined from U.S. census data in the absence of site-specific information (see Table 9 for values).

3.2 Continental Population Doses

Substantial contributions to the total population dose may arise from the transport of released ^{222}Rn across the North American continent. Formation of long-lived ^{210}Pb from ^{222}Rn may result in both inhalation and ingestion doses not only to people in the United States, but to people in Canada and Mexico as well (Ref. 10). In order to estimate population doses occurring beyond the immediate region of the site, the staff makes use of the data presented in Table 10. These data consist of estimates of population doses resulting from 1,000-Ci releases of ^{222}Rn from four specific locations in the western United States. The location closest to the mill site should be used. The population doses provided are those that would have resulted from releases during calendar year 1978, including doses to Canadian and Mexican populations, and are based on the use of the environmental dose commitment concept with an integrating period of 100 years.

For projected releases of ^{222}Rn in future years, resulting population doses are computed by assuming those doses to be proportional to the U.S. population (use the population data provided in Table 11). The anticipated annual ^{222}Rn release in kCi is multiplied by the appropriate population doses from Table 10, and these results are then multiplied by the ratio of the projected U.S. population for the year of release to the 1978 U.S. population.

3.3 Total Population Dose Commitments

Population doses over the site region and the North American continent are computed on an annual basis for the operational (milling), prereclamation (pile drying), and postreclamation phases. The total radiological impact due to emissions during the first two phases is estimated by multiplying the annual

impacts by the durations and summing. Total annual impacts for each of the three phases are obtained by

$$M_j = M_j(inh + ext) + M_j(ing) + M_j(Rn) \quad (23)$$

where

M_j is the annual committed population dose to organ j in rem/yr; and

$M_j(Rn)$ is the annual continental population dose from ^{222}Rn and its daughters to organ j in rem/yr.

Total impacts over the first two phases are obtained by

$$M_j(m\&d) = T_o M_j(m) + T_d M_j(d) \quad (24)$$

where

$M_j(d)$ is the annual committed population dose to organ j during the drying phase in rem/yr;

$M_j(m)$ is the annual committed population dose to organ j during the milling phase in rem/yr;

$M_j(m\&d)$ is the aggregate committed population dose to organ j over the milling and drying phases in rem; and

T_o, T_d are the durations of the operational and pile-drying phases, respectively, in yr.

The calculation, compilation, and presentation of these population doses is considered by the NRC staff to represent a reasonably complete description of the radiological impact incurred by the operation of a typical uranium mill.

D. IMPLEMENTATION

The models specified in this guide are being used by the NRC staff in evaluating radiological impact in connection with applications for uranium mill licenses and renewals.

Table 1

ISOTOPES AND PARTICLE SIZES FOR WHICH DIRECT AIR CONCENTRATIONS (C_{adip} VALUES) ARE REQUIRED AS INPUT DATA

Particle Size Group*	Diameter Range, μm	Mean Diameter, μm	Density, g/cm³	Unit Density Activity--Median Aerodynamic Equivalent Diameter (AMAD), μm	Deposition Velocity, m/sec
p = 1	-	1.0	8.9	3.0	1.0×10^{-2}
p = 2	-	1.0	2.4	1.5	1.0×10^{-2}
p = 3	1 to 10	5.0	2.4	7.75	1.0×10^{-2}
p = 4	10 to 80	35.0	2.4	54.0	8.82×10^{-2}
p = 5	-	0.3	1.0	0.3	0.3×10^{-2}

		Particle Size Group Index**				
i	Radionuclide	p = 1	p = 2	p = 3	p = 4	p = 5
1	uranium-238	C & R	C & R	C & R	C & R	-
2	thorium-234	se	se	se	se	-
3	protactinium-234	se	se	se	se	-
4	uranium-234	se	se	se	se	-
5	thorium-230	C & R	C & R	C & R	C & R	-
6	radium-226	C & R	C & R	C & R	C & R	-
7	radon-222***	se	se	se	se	-
8	polonium-218	se	se	se	se	C & R
9	lead-214	se	se	se	se	C & R
10	bismuth-214	se	se	se	se	C & R
11	polonium-214	se	se	se	se	se
12	lead-210	C & R	C & R	C & R	C & R	C & R
13	bismuth-210	se	se	se	se	C & R
14	polonium-210	se	se	se	se	C & R

* Particle size groups are assigned to effluents as follows: p = 1 for yellowcake dust; p = 2, 3, or 4 for fugitive ore and tailings dusts; p = 5 for ^{222}Rn air ingrowth concentrations of particulate daughters.

** The entry "C & R" indicates that the particular C_{adip} value is explicitly calculated by the staff and required as input for use of the models, equations, and data described in this guide. The entry "se" indicates that radionuclide is assumed to be in secular equilibrium with the next-higher-up parent for which the direct air concentration is explicitly calculated.

*** The air concentration of ^{222}Rn is also calculated by the staff and is required as input for use of this guide; ^{222}Rn gas is not assigned a particle size.

Table 2

ENVIRONMENTAL TRANSFER COEFFICIENTS*

	Transfer Coefficent			
	U	Th	Ra	Pb
Plant/Soil (B_{vi})				
(pCi/kg plant - wet weight)/(pCi/kg soil - dry weight)				
Edible Above Ground	2.5×10^{-3}	4.2×10^{-3}	1.4×10^{-2}	4.0×10^{-3}
Potatoes	2.5×10^{-3}	4.2×10^{-3}	3.0×10^{-3}	4.0×10^{-3}
Other Below Ground	2.5×10^{-3}	4.2×10^{-3}	1.4×10^{-2}	4.0×10^{-3}
Pasture Grass	2.5×10^{-3}	4.2×10^{-3}	1.8×10^{-2}	2.8×10^{-2}
Stored Feed (Hay)	2.5×10^{-3}	4.2×10^{-3}	8.2×10^{-2}	3.6×10^{-2}
Beef/Feed (F_{bi})				
(pCi/kg per pCi/day)	3.4×10^{-4}	2.0×10^{-4}	5.1×10^{-4}	7.1×10^{-4}
Milk/Feed (F_{mi})				
(pCi/L per pCi/day)	6.1×10^{-4}	5.0×10^{-6}	5.9×10^{-4}	1.2×10^{-4}

*Sources for these data include References 11-14.

Table 3

INHALATION DOSE CONVERSION FACTORS

	Conversion Factor, mrem/yr per pCi/m³					
Radon Decay Products						
Particle Size = 0.3 micron Density = 1.0 g/cm³ AMAD = 1.0 microns	^{210}Pb	^{210}Po				
Whole Body	7.46E+00	1.29E+00				
Bone	2.32E+02*	5.24E+00				
Kidney	1.93E+02	3.87E+01				
Liver	5.91E+01	1.15E+01				
Mass Average Lung	6.27E+01	2.66E+02				
Yellowcake Dust						
Particle Size = 1.0 micron Density = 8.9 g/cm³ AMAD = 3 microns	^{238}U	^{234}U	^{230}Th	^{226}Ra	^{210}Pb	^{210}Po
Whole Body	9.82E+00	1.12E+01	1.37E+02	3.58E+01	4.66E+00	5.95E-01
Bone	1.66E+02	1.81E+02	4.90E+03	3.58E+02	1.45E+02	2.43E+00
Kidney	3.78E+01	4.30E+01	1.37E+03	1.26E+00	1.21E+02	1.79E+01
Liver	0.0	0.0	2.82E+02	4.47E-02	3.69E+01	5.34E+00
Mass Average Lung	1.07E+3	1.21E+3	2.37E+03	4.88E+03	5.69E+02	3.13E+02
Uranium Ore Dust						
Particle Size = 1.0 micron Density = 2.4 g/cm³ AMAD = 1.5 microns	^{238}U	^{234}U	^{230}Th	^{226}Ra	^{210}Pb	^{210}Po
Whole Body	4.32E+00	4.92E+00	1.66E+02	3.09E+01	4.36E+00	4.71E-01
Bone	7.92E+01	7.95E+01	5.95E+03	3.09E+02	1.35E+02	1.92E+00
Kidney	1.66E+01	1.89E+01	1.67E+03	1.09E+00	1.13E+02	1.42E+01
Liver	0.0	0.0	3.43E+02	3.87E-02	3.45E+01	4.22E+00
Mass Average Lung	1.58E+02	1.80E+02	3.22E+03	6.61E+03	7.72E+02	4.20E+02
Fine Tailings Particulates						
Particle Size = 5.0 microns Density = 2.4 g/cm³ AMAD = 7.75 microns	^{238}U	^{234}U	^{230}Th	^{226}Ra	^{210}Pb	^{210}Po
Whole Body	1.16E+00	1.32E+00	1.01E+02	4.00E+01	4.84E+00	7.10E-01
Bone	1.96E+01	2.14E+01	3.60E+03	4.00E+02	1.50E+02	2.89E+00
Kidney	4.47E+00	5.10E+00	1.00E+03	1.41E+00	1.25E+02	2.13E+01
Liver	0.0	0.0	2.07E+02	4.97E-02	3.83E+01	6.36E+00
Mass Average Lung	1.24E+03	1.42E+03	1.38E+03	2.84E+03	3.30E+02	1.88E+02
Coarse Tailings Particulates						
Particle Size = 35.0 microns Density = 2.4 g/cm³ AMAD = 54 microns	^{238}U	^{234}U	^{230}Th	^{226}Ra	^{210}Pb	^{210}Po
Whole Body	7.92E-01	9.02E-01	5.77E+01	4.90E+01	4.43E+00	7.28E-01
Bone	1.34E+01	1.46E+01	2.07E+03	3.90E+02	1.38E+02	2.96E+00
Kidney	3.05E+00	3.47E+00	5.73E+02	1.38E+00	1.15E+02	2.19E+01
Liver	0.0	0.0	1.19E+02	4.85E-02	3.51E+01	6.52E+00
Mass Average Lung	3.33E+02	3.80E+02	3.71E+02	7.64E+02	8.70E+01	5.75E+01

*Read 2.32E+02 as $2.32 \times 10^2 = 232$.

Table 4

DOSE CONVERSION FACTORS FOR EXTERNAL EXPOSURE

Radionuclide	Dose Factor for External Dose from Air Concentrations mrem/yr per pCi/m^3	
	Skin	Whole Body*
^{238}U	1.05E-05**	1.57E-06
^{234}Th	6.63E-05	5.24E-05
^{234m}Pa	8.57E-05	6.64E-05
^{234}U	1.36E-05	2.49E-06
^{230}Th	1.29E-09	3.59E-06
^{226}Ra	6.00E-05	4.90E-05
^{222}Rn	3.46E-10	2.83E-06
^{218}Po	8.18E-07	6.34E-07
^{214}Pb	2.06E-03	1.67E-03
^{214}Bi	1.36E-02	1.16E-02
^{214}Po	9.89E-07	7.66E-07
^{210}Pb	4.17E-05	1.43E-05

Radionuclide	Dose Factor for External Dose from Ground Concentrations mrem/yr per pCi/m^2	
	Skin	Whole Body*
^{238}U	2.13E-06	3.17E-07
^{234}Th	2.10E-06	1.66E-06
^{234m}Pa	1.60E-06	1.24E-06
^{234}U	2.60E-06	4.78E-07
^{230}Th	2.20E-06	6.12E-07
^{226}Ra	1.16E-06	9.47E-07
^{222}Rn	6.15E-08	5.03E-08
^{218}Po	1.42E-08	1.10E-08
^{214}Pb	3.89E-05	3.16E-05
^{214}Bi	2.18E-04	1.85E-04
^{214}Po	1.72E-08	1.33E-08
^{210}Pb	6.65E-06	2.27E-06

*Doses to internal body organs are assumed to be the same as computed for the whole body.
**Read as 1.05×10^{-5} or 0.0000105.

Table 5

FOOD CONSUMPTION RATES USED FOR CALCULATING DOSES TO INDIVIDUALS

	Ingestion Rate by Age Group,* kg/yr			
	Infant	Child	Teen	Adult
Vegetables (Total)	-	47.8	76.1	105.
Edible Above Ground	-	17.3	28.9	39.9
Potatoes	-	27.2	42.2	60.4
Other Below Ground	-	3.3	5.0	5.0
Meat (Beef, Fresh Pork, and Lamb)	-	27.6	44.8	78.3
Milk (L/yr)	208.0	208.0	246.0	130.0

*All data are taken from Reference 6. Ingestion rates are averages for typical farm households. No allowance is routinely credited for portions of year when locally grown or home-grown food may not be available.

Table 6

INGESTION DOSE CONVERSION FACTORS

		Internal Dose Conversion Factor by Organ and Age, mrem per pCi ingested							
Age Group	Organ	^{238}U	^{234}U	^{234}Th	^{230}Th	^{226}Ra*	^{210}Pb	^{210}Bi	^{210}Po
Infant	Wh. Bod	3.33E-04	3.80E-04	2.00E-08	1.06E-04	1.07E-02	2.38E-03	3.58E-07	7.41E-04
	Bone	4.47E-03	4.88E-03	6.92E-07	3.80E-03	9.44E-02	5.28E-02	4.16E-06	3.10E-03
	Liver	0	0	3.77E-08	1.90E-04	4.76E-05	1.42E-02	2.68E-05	5.93E-03
	Kidney	9.28E-04	1.06E-03	1.39E-07	9.12E-04	8.71E-04	4.33E-02	2.08E-04	1.26E-02
Child	Wh. Bod	1.94E-04	2.21E-04	9.88E-09	9.91E-05	9.87E-03	2.09E-03	1.69E-07	3.67E-04
	Bone	3.27E-03	3.57E-03	3.42E-07	3.55E-03	8.76E-02	4.75E-02	1.97E-06	1.52E-03
	Liver	0	0	1.51E-08	1.78E-04	1.84E-05	1.22E-02	1.02E-05	2.43E-03
	Kidney	5.24E-04	5.98E-04	8.02E-08	8.67E-04	4.88E-04	3.67E-02	1.15E-04	7.56E-03
Teenager	Wh. Bod	6.49E-05	7.39E-05	3.31E-09	6.00E-05	5.00E-03	7.01E-04	5.66E-08	1.23E-04
	Bone	1.09E-03	1.19E-03	1.14E-07	2.16E-03	4.09E-02	1.81E-02	6.59E-07	5.09E-04
	Liver	0	0	6.68E-09	1.23E-04	8.13E-06	5.44E-03	4.51E-06	1.07E-03
	Kidney	2.50E-04	2.85E-04	3.81E-08	5.99E-04	2.32E-04	1.72E-02	5.48E-05	3.60E-03
Adult	Wh. Bod	4.54E-05	5.17E-05	2.13E-09	5.70E-05	4.60E-03	5.44E-04	3.96E-08	8.59E-05
	Bone	7.67E-04	8.36E-04	8.01E-08	2.06E-03	4.60E-02	1.53E-02	4.61E-07	3.56E-04
	Liver	0	0	4.71E-09	1.17E-04	5.74E-06	4.37E-03	3.18E-06	7.56E-04
	Kidney	1.75E-04	1.99E-04	2.67E-08	5.65E-04	1.63E-04	1.23E-02	3.83E-05	2.52E-03

*Adult whole body and bone dose conversion factors for ^{226}Ra have been obtained from Reference 6 and are based on applicable models and data from Reference 15. ^{226}Ra whole body and bone dose conversion factors for other age groups have been computed by assuming the same proportion to adult whole body and bone dose factors as given in Reference 16. All other dose conversion factors are directly from Reference 16.

Table 7

AVERAGE AGRICULTURAL PRODUCTIVITY FACTORS FOR VARIOUS STATES

State	State-Average Productivity,* kg/yr per km^2		
	Vegetables	Meat	Milk
Arizona	580	1,040	1,130
Colorado	2,800	3,200	1,400
Idaho	14,200	2,000	3,400
Montana	1,800	2,000	370
Nevada	18	510	230
New Mexico	280	1,150	460
South Dakota	2,400	6,400	3,600
Texas	1,200	5,300	2,100
Utah	370	790	1,800
Washington	10,700	1,600	6,000
Wyoming	320	1,400	230

*Data presented are based on a staff survey and analysis of available data on agricultural productivity for 1973.

Table 8

FOOD CONSUMPTION RATES USED FOR CALCULATING DOSES TO POPULATIONS

Food Category	Average Consumption Rates,* kg/yr) Infants	Children	Teens	Adults
Vegetable Pathway				
Berries and Tree Fruit	0	54.1	63.9	49.2
Fresh Vegetables**				
1. Potatoes	0	27.2	42.3	60.4
2. Other root veg.	0	3.4	5.0	5.0
3. Leafy vegetables	0	5.8	9.4	13.9
4. Other above-ground vegetables	0	11.4	19.5	26.0
Processed Vegetables				
1. Potatoes	0	2.3	3.6	5.2
2. Other root veg.	0	0.9	1.4	1.4
3. Leafy vegetables	0	0.4	0.6	0.8
4. Other above-ground vegetables	0	14.4	24.6	32.8
Grain, Rice, and Wheat	0	118.2	136.2	90.8
Total Vegetables	0	238.1	306.5	285.5
Meat Pathway				
Beef and Lamb**	0	21.8	35.9	64.0
Unprocessed Pork**	0	5.9	8.9	14.3
Poultry and Processed Pork	0	21.0	33.2	49.6
Total Meat	0	48.7	78.0	127.9
Milk Pathway (L/yr)				
Fresh Milk**	207.6	207.6	246.0	129.6
Milk Products	0	27.2	45.4	46.7
Total Milk	207.6	234.8	291.4	176.3

*All data are taken from Reference 6 and are representative of average consumption rates by individuals at farm residences.

**These food categories are evaluated for individual doses from ingestion pathways.

Table 9

AGE DISTRIBUTION OF POPULATION, AVERAGE AND PER CAPITA CONSUMPTION RATES, AND FRACTIONS USED IN THE ABSENCE OF SITE-SPECIFIC DATA

Age Group	Fraction of Population*	Average Total Consumption Rates,** kg/yr		
		Vegetables	Meat	Milk
Infants	0.0179	0	0	207.6
Children	0.1647	238.1	48.7	234.8
Teenagers	0.1957	306.5	78.0	291.4
Adults	0.6217	285.5	127.9	176.3

	Fraction of Regional Production Ingested by Each Age Group		
Age Group	Vegetables	Meat	Milk
Infants	0	0	0.0178
Children	0.1418	0.0780	0.1850
Teenagers	0.2167	0.1485	0.2728
Adults	0.6415	0.7735	0.5244

*Age fractions given reflect average values for the entire U.S. population indicated by 1970 census data, as reported in Reference 17.

**Consumption rates given are from Table 8 and are not those used for, or appropriate to, the calculation of maximum individual doses.

Table 10

CONTINENTAL POPULATION DOSES PER kCi OF ^{222}Rn RELEASED IN 1978

Release Site	Population Dose Resulting from a 1-kCi Release of ^{222}Rn During 1978, organ-rem*			
	Bronchial Epithelium	Whole Body	Pulmonary Lung	Bone
Casper, Wyoming	56.	8.8	2.0	120.
Falls City, Texas	72.	5.8	1.6	77.
Grants, New Mexico	52.	8.2	1.8	110.
Wellpinit, Washington	43.	9.0	1.7	120.
Average	56.	8.0	1.8	110.

*Values given are based on data reported in Reference 10 and amended for inclusion in Reference 1. Exposure pathways considered include inhalation and ingestion. Isotopes considered include ^{222}Rn and its short-lived daughters, ^{210}Pb, ^{210}Bi, and ^{210}Po. A 100-year integrating period was used in the application of the environmental dose commitment concept.

Table 11

PROJECTED POPULATION OF THE UNITED STATES, 1978-2100

Year	Projected U.S. Population, millions*	Year	Projected U.S. Population, millions*
1978	218.4	1992	247.4
1979	220.2	1993	249.3
1980	222.2	1994	251.1
1981	224.2	1995	252.8
1982	226.3	1996	254.4
1983	228.5	1997	255.9
1984	230.7	1998	257.5
1985	232.9	1999	258.9
1986	235.1	2000	260.4
1987	237.2	2025	287.5
1988	239.4	2050	291.1
1989	241.5	2075	291.9
1990	243.5	2100	293.0
1991	245.5		

*Population projections through the year 2000 are from Reference 18. Later projections were obtained from Reference 10 and are based on a predicted growth rate obtained from Reference 19.

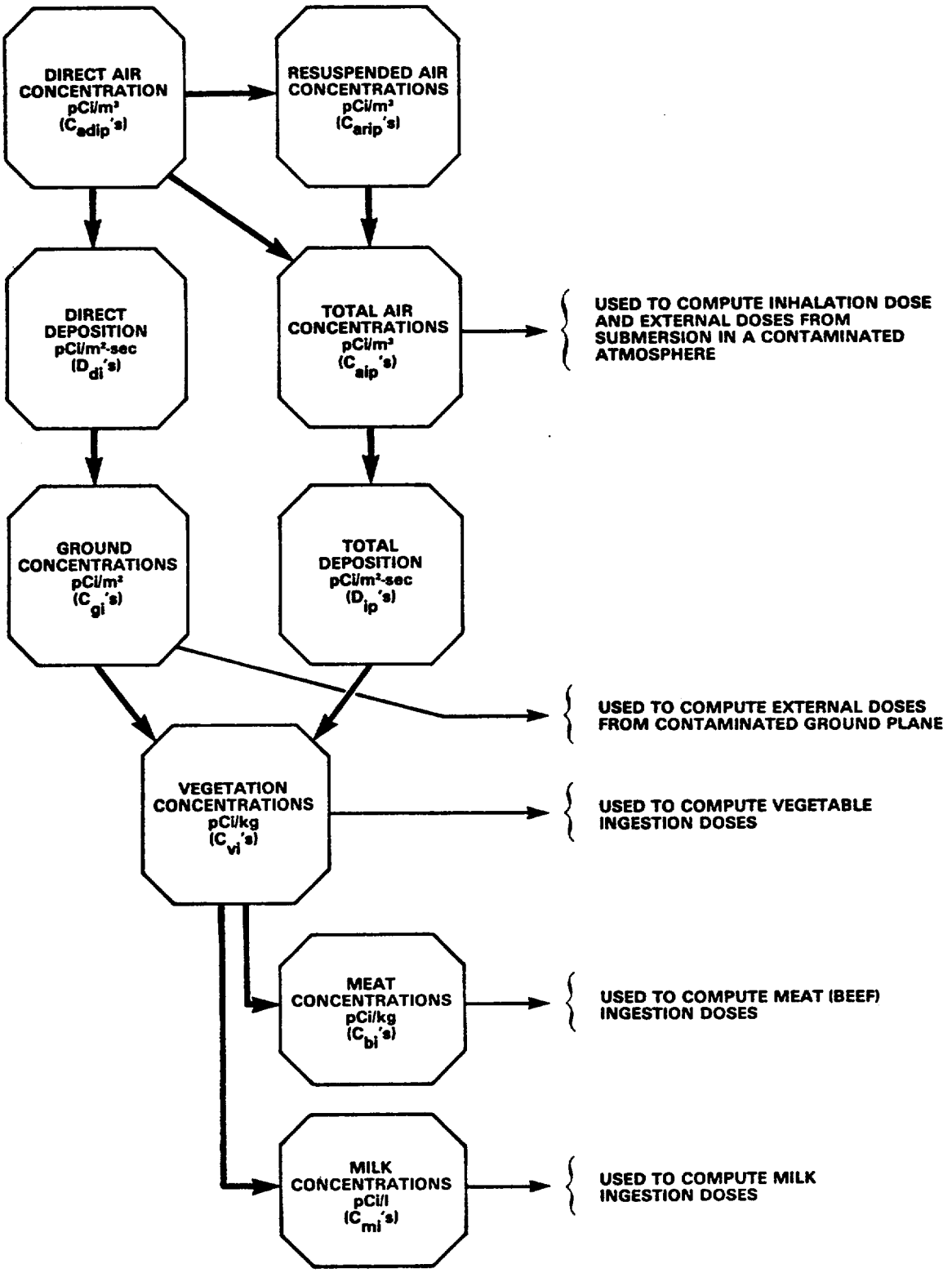

Figure 1. Schematic Diagram of Information Flow and Use For Dose Calculations

Table 12

CONVERSION FACTORS INTO SI UNITS

	Old Units*	New SI Units	Conversion Factor from Old to New Unit
Activity Concentrations (Environmental)			
Airborne Particulates and Gas	$pCi \cdot m^{-3}$	$Bq \cdot m^{-3}$	3.70E-02
Liquids (Water, Milk, etc.)	$pCi \cdot L^{-1}$	$Bq \cdot L^{-1}$	3.70E-02
Solids (Soil, Sediment, Vegetation, Food Stuff, etc.)	$pCi \cdot kg^{-1}$	$Bq \cdot kg^{-1}$	3.70E-02
Activity Concentrations (Effluent) Gas (Air)	$(\mu Ci \cdot mL^{-1})$**	$Bq \cdot m^{-3}$	3.70E+10
Liquid	$(\mu Ci \cdot mL^{-1})$**	$Bq \cdot L^{-1}$	3.70E+07
Exposure Rate (Environmental)	$\mu R \cdot h^{-1}$	$C \cdot kg^{-1} \cdot h^{-1}$	2.58E-10
Absorbed Dose	mrad	Gy	1.00E-05
Dose Equivalent	mrem	Sv	1.00E-05
Dose Equivalent Rate (Commitment)	$mrem \cdot yr^{-1}$	$Sv \cdot yr^{-1}$	1.00E-05

*Sanctioned for temporary use.
**Adopted because of established convention and use in maximum permissible concentration (MPC) tabulations.

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SYMBOLS

Symbol	Description
a	Equal to (t - 1.82) if t > 1.82 and otherwise equal to zero in yr
A_s	Area of segment s in km^2
B_{vi}	Soil-to-plant transfer coefficient for radionuclide i and vegetation type v, (pCi/kg(wet) plant per pCi/kg(dry) soil)
C_{adip}	Calculated direct air concentration of radionuclide i in particle size p resulting from operational releases in pCi/m^3
C_{ai}	Total air concentration of radionuclide i in pCi/m^3
$C_{aip}(t)$	Calculated total air concentration of radionuclide i in particle size p at time t in pCi/m^3
$C_{arip}(t)$	Calculated resuspended air concentration of radionuclide i in particle size p at time t in pCi/m^3
$C_{arip}(T_d)$	Residual resuspended air concentration of radionuclide i in particle size p resulting from operational releases at the end of the T_d-year drying period in pCi/m^3
C_{bi}	Resulting average concentration of radionuclide i in meat in pCi/kg
C_{fis}	Concentration of radionuclide i in food category f in segment s in pCi/kg(wet weight)
$C_{gi}(t)$	Calculated ground surface concentration of radionuclide i at time t in pCi/m^2
$C_{gi}(T_d)$	Residual ground concentration of radionuclide i resulting from operational releases at the end of the T_d-year drying period in pCi/m^2
$C_{gi}(T_o)$	Ground concentration of radionuclide i at the time of mill shutdown in pCi/m^2
$C_{g12}(Pb \leftarrow Ra)$	Incremental ^{210}Pb ground concentration resulting from ^{226}Ra deposition in pCi/m^2
C_{hi}	Concentration of radionuclide i in hay (or other stored feed) in pCi/kg(wet weight)
C_{mi}	Resulting average concentration of radionuclide i in milk in pCi/L

SYMBOLS (Continued)

C_{pgi}	Concentration of radionuclide i in pasture grass in pCi/kg (wet weight)
C_{vi}	Resulting concentration of radionuclide i in vegetation v in pCi/kg(wet weight)
C_{vis}	Average concentration of radionuclide i in vegetable type v produced in segment s in pCi/kg(wet weight)
$C_{vis}(avg)$	Average concentration of radionuclide i averaged over all types of vegetables in segment s in pCi/kg(wet weight)
$DCF_{ij}(cld)$	Dose conversion factor for cloud exposure from radionuclide i to organ j in mrem/yr per pCi/m^3
$DCF_{ij}(gnd)$	Dose conversion factor for ground exposure from radionuclide i to organ j in mrem/yr per pCi/m^2
$DCF_{ijk}(ing)$	Ingestion dose conversion factor for radionuclide i in organ j of an individual in age group k in mrem/pCi ingested
$DCF_{ijp}(inh)$	Inhalation dose conversion factor for radionuclide i, organ j, and particle size p in mrem/yr per pCi/m^3
D_{di}	Resulting direct deposition rate of radionuclide i in pCi/m^2 per sec
D_i	Total deposition rate, including deposition of resuspended activity, of radionuclide i in pCi/m^2 per sec
$d_j(ext)$	External dose to organ j in mrem/yr
$d_j(inh)$	Inhalation dose to organ j in mrem/yr
$d_{jk}(ing)$	Ingestion dose for organ j of an individual in age group k in mrem/yr
$d_{jk}(tot)$	Total dose to organ j of an individual in age group k from all exposure pathways in mrem/yr
$d_{js}(ext)$	Average external dose to organ j in segment s in mrem/yr
$d_{js}(inh)$	Average inhalation dose to organ j in segment s in mrem/yr
E_f	Factor to account for activity remaining after food preparation, dimensionless
E_v	Fraction of the foliar deposition reaching edible portions of vegetation v, dimensionless

SYMBOLS (Continued)

F_{bi}	Feed-to-meat transfer coefficient for radionuclide i, in pCi/kg per pCi/day ingested (see Table 2)
F_{fk}	Fraction of the production of food type f ingested by individuals in age group k, dimensionless
F_{mi}	Feed-to-milk transfer coefficient for radionuclide i in pCi/L per pCi/day ingested (see Table 2)
F_{pg}, F_h	Fractions of the total annual feed requirement assumed to be satisfied by pasture grass or locally grown stored feed (hay), respectively, dimensionless
F_{pk}	Fraction of the regional population belonging to age group k, dimensionless
F_r	Fraction of the total deposition retained on plant surfaces, 0.2, dimensionless
G_{fs}	Productivity factor for food f in segment s in kg/yr per km^2
I_{ik}	Activity ingestion rate of radionuclide i by an individua in age group k in pCi/yr
M_j	Annual committed population dose to organ j in rem/yr
$M_j(d)$	Annual committed population dose to organ j during the drying phase in rem/yr
$M_j(ing)$	Resulting regional population dose from food ingestion for organ j in rem/yr
$M_j(inh + ext)$	Resulting population dose from inhalation and external exposure pathways in rem/yr
$M_j(m)$	Annual committed population dose to organ j during the milling phase in rem/yr
$M_j(m\&d)$	Aggregate committed population dose to organ j over the milling and drying phases in rem
$M_j(Rn)$	Annual continental population dose from ^{222}Rn and its daughters to organ j in rem/yr
p	Assumed soil areal density for surface mixing, 240 kg(dry weight)/m^2
P_s	Population residing in segment s
Q	Assumed feed ingestion rate at 50 kg(wet weight)/day

SYMBOLS (Continued)

Q_{fi}	Gross activity content of radionuclide i in food f in pCi/yr
$R_p(t)$	Ratio of the resuspended air concentration to the ground concentration for a ground deposit of age t yr for particle size p in m^{-1}
t	Time interval over which deposition has occurred in sec
T_d	Duration of time required to dry the tailings pile prior to reclamation in yr
T_o	Duration of the operational phase in yr
t_v	Assumed duration of exposure while vegetation v is growing in sec
U_{fk}	Average consumption rate of food type f for an individual in age group k (see Table 8 for values) in L/yr or kg/yr
U_{mk}, U_{bk}	Milk (in L/yr) and meat (in kg/yr) ingestion rates for an individual in age group k
U_{vk}	Ingestion rate of vegetable category v for age group k, in kg(wet weight)/yr
V_p	Deposition velocity of particle size p in m/sec (see Table 1)
W_{vs}	Weighting factor for vegetable type v in segment s (fraction of total production), dimensionless
Y_v	Assumed yield density of vegetation v, in kg/m^2 (wet weight)
$\delta(t)$	Zero if $t \leq 1.82$ and unity otherwise, dimensionless
λ_e	Assumed rate constant for environmental loss in sec^{-1}
λ_i	Radioactive decay constant for radionuclide i in sec^{-1}
λ_i^*	Effective removal constant for radionuclide i on soil in yr^{-1}
λ_n^*	Effective rate constant for loss by radioactive decay and migration of a ground-deposited radionuclide and equal to $\lambda_n + \lambda_e$ in sec^{-1}
λ_R	Assumed decay constant of the resuspension factor (equivalent to a 50-day half-life), 5.06 yr^{-1}
λ_w	Decay constant accounting for weathering losses (equivalent to a 14-day half-life), 5.73×10^{-7} sec^{-1}

VALUES OF CONSTANTS

Terminal value of the resuspension factor for particles with a deposition velocity of 0.01 m/sec	$10^{-9}m^{-1}$
Initial value of the resuspension factor for particles with a deposition velocity of 0.01 m/sec	$10^{-5}m^{-1}$
Deposition velocity for the particle size for which the initial resuspension factor value is $10^{-5}/m$	0.01m/sec
Fraction of vegetable activity remaining after food preparation, dimensionless	0.5
Effective reduction factor because of structural shielding for indoor exposure periods	0.825
Time required to reach the terminal resuspension factor	1.82 yr

APPENDIX A

SITE-SPECIFIC INFORMATION AND DATA USED BY THE NRC STAFF IN PERFORMING RADIOLOGICAL IMPACT EVALUATIONS FOR URANIUM MILLING OPERATIONS

Table A-1 lists and partially describes most of the information and data commonly used by the NRC staff in performing its uranium mill radiological impact evaluations. All the data detailed in Table A-1 are not always available on a site-specific basis, in which case the staff will employ conservative estimates or assumptions. In some situations, the data identified in Table A-1 may not be adequate, so the staff will attempt to secure additional information. This situation may arise, for instance, when operations at more than one site are involved and the staff is required to evaluate combined impacts. In most cases, however, provision of the data identified in Table A-1 allows the staff to completely fulfill its responsibilities with regard to the preparation of a thorough, knowledgeable, and technically sound radiological impact evaluation.

Table A-1

PLANT, PLANT OPERATIONS, METEOROLOGICAL, AND ENVIRONMENTAL DATA ROUTINELY USED BY THE NRC STAFF IN PERFORMING RADIOLOGICAL IMPACT EVALUATIONS

I. PHYSICAL PLANT DATA

A. Detailed site plot plan (overlaid on topographic map with scale and true north arrow) clearly identifying all locations of--

1. Site property boundaries
2. Raw ore storage pads
3. Primary crushers
4. Secondary crushers
5. Crushed ore storage areas
6. Ore grinders
7. Yellowcake dryer and yellowcake dryer stack*
8. Yellowcake packaging area and exhaust stack
9. Tailings impoundments and their boundaries
10. Any heap leach piles and their boundaries
11. Restricted area boundaries if different from site property boundaries
12. Fences

B. Plant operations data

1. General data

a. Ore processing rates for all crushers and grinders, MT/d; hr/d and d/yr operational
b. Raw ore grade, % U_3O_8 by weight, average and range
c. Fractions of uranium, thorium, radium, and lead in raw ore expected to flow through to tailings
d. Expected yellowcake purity, % U_3O_8 by weight, average and range, MT/yr produced
e. Expected calendar years of initial ore milling, final ore milling, and completion of tailings area reclamation

* Part of the input to the NRC staff's impact assessment computer code consists of X, Y, and Z coordinates for various release and receptor locations. The staff routinely determines these coordinates with respect to the topographic elevation at the location of the yellowcake dryer stack. A list of all such locations should be given in the radiological assessment.

Table A-1 (Continued)

2. Ore storage data

   a. Areas of each pile or bin complex, m^2
   b. Ore storage masses
   c. Ore grades, % U_3O_8 by weight
   d. Antidusting measures routinely implemented
   e. Anticipated dusting rates, MT/yr
   f. Anticipated ^{222}Rn releases, Ci/yr
   g. Fractions of input ore sent to storage

3. Crushing, grinding data

   a. Description of ventilation air filtration equipment
   b. Design efficiency of exhaust filters
   c. Minimum efficiencies of exhaust filters
   d. Filter testing procedure and schedule if applicable
   e. Fraction of time filters not operational or used
   f. Any measured effluent concentrations
   g. Stack heights and airflows
   h. Anticipated release rates, kg/hr or kg/MT yellowcake processed
   i. Anticipated ^{222}Rn release rate, Ci/yr
   j. Fractions of ore throughput reaching filters as dust

4. Yellowcake drying and packaging data

   a. Processing rates, MT/hr, for drying and packaging if different
   b. Hr/d and d/yr drying and packaging operations are carried out
   c. Description of all ventilation air filtration equipment with design, expected, and minimum efficiencies
   d. Filtration equipment testing procedures and frequencies
   e. Any measured effluent concentrations
   f. Stack heights and airflows
   g. Anticipated release rates, kg/hr, for the dryer stack, the packaging area ventilation exhaust, and any yellowcake storage area ventilation exhausts
   h. Annual yellowcake yield, MT/yr

5. Tailings impoundment system (including evaporation or settling ponds) data

   a. Complete physical, chemical, hydrological, and radiological description
   b. Total area, surface areas expected to be under water, saturated, moist, and dry (indicate surface moisture contents used as basis of estimates)

Table A-1 (Continued)

c. Description of antidusting measures routinely implemented and their expected effectiveness
d. Anticipated dusting rates for saturated, moist, and dry surface areas, g/m^2 per sec
e. Anticipated ^{222}Rn release rates for underwater, saturated, moist, and dry surface areas, Ci/yr per m^2
f. Estimated drying time required prior to initiation of reclamation procedures and basis
g. Estimated time required to stabilize and reclaim after drying and basis
h. Postreclamation estimated ^{222}Rn release rate, Ci/yr per m^2, and basis

II. METEOROLOGICAL DATA

A. Joint frequency data

1. National Weather Service (NWS) station data

a. Locations of all NWS stations within 80 km (50 mi)
b. Available joint frequency distribution data by wind direction, wind speed, and stability class (3-dimensional numerical array)
c. Period of record by month and year
d. Height of data measurement

2. Onsite meteorological data

a. Location and heights of instrumentation
b. Description of instrumentation
c. Minimum of 1 full year of onsite joint frequency distribution data broken down by wind direction, wind speed, and stability class (3-dimensional array) with a joint data recovery of 90 percent or more

B. Miscellaneous data

1. Annual average mixing depth heights
2. Description (general) of regional climatology, particularly including frequencies and durations of extreme wind speeds

III. ENVIRONMENTAL DATA

A. A detailed topographic map of the area within 8 km (5 mi) of the site showing the locations of all--

1. Site boundaries
2. Lands owned, leased, or otherwise controlled (including mill site claims) by the applicant

Table A-1 (Continued)

3. Lands privately owned
4. Lands under the jurisdiction of the U.S. Bureau of Land Management
5. Lands otherwise publicly held
6. Lands useable and available for grazing
7. Private residences or other structures used by the general public
8. Vegetable or other crops, identified by type
9. Private, public, and industrial water wells and natural springs
10. Milk animals (cows or goats)

B. Regional data (within 80 km)

1. Population distributions by direction (16) and radius (for 1, 2, 3, 4, 5, 10, 20, 30, 40, 50, 60, 70, and 80 km) for a recent year (no earlier than 1970), for the last year of expected milling (approximate), and for the last year prior to completion of tailings area reclamation (approximate) with expected age group fractions (if available)

2. Available county food production data, kg/yr, for vegetables (by type and totals), meat (all types), and milk; any available future predictions by local governmental, industrial, or institutional organizations

APPENDIX B

STAFF METHODOLOGY FOR THE COMPUTATION OF 100-YEAR ENVIRONMENTAL DOSE COMMITMENTS

A primary objective of the NRC staff's radiological impact analysis is to estimate the aggregate radiological impact of the evaluated facilities. In attempting to achieve this goal, the staff employs the concept of environmental dose commitment (EDC) and uses an integrating period of 100 years. In adopting this general calculational approach, the staff has also endeavored to select and employ a specific calculational scheme suitable for routine use, both by the NRC staff and by uranium milling license applicants. The specific technique used by the staff is, for this reason, greatly simplified but somewhat less comprehensive in comparison with other published approaches for EDC computation. This appendix describes the staff's technique for EDC evaluation and addresses the rationale for selecting a 100-year integrating period.

Ordinarily, to compute maximum individual doses, the staff uses environmental concentrations calculated for the final year of the particular phase of milling operations. The duration of the operational (milling) phase is most often estimated to be 15 to 20 years, while drying of tailings piles in the prestabilization phase may require from 2 to 5 years or slightly longer. The lengths of these time intervals define the value of the time variable "t" that appears in Equations 2, 3, 4, and 6 of Regulatory Position 1, Concentrations in Environmental Media, of this guide.

The staff technique for evaluating regional population EDCs for an integrating period of 100 years following activity release involves artificially setting the value of t to 101 years. The specific procedural steps taken by the staff in the calculation of 100-year EDCs are then as otherwise described in Regulatory Positions 1 and 3 and as follows:

1. Obtain all necessary input direct air concentrations, as identified in Table 1 of the guide, for average release rates (by radionuclide) over the time interval of the phase being evaluated.

2. Evaluate all required environmental media concentrations by means of the equations provided for this purpose in Regulatory Position 1, using a value of 101 years for the variable t appearing in Equations 2, 3, 4, and 6.

3. Based on the environmental media concentrations computed for t = 101 years, using appropriate population, agricultural, and other data as described in Regulatory Position 3, calculate the regional population doses for all exposure pathways for an exposure period of 1 year.

4. Sum the computed doses, as appropriate, over all exposure pathways.

These calculational procedures actually result in the computation of the population dose commitments resulting from a 1-year exposure period to environmental concentrations existing during the 101st year of releases at the constant rates employed. The similarity of this result to the desired EDC (the population dose commitments resulting from a 100-year period of exposure to environmental concentrations resulting from constant releases over a 1-year time period) is illustrated in Table B-1, which provides a comparison of staff and conventional methodologies for EDC computation. This table has been organized to display the component parts of each calculational method. Line-by-line equivalence of these component parts can be readily demonstrated under conditions of constant population, population distribution, and agricultural productivity in the site region.

The staff has elected to use the approach described, rather than the more conventional approach, and a 100-year integrating period, primarily for the following reasons:

1. The major exposure pathways are dominated by doses resulting from airborne activity, which decreases rapidly in the absence of a continuing source (the resuspension factor has a half-life of about 50 days);

2. The major dose impact of ground concentrations arises from the food ingestion pathways, which depend on estimates of agricultural productivity (forecast data for food productivity in specific areas are rare and are considered to be potentially unreliable);

3. Inordinate computational difficulties are involved in routinely taking into account growth trends not amenable to description by very simple mathematical functions; and

4. The vast majority of resulting population exposure results from environmental concentrations at distances between 20 and 80 km (32 and 50 mi) from the site at which routine atmospheric dispersion calculations cannot generally yield results with sufficient accuracy to justify accounting for minor perturbations.

Table B-1

COMPARISON OF STAFF AND CONVENTIONAL TECHNIQUES FOR ENVIRONMENTAL DOSE COMMITMENT CALCULATION

	NRC Staff EDC Calculational Technique* (Defined as population dose commitments resulting from a 1-year period of exposure to environmental concentrations present during the 101st year of constant releases)			Conventional EDC Calculational Technique (Defined as population dose commitments resulting from a 100-year period of exposure to environmental concentrations resulting from constant releases over a 1-year period)		
Line	Exposure Interval, yr	Release Interval, yr	Average Time Difference, yr	Exposure Interval, yr	Release Interval, yr	Average Time Difference, yr
1	100 - 101	100 - 101	0	0 - 1	0 - 1	0
2	"	99 - 100	1	1 - 2	"	1
3	"	98 - 99	2	2 - 3	"	2
4	"	97 - 98	3	3 - 4	"	3
5	"	96 - 97	4	4 - 5	"	4
6	"	95 - 96	5	5 - 6	"	5
.	.	.	.	.	.	.
.	.	.	.	.	.	.
.	.	.	.	.	.	.
.	.	.	.	.	.	.
.	.	.	.	.	.	.
94	"	7 - 8	93	93 - 94	"	93
95	"	6 - 7	94	94 - 95	"	94
96	"	5 - 6	95	95 - 96	"	95
97	"	4 - 5	96	96 - 97	"	96
98	"	3 - 4	97	97 - 98	"	97
99	"	2 - 3	98	98 - 99	"	98
100	"	1 - 2	99	99 - 100	"	99
101	"	0 - 1	100	100 - 101	"	100

*This table has been purposely organized to portray a line-by-line similarity between staff and conventional EDC computation methods. Computation by both methods is broken down into component parts that, under conditions described in the text, can be shown to be mathematically identical.

APPENDIX C

RADON DOSE CONVERSION FACTOR

The basis on which the NRC staff has relied for its radon daughter inhalation dose conversion factor consists of the following major component parts:

1. The indoor working level (WL) concentration resulting from an outdoor ^{222}Rn concentration of 1 pCi/m^3 is approximately 5.0×10^{-6} WL.

2. The number of cumulative working level months (WLM) exposure per year for an average individual at a constant concentration of one WL is 25 WLM/yr.

3. The committed dose equivalent to the bronchial epithelium (basal cell nuclei of segmented bronchi) per unit WLM exposure is 5000 mrem (5 rem).

These component parts enter into the following equation, which yields the ^{222}Rn inhalation dose conversion factor used by the staff:

$$\frac{5.0 \times 10^{-6}\ \text{WL}}{\text{pCi/m}^3} \times \frac{25\ \text{WLM/yr}}{\text{WL}} \times \frac{5000\ \text{mrem}}{\text{WLM}} = \frac{0.625\ \text{mrem/yr}}{\text{pCi/m}^3}$$

Each of the three components identified above are derived from the following sources and data:

1. 5×10^{-6} WL per pCi/m^3 of ^{222}Rn is established by the assumed indoor air concentration ratios for ^{222}Rn, ^{218}Po, ^{214}Pb, and ^{214}Bi of 1.0/0.90/0.51 and 0.35. These concentration ratios and the derived conversion factor are representative of conditions in a reasonably well-ventilated structure (Refs. 1 and 2 for Appendix C).

2. 25 WLM/yr per WL concentration is derived from the assumption that an average individual's average breathing rate will be about 50 percent of that of a working miner. A WLM is defined, in terms of exposure to a working miner, as one month's occupational exposure to a 1-WL concentration. This assumed breathing rate would result in an average individual receiving about

0.5 WLM as a result of the same length of exposure to air at a 1-WL concentration. The following relationship applies:

$$(8760 \text{ hr/yr}) \times \frac{12 \text{ WLM/yr-WL}}{40 \text{ hr/wk} \times 52 \text{ wk/yr}} \times 0.5 = 25 \text{ WLM/yr-WL}$$

3. Five rem/WLM is the value derived from applying a quality factor (QF) of 10 for alpha radiation to convert from rad to rem (Refs. 1, 2, and 3 of Appendix C) to the figure of 0.5 rad/WLM as reported in the BEIR Report (page 148 of Ref. 3 of Appendix C).

The NRC staff considers the above basis for its ^{222}Rn inhalation dose conversion factor to be both sound and reasonable. The staff acknowledges that radon dosimetry is extremely complex and strongly influenced by assumed environmental and biological conditions. In view of the large variations induced by rather small changes in the assumed free-ion fraction, relative equilibrium, thickness of the intervening tissue and mucous layers, etc., the staff has endeavored to use physical, environmental, and other data reasonably representative of average conditions.

REFERENCES FOR APPENDIX C

1. Environmental Protection Agency, "Potential Radiological Impact of Airborne Releases and Direct Gamma Radiation to Individuals Living Near Inactive Uranium Mill Tailings Piles," EPA Report EPA-520/1-76-001, January 1976.

2. Environmental Protection Agency, "Environmental Analysis of the Uranium Fuel Cycle, Part I--Fuel Supply," EPA Report EPA-520/9-73-003-B, October 1973.

3. National Academy of Sciences--National Research Council, "The Effects on Populations of Exposure to Low Levels of Ionizing Radiation," Report of the Advisory Committee on the Biological Effects of Ionizing Radiations (BEIR), November 1972.

VALUE/IMPACT STATEMENT

1. PROPOSED ACTION

1.1 Description

The proposed action consists of the development and publication of a routine methodology for assessing the radiological impacts of routine radioactive releases from uranium mills. These radiological impacts include doses to exposed individuals, doses to the population within an 80-km (50-mi) radius, doses to the population of the entire United States, and doses to the population of the North American Continent. Evaluations made using the published methodology would serve several regulatory and licensing purposes for which the methodology must be suitable. These purposes include evaluating compliance with 40 CFR Part 190 and NRC regulations, evaluating impacts of releases as part of the overall ALARA evaluation, and evaluation of environmental impacts to meet NEPA requirements.

1.2 Need

Radiological impact evaluations for routine releases from uranium mills have been carried out in the past, and numerous new and repeat evaluations will probably be required in the future. Past evaluations have been prepared by NRC personnel or by personnel from national laboratories under contract. These assessments have lacked a uniformity of approach and purpose for numerous reasons, the most important being the absence of a standardized routine procedure. Other reasons include, but are not limited to, the evolution of new models, techniques, and data; the development of new concerns requiring new methods of analysis; and the problems associated with having evaluations prepared by different groups of people. This situation needed to be corrected. The proposed action includes the publication of state-of-the-art analytical models, including environmental transport models and data, models and data for human dosimetry, and appropriate data for receptor characteristics. An example

of the problems to be addressed by this effort is the evaluation of the long-term time-integrated impact of mill tailings piles, heretofore assessed by NRC only in terms of the impact during a single year.

1.3 Value/Impact

1.3.1 NRC

The document conveying the results of the proposed action will be a useful tool and should result in substantial benefits to NRC. These include upgrading the quality of future evaluations, particularly with regard to uniformity, completeness, and the application of more up-to-date methods and data. Other benefits will include greater flexibility in personnel assignments and reduced allocations of personnel time to completing evaluations.

1.3.2 Other Government Agencies

Other agencies will have available a reliable reference document explaining NRC's evaluation techniques. If evaluations can be conducted more uniformly, other agencies concerned with radiological and health impacts would benefit from these evaluations as they become more familiar with a routine approach and require less time to review NRC evaluations.

1.3.3 Industrial and Public Interest Groups

Clearly predictable impacts on these groups include the costs involved in familiarizing themselves with the proposed regulatory guide. Benefits will be derived from more easily predicting and understanding the results of NRC evaluations. Some differences from past evaluation techniques have been incorporated in this guide, but based on public comment, the degree and effects of such alterations appear to be minimal.

1.3.4 Public

The public will derive a benefit from the availability of a reference document explaining NRC evaluation techniques, and a further benefit will be derived from the increase in quality of NRC evaluations and subsequent licensing decisions and regulatory requirements.

2. TECHNICAL APPROACH

The technical approach to be used is based in part on contract work prepared by staffs of the Argonne National Laboratory, the Pacific Northwest Laboratory, and the Oak Ridge National Laboratory. This approach reflects techniques currently being adopted for use in review of uranium milling license applications and license renewal applications by the Office of Nuclear Material Safety and Safeguards. Comments on the technical approach were solicited by the issuance of Draft Regulatory Guide RH 802-4 for public comment. The comments received were evaluated and modifications were made to the guide where appropriate.

3. PROCEDURAL APPROACH

In its preliminary value/impact assessment, the staff considered several procedural approaches for carrying out the proposed action and selected the publication of a regulatory guide.

4. STATUTORY CONSIDERATIONS

4.1 NRC Authority

The product document establishes routine procedures by which NRC will evaluate radiological impacts of routine airborne releases from uranium mills. These evaluations will be and are being used in "as low as is reasonably achievable" determinations to evaluate compliance with NRC regulations, to evaluate compliance with EPA's 40 CFR Part 190 regulation, and to evaluate environmental impacts as part of NRC's overall NEPA determination.

4.2 Need for NEPA Assessment

The proposed action on calculational models did not require an environmental impact statement as it was not "a major Commission action significantly affecting the quality of the environment" as detailed in paragraph 51.5(a)(10) of 10 CFR Part 51.

5. RELATIONSHIP TO OTHER EXISTING OR PROPOSED REGULATIONS OR POLICIES

No potential conflicts with other agencies have been identified. However, the proposed regulatory guide will be a principal tool in the implementation of EPA regulation 40 CFR Part 190. Implementation of 40 CFR Part 190 is an NRC responsibility.

There is some possibility that backfitting requirements may result from implementation of 40 CFR Part 190. Such possible requirements will not result from the proposed action, but rather from the EPA regulation.

6. SUMMARY AND CONCLUSIONS

Guidance on routine procedures for evaluating the radiological impact of routine airborne releases of radioactive material from uranium mills should be developed and published in a regulatory guide.